THE IMPACT ON CHINESE PASSENGER AIRLINES BY INCLUDING THEM IN EMISSION REDUCTION SCHEMES

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Declaration

I, Xuebing Wang, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Signed,

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Abstract

Civil Aviation contributes to 2-3% of global total GHG emissions. Although it is a small share, the growth rate of aircraft emissions is faster than most industries in the world. Scientists and aircraft manufacture keen to find means to improve fuel efficiency and reduce aircraft emissions. However, technology innovation is not going to be achieved in the near future. Therefore, governments and international organisations placed their focus on policy instruments. This thesis selects China, the largest emitter in the world, as an example to study how emissions mitigation schemes could influence the airline industry.

While there has been a spectacular growth in Chinese aviation in recent decades, driven by economic and population growth, limited research has focused on the consequential increase in carbon dioxide emissions from the Chinese aviation industry, which has grown on average by 12% per annum since 1986. Therefore, this research firstly examined historical drivers pushing aviation sector to grow; and then develops a range of empirical models of future aviation growth to explore the cost impact of emission abatement instruments on the growth and competitiveness of the Chinese aviation industry. By using flights between EEA countries and China as a case study, the thesis develops a more detailed region-paired demand model to project future growth of international aviation; and also compared discrete choice analysis with the market share model and myopic game theory to examine the impact on airline competition due to mitigation schemes.

There are significant policy challenges in developing mitigation schemes for international aviation, which are explored in this thesis as well. The empirical analysis of the thesis provides a better understanding to policymakers about how to cooperate with developing countries and developed countries together in dealing with the issue of high volumes of aircraft emissions.

Impact Statement

This is one of the first pieces work investigating impacts on Chinese passenger airlines by including them in emission mitigation schemes. China not only is the largest emitter in the world but also is going to be the largest passenger air travel carrier by 2030. Therefore, the research is significant to policymakers in China and other stakeholders in the global aviation industry since it could provide a better understanding for them when making mitigation policies in the airline industry.

My research not only would impact policymakers' decisions but also would give some insights for airline companies to help them to make business strategies to achieve their sustainable growth target and fulfil their social responsibilities under the carbon constraint. Besides, the research could show air travel passengers the implications of their choice to fly and make them realise the significance about reducing aircraft emissions.

In addition, the methodology developed in the thesis could contribute research in the area of aircraft emissions abatement. The main simulation model built in this research compared impacts on direct CO_2 emissions from three different mitigation policies, which can be used to analyse impacts on other aircraft emissions and even the whole aviation industry. Although my research placed focus on the Chinese passenger airline industry, it could be applied to regional, national or even international scope.

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List of Acronyms

ACOS	Aviation Operating Cost Model
ADEM	Air Transport Demand Model
ADF	Augmented Dickey-Fuller
AERO-MS	The Aviation Emissions and Evaluation of Reduction Options Modelling System
AIC	Akaike Information Criterion
AIM	Aviation Integrated Modelling
APD	Air Passenger Duty
ASAs	Air Service Agreements
ASTM	American Society for Testing and Materials
ATAG	Air Transport Action Group
ATEC	Aircraft Technology Model
ATM	Air Traffic Management
BAU	Business-as-usual
BWB	Blended Wing Body
CAAC	Civil Aviation Adminstration of China
CAC	Command-and-Control
CAEP	Committee on Aviation Environmental Protection
CAL ETS	California Cap-and-Trade Scheme
CBDR	Common but Dirrerentiated Responsibilities
CDM	Clean Development Mechanism
CERs	Certified Emission Reductions
CFRP	Carbon Fibre Reinforced Plastic
CGE	Computable General Equilibrium
CH4	Methane
CISDL	Centre for International Sustainbale Development Law
CLEEN	Continuous Lower Energy Emissions and Noise
CO2	Carbon Dioxide
CO2e	Cabon Dioxide Equivalent
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation

CPM	Carbon Pricing Mechanism
DECI	Direct Economic Impacts Model
EABF	European Advanced Biofuels Flightpath
EC	European Commission
ECJ	European Court of Justice
EEA	European Economic Area
EIA	Energy Information Administration
EITE	Emission Intensive Trade Exposed Activities
EPA	Envionmental Protection Agency
EPPA	Emissions Prediction and Policy Analysis
ERA	Envirionmentally Reponsible Aviation
ERF	Emission Reduction Fund
ERUs	Emissions Reduction Units
ESCs	Energy Saving Certificates
ETS	Emissions Trading Scheme
EU	European Union
EU ETS	European Emissions Trading System
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration
FET	Federal Excise Tax
FLEM	Flights and Emission Model
FTK	Freight Tonne Kilometre
GAID	Global Airline Industry Dynamics
GATS	General Agreement on Trade in Services
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
GHG	Green House Gas
GIACC	Group on International Aviation and Climate Change
GLARE	Glass Laminate Aluminium Reinforced Epoxy
GWP	Global Warming Potential
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IEA	International Energy Association

IND PAT	India's Perform, Archieve and Trade Scheme
IOUs	Investor-Owned Utilities
IPCC	Intergovermental Panel of Climate Change
JADC	Japan Aircraft Development Corporation
JI	Join Implementation
LCCs	Low-Cost Carriers
LDCs	Least Developed Countries
LLDCs	Landlocked Developing Countries
LR	Likelihood Ration
LTO	Landing and Take-Off
MBM	Market Based Mechanism
MIT	Massachusetts Institute of Technology
MODDTF	Modelling and Database Task Force
NASA	National Aeronautics and Space Administration
NBSC	National Bureau of Statistics of China
NDRC	(NDRC 2016) and Reform Commission
NLCCC	The National Leading Committee on Climate Changes
NLR	National Aerospace Laboratory
NOx	Nitrogen Oxides
NSW GGAS	New South Wales Greenhouse Gas Abatement Scheme
NZ ETS	New Zealand Emissions Trading Scheme
O3	Ozone
OAG	Official Airline Guide
OD pair	Origin Destination Pair
OECD	Organisation for Economic Cooperation and Development
OSSA	One Single Sky Agreement
PED	Price Elasticity of Demand
RGGI	Regional Greenhouse Gas Initative
RPK	Revenue Passenger Kilometre
RTK	Revenue Tonne Kilometre
SEC	Specific Energy Consumption
SESAR	Single European Sky Air Traffic Management

	Research
SIDCs	Small Island Developing Countries
SO2	Sulphur Dioxide
SPK	Synthetic Paraffinic Kerosene
UA	United Airlines
UHCA	Ultra High Capacity Aircraft
UNFCCC	United Nations Framework Convention on Climate Change
UNWTO	United Nations World Tourism Organisation
VAR	Vector Autoregressive
VAT	Value Added Tax
WCI	West Climate Initiative
XWB	Extra Wide Body

Chapter 1 Introduction

1.1 Overview

Since the Wright brothers achieved a way to power the aeroplane in 1903, people have been dedicated to applying aircraft to passenger transportation, especially in long-haul travel[1]. In 1927, Charles Lindberg embarked on the first successful transatlantic flight, which accelerated the development of the aircraft. In the mid-1930s, the first all-metal aircraft, Douglas DC-3, with a 21-passenger capacity, came into service (Grant 2017). This was a milestone in the history of the aviation industry. The civil aviation sector, especially for international flights, expanded after World War II; however, it was a different case for China because of its civil war. After World War II, the failure of the negotiation between the communist party and the nationalist party led to a significant civil war in China that lasted ten years. Therefore, the civil aviation sector only started to grow after the finish of the civil war and the foundation of the People's Republic of China in 1949. Notably, the civil aviation industry was regulated by the Chinese air force until the 1980s.

With the development of the economy, more people have travelled abroad in recent decades. As can be seen from statistics from the United Nations World Tourism Organisation (UNWTO), the number of international tourist arrivals, including leisure and business travellers using all types of transportation, was 25 million (UNWTO 2010) in 1950 and increased to 1,184 million in 2015 (UNWTO 2016). The share of air transport in international tourism in 1950 can be assumed to be extremely small in comparison with other modes of transportation, even though there is a lack of exact data on this point;

[1] According to EUROCONTROL (2011), short-haul flights are for routes shorter than 1,500 km, medium-haul flights are for routes between 1,500 to 4,000 km, and long-haul flights are for routes longer than 4,000 km. However, most airlines define their routes only in two categories: short-haul (domestic flights and flights to neighbouring countries) and long-haul (international flights to non-neighbouring countries) (Dennis 2004: Air Berlin, Air France, Virgin Australia; Hong Kong International Airport 2016; Japan Air Lines 2007; American Airlines 2015). For some countries, like the United States, routes that cross country (i.e. New York to San Francisco or New York to Los Angeles) are also categorised as long-haul (Great Circle Mapper; United Airlines 2015).

however, there are 54% of overnight passengers travelling by air in 2015 and this share can be expected to grow in the future (UNWTO 2016).

Considering aviation specifically, the revenue tonne kilometres (RTK) for both passenger and freight in air transport increased from around 178 billion in 1986 (International Civil Aviation Organisation [ICAO] 1998) to 817 billion in 2015 (ICAO 2016), which means RTK increased almost 4.6 times since 1986. Statistics shows (ICAO 2016), in 2015, 1,436 million passengers were carried worldwide on international trips, while 2,097 million passengers were carried on domestic travel; with regard to air cargo, a total of 50.7 million tonnes was carried on both national and international flights. China, achieving the second place for RTK in 2015, carried 84,872 million tonne-km in passengers and freight on domestic and international flights. Thus, Chinese flights accounted for 10.39% of global air transport.

Because the aviation industry has high-energy intensity, aircraft emissions can be expected to multiply due to the tremendous increase in air traffic. Regarding passenger flights, Airbus (2016) forecasts that 16 trillion revenue passenger kilometres (RPK)[2] will be carried by aeroplanes by the end of 2035, which is 2.4 times more than in 2015. The United States will remain in first place in air passenger transport until around 2030, and then it will drop behind China to second place, which means China will be the largest air passenger market in the future (International Air Transport Association [IATA] 2014). On the other hand, Chinese airlines will contribute to a significant portion of aircraft emissions in the future. Therefore, it is significant to consider drivers behind the rapid growth of the Chinese aviation industry and to pursue mitigation options to achieve environmentally sustainable growth of the industry.

[2] Note that RPK is a traffic indicator of airline flights that calculated by multiplying the number of revenue paying passengers onboard the vehicle by the travelled distance.

1.2 Aviation and Climate Change

According to the fifth assessment from the Intergovernmental Panel on Climate Change (IPCC 2014a) Synthesis Report, the warming of the climate system is ‘unequivocal’; the period from 1983 to 2012 was likely the warmest 30-year period in the last 1,400 years. As the data in the synthesis report shows, the temperature (combined land and ocean surface) has increased by 0.85°C since 1880 (IPCC 2014a). Consequently, the snow and ice have diminished and the sea level has risen. Runoff and water resources downstream have been affected as well. Many species have been affected in various aspects, such as shifting their geographic ranges, seasonal activities, migration patterns, abundances and species interactions (IPCC 2014b).

It has been recognised that changes in climate systems have influenced not only the natural system but also the socio-economic system. The most notable is the impact on food production, which refers to the number of people at risk of hunger. Based on research of Parry et al. (2004), there will be negative impacts on world crop fields, between -9% and -22% in all projection scenarios if climate change continues.

According to the report, the anthropogenic greenhouse gas (GHG) emissions have grown rapidly from 27 GtCO_2-eq in 1970 to 49 GtCO_2-eq in 2010 (IPCC 2014a). Figure 1 shows the major source is CO_2 emissions from fossil fuel consumption. By the end of 2010, CO_2 emissions were 65% of total GHG emissions from gases. If examined by economic sector, as presented in Figure 2, transport only consists of 14.3% for both direct GHG emissions and indirect CO_2 emissions, which is a small share of total emissions. Therefore, there are always discussions about whether it is fair to consider transport as a major contributor of climate change, especially civil aviation, an even smaller one for the transport sector, which contributes approximately 2%–3% of global anthropogenic GHG emissions.

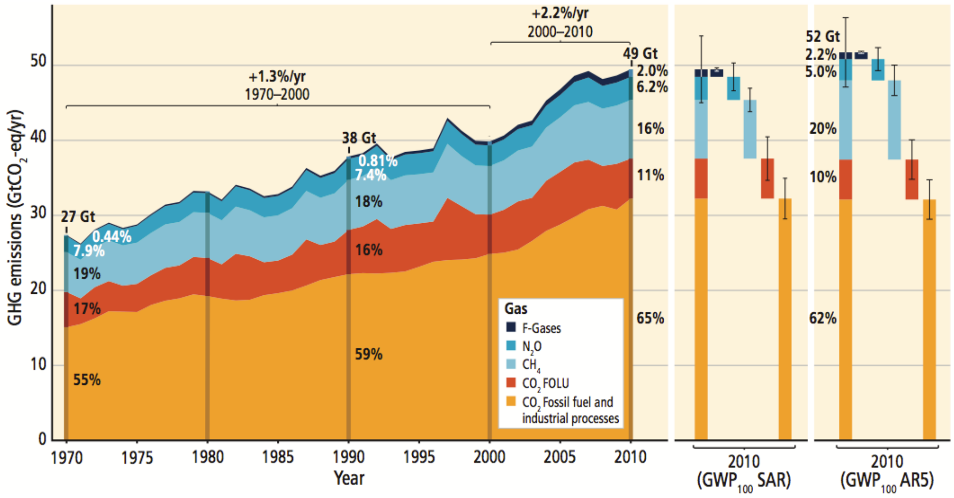

Figure 1 Total annual anthropogenic GHG emissions by gases 1970–2010

(Source: IPCC 2014)

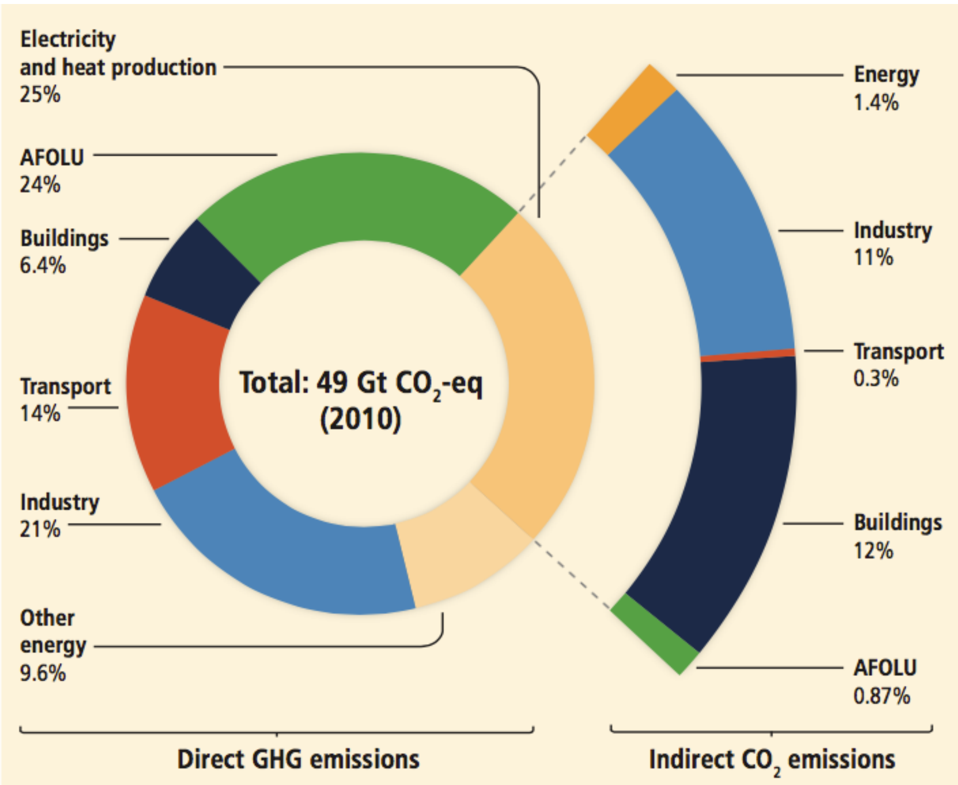

Figure 2 Total anthropogenic GHG emissions from economic sectors in 2010

(Source: IPCC 2014)

However, when it comes to emissions reductions, the share of the total GHG emissions is not the primary factor to consider. Instead, the following factors should be considered: a) the growth rate of the aviation industry; b) emissions reductions targets; and c) the emissions intensity of the aviation industry. Clearly, as an industry that highly depends on fuel combustion, the emissions intensity of the aviation industry is relatively high compared to most energy-intense industries (Gössling and Upham 2009). Even though the second largest emitter—US withdrew from the Paris Agreement, the largest emitter China has insisted on an ambitious reduction target, which means the aviation industry, an energy-intensive industry, should be included in their new mitigation plan.

Given the inclusion of the aviation industry in the European Union Emissions Trading System (EU ETS), the necessity of reducing aircraft emissions has been recognised by the European Commission (EC). The EU ETS initially tried to include all airlines flying to and depart from EU airports; but finally, it is only applied to airlines of countries included in the European Economic Area (EEA) due to the strong opposition of other countries. However, the action from the EU has boosted the progress of building international aviation mitigation scheme under ICAO. In 2016, at ICAO's 39th Assembly, member states agreed to the establishment of the Carbon Offsetting Reductions Scheme for International Aviation (CORSIA). Although this is a voluntary scheme initially, it is still an important step for international aviation emissions mitigation.

1.3 Research Aims and Question

The aims of this thesis are to investigate the impact on the Chinese aviation industry by applying different mitigation instruments and to explore the political implications in a global scope. It achieves these aims through a range of modelling work to examine how carbon constraint influences air travel demand, CO_2 emissions, airline revenue and the competitiveness of Chinese airlines. By examining the climate impact on the Chinese aviation industry, this thesis addresses the necessity to mitigate aircraft emissions internationally, which means international co-operation is needed for international aviation decarbonisation. The thesis is driven by the following objectives:

- To discuss the relationship between aircraft emissions and climate change;
- To discuss different mitigation options for the aviation industry, including both technology innovation and policy options;
- To examine the climate impact of Chinese airlines by exploring the historical drivers pushing the growth of air travel demand and building a baseline scenario for future growth in the Chinese aviation and relevant CO_2 emissions;
- To investigate possible outcomes of different mitigation instruments on both Chinese domestic and international flights and the competitiveness of Chinese airlines; and
- To discuss the role of China in international negotiation for aircraft emissions abatement and future global co-operation.

To investigate through modelling the possible outcomes of different market-based mechanisms for air travel demand, CO_2 emissions, airline revenue and the competitiveness of Chinese airlines, and to use these model results as a basis to the following research question:

How will Chinese passenger airlines achieve environmentally sustainable growth through different aircraft emissions abatement instruments?

1.4 Thesis Structure

The thesis is organised as follows: **Chapter 2** begins with an overview of the history of the development of the aviation industry at both global and regional level and projections of future aircraft emissions. By examining the history of the development of the airline sector, the chapter presents a clear understanding of what climate issues exist in the aviation industry. This chapter also draws out why we need to decarbonise the civil aviation sector by projecting the future emissions of the airline industry. In particular, Chapter 2 also explores the historical CO_2 emissions from China—the largest emitter in the world—and discusses the necessity to reduce CO_2 emissions from Chinese energy-intensive industries, especially the air transport sector.

Chapter 3 discusses industry developments in previous 60 years and what can be expected from technology and operational improvements to reduce fuel consumption and aircraft emissions. First, this chapter shows how fuel efficiency has been improved and gives prospects on how the technology could be further enhanced. There is an assessment of several technologies as to their feasibility in increasing fuel efficiency. There is a discussion of measures in flight operation and flying path optimization to understand how they can contribute to aircraft emissions abatement.

Chapter 4 introduces the context of aviation and climate policy, and it indicates how the airline industry could fit into those climate regulatory frameworks. Then the chapter discusses various policy options—regulatory, economic and voluntary approaches—for aircraft emissions abatement. The first international aviation emissions trading scheme—EU ETS—is discussed in this chapter; arguments about its implications and issues are studied. We identified both political and legal challenges in expanding EU ETS or building a global emissions trading scheme. Moreover, this chapter argues that the progress in abatement of the aviation industry, led by ICAO, which presents the possibility of a global co-operation in reducing emissions from the international aviation industry.

Chapter 5 seeks to add to the discussion of the Chinese aviation industry in international emissions mitigation, in particular, the potential role of a global aviation mitigation instrument. It estimates the role of the Chinese aviation industry in international emissions reduction, in particular, the possible role of a global aviation mitigation mechanism. To conduct such analysis, this chapter first examines the historical drivers of the emissions in the Chinese aviation industry, and secondly provides a benchmark baseline scenario in the absence of any significant policy. Furthermore, the application of several abatement options in the Chinese airline industry is discussed, which gives a better understanding of what other instruments the Chinese aviation industry could adopt in the future to further reduce aircraft emissions.

Chapter 6 models both domestic and international flights carried by the Chinese airlines, in particular the impacts of applying a carbon tax and, alternatively, of joining an emissions trading scheme or a carbon offsetting scheme on airfares, passenger behaviours, extra costs, emission reductions and airline revenue loss. Because the baseline activity and CO_2 emissions from flights carried by Chinese airlines up to 2030 were projected in the previous chapter, this chapter projects the effects of carbon taxation, the effects of joining an emission trading scheme or the effects a carbon offsetting scheme by modelling the price impacts on travel behaviour and the subsequent impact on emissions in the future. The chapter concludes with a sensitivity analysis for several variables—price elasticity of demand, market growth and efficiency growth—that could influence the primary output to a great extent.

As the final empirical chapter, **Chapter 7** compares a discrete choice model on air travel demand with a market share model on airline competition to examine how emissions mitigation instruments influence passengers' choice of airlines and how airline companies would compete with each other under carbon constraints. It examines drivers that influence how passengers choose airlines and how passengers' choices influence airline market share. By comparing these two models, this chapter chooses international flights between EEA countries and China as the case to project whether different international aircraft mitigation schemes would lead to competition distortion from passengers' perspective.

Finally, **Chapter 8** discusses the limitations of research methodologies and synthesises the research findings. It highlights the main practical, theoretical and methodological contributions of the research, and it suggests some directions for further studies.

Chapter 2 Aircraft Emissions

This chapter presents an overview of the global airline industry, including its development and status. In addition, a review of climatic impacts from the aviation industry has been addressed, which indicates the importance of the aviation sector in global GHG emissions mitigation. Then, there is a summary of projections of future emissions, which explains why further actions need to be taken soon. In particular, this chapter reviews historical emissions from China, including both national and sectoral, which indicates the necessity of reducing CO_2 emissions from China.

2.1 Overview

The development and expansion of the airline industry have boosted the growth of the world economy. As a dominant force in the global economy, the aviation sector transported, on average, 2.9 trillion passengers and 46 million tons of cargo in recent years (ICAO 2016). By the end of 2014, the airline industry supported 62.7 million jobs worldwide (IATA 2017). In addition, the air transport sector contributes $65,200 million in profits to the global gross domestic production (GDP) (ICAO 2016), which is higher than the GDP of most countries. The rapid increase in the air transport industry enabled other industries to develop, such as aircraft manufacturing and tourism, which contributes to more than 33,000 jobs and $150 million of revenue to those sectors (Air Transport Action Group [ATAG] 2016a). Moreover, the growth of the airline industry has stimulated international trade by providing a more efficient way to enter the international market; for instance, in 2010, the total value of air freight transport represented 35% of all international trade (ATAG 2016a). The aviation sector facilitates the mobility of merchandise, labour and travellers, which increases foreign investments and accelerates the development of the global economy. The improvement of operational efficiency in the aviation sector enlarges the intensity of competition and boosts industry innovation; the benefits this kind of improvement and innovation delivers to society are larger than the benefits to the sector itself.

The deregulation of the aviation industry began in the US in the 1970s, which put forward the market competition in the sector. In 1978, the US president signed the Airline Deregulation Act of 1978, which withdrew the authority of examination, approval and market entry of domestic flights and allowed airlines to price their services to some extent. In the following year, the US put forward the liberalisation of international flights, signing several bilateral agreements with the Netherlands, Singapore, Jamaica, and others.

Then, following in the steps of the US, the United Kingdom (UK) also signed a couple of bilateral agreements with other Commonwealth countries to support the deregulation and liberalisation of the airline industry. Furthermore, the deregulation of the aviation sector has begun in European countries. Since 2000, the liberalisation of the air transport industry has transferred from domestic to regional and even global. Achievements in deregulation and liberalisation have been made between several regions, such as North America, the EU, South Asia and Australia–New Zealand. With the acceleration of the process of economic globalisation, there has been rapid growth in the liberalisation of international air transport. In March 2007, the US and the EU signed the Open Skies Agreement, which allows airlines from EU countries to fly to any airport in the US and vice versa. With the industry reform beginning in China since 1993, the Chinese government has loosened its grip on the air transport sector, especially for international flights. By the end of 2015, Chinese airlines have scheduled flights to 137 cities in 55 countries (Civil Aviation Administration of China [CAAC] 2016).

At present, 1,402 commercial airlines are operating over 34.8 million scheduled commercial flights worldwide per annum (ATAG 2016a). In 2016, all airlines flew 28,177 aircraft that transport 872 billion RTK on passenger, freight and mail flights to over 3,800 airports in total (ICAO 2016). Over the previous 30 years, the total RTK of the world air travel has increased 5% annually because of global economic growth. Airbus (2016) forecasts that air travel demand will still increase by 4%–5% per year up until 2050.

Figure 3 compares annual growth rates of air passengers transported by US airlines (first ranking in total air travel turnover in the world), Chinese airlines (second ranking in total air travel turnover in the world in 2015) and all airlines during the period of 1986–2015. In most years, the growth rates of global air traffic have been positive, except for 1993, 2001, 2003 and 2008. The small decrease in 1993 is a substantial result of the First Gulf War and the economic recession. Air passenger transport declined in 2001 and 2002 due to the impacts of the 9/11 terror attacks in the US. Finally, air travel decreased in 2008 due to the global financial crisis.

Figure 3 also indicates that the growth rate of passengers carried by Chinese airlines outpaces the growth rate of the world airlines and US airlines in most years, except for 1989, 1997, 1999 and 2010. Air passenger transport declined in 1989 due to a series of political disturbances in China. Then in 1997 there was the Asian financial crisis. In 1999, air travel declined due to public panic after two aircraft crashes. Lastly, in 2010 there was an earthquake in Qinghai Province. Moreover, the increase speed of US airlines and Chinese airlines have decreased in recent years; however, US airlines and Chinese airlines have different cases. Even the speed of growth of air passengers carried by Chinese airlines have slowed down, with Chinese airlines carrying an increasing share of passengers, from 1% in 1986 to 12% in 2015 of total passenger transported by all carriers worldwide. On the other hand, the proportion of air passenger traffic carried by US airlines decreased from 49% in 1985 to 23% in 2015.

Except for the early development stage of the Chinese passenger air transport, there are two years seems to have strong growth—2004 and 2009. As we all know, there was a severe disease—SARS—broke out in China in 2003, which led to a huge decrease in all transport models. After the disease had been controlled, an increase in air transport was expected in 2004. In addition, the global financial crisis and the economic recession started from the US since 2007, which results in demand drop of international air transport worldwide, especially the US. However, China basically was not affected by the global economic recession that explains why the growth of international passengers carried by Chinese airlines was remarkable in 2009.

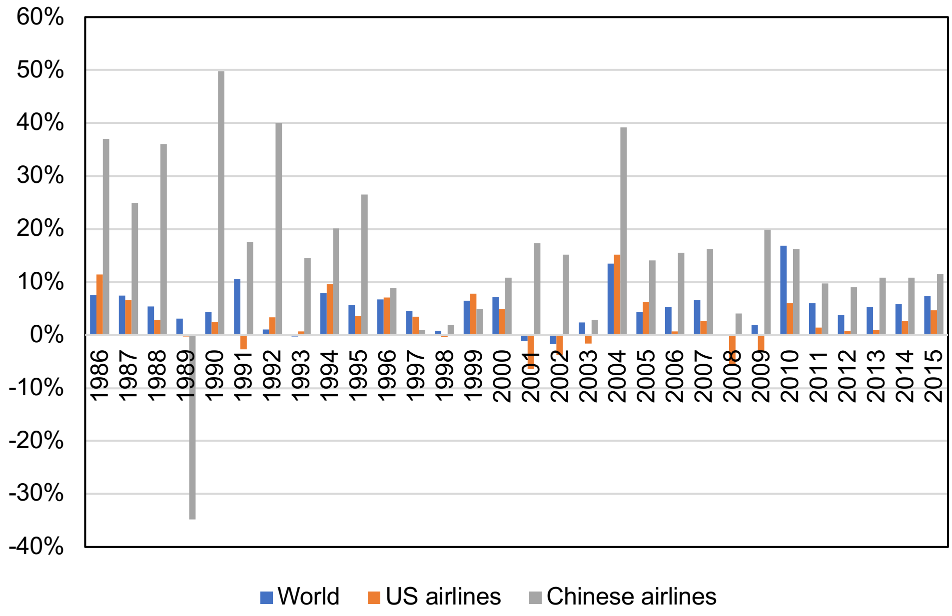

Figure 3 Annual growth rates of passenger carried during 1986–2015

(Data sources: ICAO; World Bank Database)

Figure 4 presents the growth of air freight volumes by regions of the world carried by all airlines between 1985 and 2015. As can be seen from the figure, air cargo transport in Asia–Pacific increased most rapidly, surpassing Europe since 1997 to become the largest air cargo market. Furthermore, there is a similar plot about air freight traffic in Europe and North America. Due to the impacts of the global financial crisis and economic recession, air cargo transport in Asia–Pacific, North America and Europe declined in 2008, 2009 and 2010 to some extent.

The remaining three regions—Africa, Latin America and Caribbean, and the Middle East—have similar growth rates until 2002, as illustrated in Figure 4. Since 2002, air freight volumes in the Middle East have increased much more than the other two regions; it even approached the volumes of Europe and North America in 2015.

That indicates the air cargo transport sector in the Middle East is not affected by the global financial crisis and economic recession too much. This may result from the increasing investments in Middle East from China; in particular, China has been the largest investor of the Middle East area in 2016 which exceeds the US (X. Han 2017).

The share of air passenger and freight transport by world regions in 2015 is illustrated in Figure 5. The data indicates the Asia–Pacific market has outgrown the North American market to be the largest aviation market in the world, while the European market has become the second largest. There is the same pattern in both air passenger transport and air freight traffic, for which, by the end of 2015, Asia–Pacific has the largest market share in both passenger and freight air traffic, while Africa represents the smallest proportion of the aviation industry.

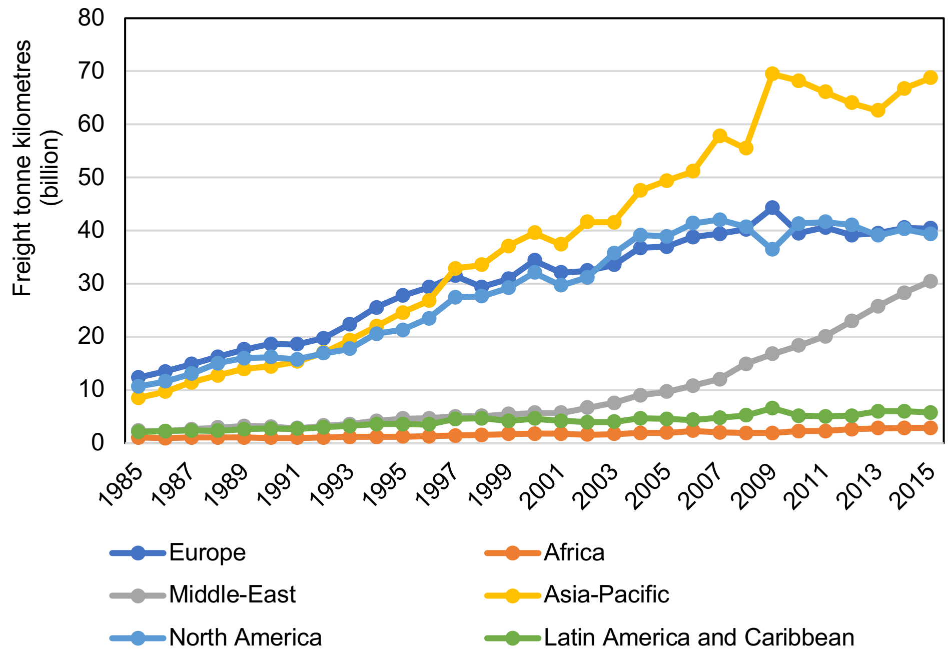

Figure 4 Growth of air freight volumes from 1985–2015

(Data source: World Bank Database)

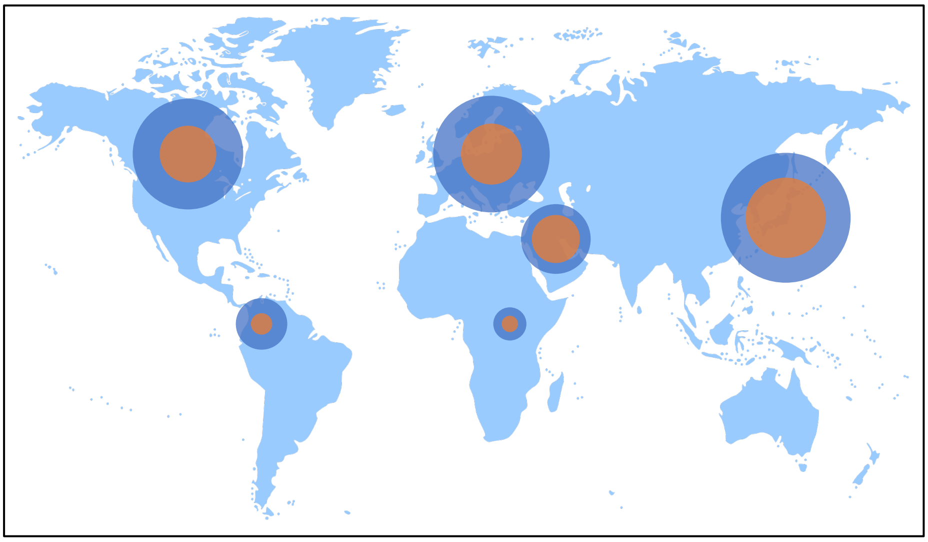

Figure 5 Air transport by regions in millions RTK[3] by the end of 2015

(Data source: ICAO 2016. The size of the bubble presents the number of RTK)

The current development of the aviation sector is not uniform; it is significantly affected by the demands of emerging countries, such as Brazil, China, India and Russia. There is an average of 4%–5% annual rate of growth in the aviation sector globally. In particular, as one of the most successful years for the airline industry, a total of $65.2 billion profit was achieved in 2016 (ICAO 2016). IATA (2014) forecasts that the period between 2012 and 2032 will be more profitable.

Despite the influence of the economic crisis in 2008, competition from other transportation approaches has resulted in difficulties in the air cargo market. The total amount of freight tonnes kilometres (FTK) in 2012 obtained a nearly 4% rate higher than the achievements before the 2008 financial crisis which is even 20% more than the lowest in 2009 (Sausen and Schumann 2000). Between 2012 and 2032, the annual growth rate of air freight could be approximately 4.8% (Airbus 2016). During this period, there is

[3] RPK converts to RTK by assuming each passenger, including luggage, averages 90 kg.

demand for up to 1,860 converted aircraft[4] with 900 new aircraft. The intraregional and domestic markets are resilient while facing weak trade and economic growth and helping to overcome the demands of freighter aeroplanes.

One of the largest markets for freighter aircraft would still be North America, while Asia–Pacific would grow three times during the forecast period. This phenomenon can be explained based on the fact that the increase in air cargo demands would eventually correlate to business confidence and world trade. The Airbus Global Market Forecast shows that the growing demand for aircraft would be 30,000 for new-build freighter aircraft and passengers under the long-term growth of the aviation industry. No doubt many of the current needs would be based on the new markets, namely, Africa, South America and Asia. On the other hand, the most mature markets of North America and Europe would continue to increase the benefits from the emerging regions with the growth of air transportation. In any sense, the growth of aviation would expose the air transport sector to additional risks in policy caused by the related impacts on the environment.

2.2 Aircraft Emissions

2.2.1 The effect of aviation on climate change

Together with the fast growth of the aviation industry and the energy consumption from the increase in new aircraft, the significant impacts of aviation on the environment need consideration. Aircraft emissions affect the relative balance in the atmosphere and, hence, the climate systems could be changed based on different factors. Those factors consist of the carbon dioxides (CO_2) and nitrogen oxides (NOx) of GHG that are directly emitted from the aviation sector, which would severely impact the chemical properties in the atmosphere. Changes to NOx in the air would affect the amounts of ozone (O_3) and methane (CH_4). The aircraft leaves contrails that could induce cirrus clouds, an effect that has severely non-negligible

[4] Converted aircraft means aircraft manufacturers convert retired passenger aeroplanes to freighter aeroplanes to extend their working life, which could save them from being parked and replace less efficient freighters at the same time.

effects on climate change. For example, fuel sulphur has been transformed into gaseous H_2SO_4, which is a significant aerosol precursor for the issues of air pollution. The emissions of particulates from the aviation sector could be either directly scattered or absorbed by solar radiations that impact the microphysical and the optical properties percentages in the air.

In terms of quantifying all sources of GHGs, carbon dioxide equivalent (CO_2e)[5] has been introduced as the metric because CO_2 is the most significant GHG. To quantify one GHG emission in CO_2 is to multiply the amount of this kind of emission in tonne with its global warming potential (GWP)[6] value, which allows us to measure different emissions in one single metric. The reason why we need to have the metric is to build a reasonable framework to quantify how we can benefit from emissions reductions in different sources. Although CO_2 has been considered as the most significant GHGs, emissions like CH_4 and NO_x have more powerful impacts on climate change, especially the ascendant of temperatures coming from air pollution have similar effects as CO_2 emissions. The table below lists GWP values of several GHG emissions from IPCC Fifth Assessment (2014a). The GWP value for CO_2 equals to one exactly since it is the baseline unit to quantify all GHG emissions.

Table 1 GWP values and lifetimes from 2013 IPCC Fifth assessment

	Lifetime(years)	GWP	
		20 years	100 years
Methane	12.4	86	34
HFC-134a (hydrofluorocarbon)	13.4	3790	1550
CFC-11 (chlorofluorocarbon)	45	7020	5350
Nitrous oxide (N_2O)	121	268	298
Carbon tetrafluoride (CF_4)	50000	49650	7350

[5] CO2e is a measurement for describing how much global warming can be caused by a given amount and type of GHGs. In some rare cases, CO2e also refers equivalent carbon dioxide, which is another similar but distinct measurement from what we described above.
[6] Global warming protential is a relative measure of how much heat a GHG traps in the atmosphere.

In general, CO_2 is considered one of the most significant GHGs emitted by the aviation sector; therefore, it is included in the EU ETS (Stephenson 2012). In 2012, aircraft had emitted globally a total of 689 million tonnes of CO_2, which increased to 710 million tonnes by 2013 (ATAG 2013). Almost 80% of the gas emissions from the aviation industry are based on aircraft travelling an average of 1,500 km (ATAG 2016b). However, there is no better transportation approach with respect to time efficiency and direct CO_2 emissions. In particular, ICAO (2009) forecasted that aviation emissions would grow 300%–700% by 2050 compared to the level of emissions in 2005. In addition, the emission of CO_2 from the aviation sector would be almost three times from 2000–2050.

2.2.2 Projections for the airline industry

To forecast future air travel demand, different authorities, such as Airbus, Boeing, IATA, ICAO and Japan Aircraft Development Corporation (JADC), have produced several studies. They adopted different explanatory variables in their methodologies for both passenger and freight traffic, which can be seen in Table 2.

Because GDP is one of the primary drivers for the growth of air transport demand, especially for those industrialised countries, all authorities that presented in Table 2 adopt it as an independent variable to estimate the future global air traffic market. The growth of the airline industry has grown as twice the rate of the annual increase of the world economy in previous years; however, this kind of relationship is weakened in some emerging countries, i.e. China. As a result, researchers tend to use private consumption as an analysing factor to study air traffic demand. The degree of urbanisation in investigated regions enables growth in wealth, which includes private consumption; thus, Airbus also takes it into account in their forecasts of passenger air transport demand. The composition of the labour force serves a similar function. Obviously, the population is another major force that drives the market growth of air passenger travel.

From travellers' perspectives, quality of service is quite significant when choosing an aircraft carrier; which leads to a more precise estimation about demand projections on airline basis. Most organisations consider travel attractiveness a critical explanatory factor to address the increase in the aviation industry. In particular, it has significant impacts on the origin–destination pair (OD pair) analysis. Because leisure travel is the primary purpose of air transport, interesting tourist places would attract more passengers flying to places with attractive sights. Considering various levels of attractiveness enables a more accurate analysis of the demand for air passenger traffic. Still, from the passenger perspective, the simplicity of immigration procedures is a consideration in choosing travel destinations.

JADC's (2016) analysis uses alternative transport modes in its methodology to investigate how different choices could influence air passenger travel demand, especially for the Chinese domestic airline market, which is one of the top 10 OD passenger markets in the world. Since the emergence of high-speed rail in China, more passengers prefer to travel by rail instead of air due to easy access to train stations. In particular, ICAO (2016)put a dummy variable into its projection equation, which refers to the effect of the 'special' event, i.e. 9/11, severe acute respiratory syndrome (SARS).

For air freight demand forecasting, world commerce (the volume of global trade) is a primary force driving the rise of air cargo. Another major driver for air freight transport is GDP development, which is the same with passenger air traffic; however, some studies choose the proportion of international trade to world GDP rather than using GDP itself. As shown in Table 2, several factors can be considered in forecasting the demand for both passenger and freight air transport: emerging technology, business model innovation, industry competitiveness and infrastructure, market liberalisation and crude oil prices. 'Emerging technology' refers to new aeroplanes with improved economics and capabilities. 'Business model innovation' means scheduling services to leisure destinations and forming networks for low-cost carriers (LCCs). Both factors would influence demand projections of emerging markets, such as China, Brazil and India.

By developing infrastructures in the airline industry, airlines could provide better services to passengers that can contribute to the future demand growth. For instance, by offering easier connections to airports, both passengers and freight companies are more likely to choose air transport over other transportation modes. Air traffic demand will benefit from the competition among different airlines because aircraft carriers could offer different prices and flight frequencies to attract passengers and commercial corporations. With greater market liberalisation, opportunities for air carriers will increase, build up LCC networks, open new flying routes and facilitate airline competition. Service charge is another essential driver behind air transport demand. Because it is hard to obtain airline services' prices, most authorities choose crude oil prices, the main cost of air travel, instead to analyse price impacts.

Table 2 Drivers behind the growth of air transport demand

Demand	Variables	Airbus	Boeing	IATA	ICAO	JADC
Passenger	GDP development	✔	✔	✔	✔	✔
	Private consumption	✔				
	Urbanisation	✔				
	Population	✔	✔			✔
	Labour force composition	✔	✔			
	Quality of service		✔	✔		✔
	Travel attractiveness	✔	✔	✔		✔
	Immigration procedure simplification	✔				
	Alternative transport approach					✔
	Effect of 'special' events				✔	

Freight	World commerce	✔	✔			
	International trade as a share of GDP		✔			
Passenger & Freight	Emerging technology	✔	✔			✔
	Business model innovation	✔	✔	✔		
	Industry competitiveness and infrastructure	✔	✔	✔		
	Market liberalisation	✔	✔	✔		✔
	Crude oil price	✔			✔	✔

(Source: Airbus 2016; Boeing 2015; IATA 2014; ICAO 2016; JADC 2016)

2.2.2.1 Air passenger transport

Figure 6 illustrates the historical development of air passenger traffic and different forecasts from several well-known organisations. Different annual increases have been predicted based on the different methodologies adopted in the projections. The air transport volumes worldwide in passenger kilometres are forecasted to increase from 6.6 trillion in 2015 to 16 trillion (Airbus 2016), 17.27 trillion (Boeing 2015), 14.82 trillion (IATA 2014), 17.6 trillion (ICAO 2016) and 16.35 trillion (JADC 2016) by the end of 2035. As can be seen from Figure 6, all forecasts have similar growth rates even though they have different methodologies and estimation variables. By 2035, the passenger traffic by air will increase at least 1.2 times.

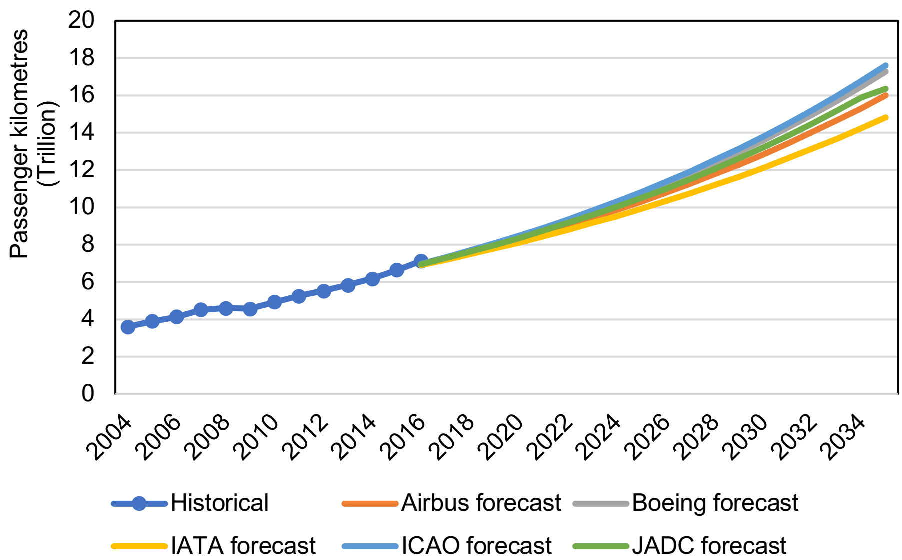

Figure 6 Forecasts of air passenger transport up to 2035

(Data source: Airbus 2016; Boeing 2015; IATA 2014; ICAO 2016; JADC 2016)

Looking at air passenger transport by region from Airbus forecasts, shown in Figure 7, Europe and North America have a low annual growth rate of 3.4%, because their markets are relatively mature. Therefore, the RPK of European airlines will increase from 1.76 trillion in 2015 to 3.44 trillion in 2035, while the RPK of North American airlines will grow from 1.62 trillion–3.17 trillion during the same period. The market share of these two regions will shrink from 27% in 2015 to 21% in 2035 and from 25% to 20% in the same time period, respectively.

In contrast, air passenger travel in Asia–Pacific and the Middle East have a more substantial increase than other regions, and they are forecasted to grow from 2.1 trillion in 2015 to 6.15 trillion in 2035 and from 0.6 trillion to 2.01 trillion in the same time, respectively. The growth rate of the RPK in Asia–Pacific and the Middle East during the same period is forecasted to be 5.5% and 6.2% annually, respectively. Furthermore, Asia–Pacific will continue to be the largest air passenger transport market in the world in 2035 with a proportion of 38% of the total global RPK. China, as the second largest air travel country, will increasingly play a significant role in pushing the demand growth of air passenger traffic.

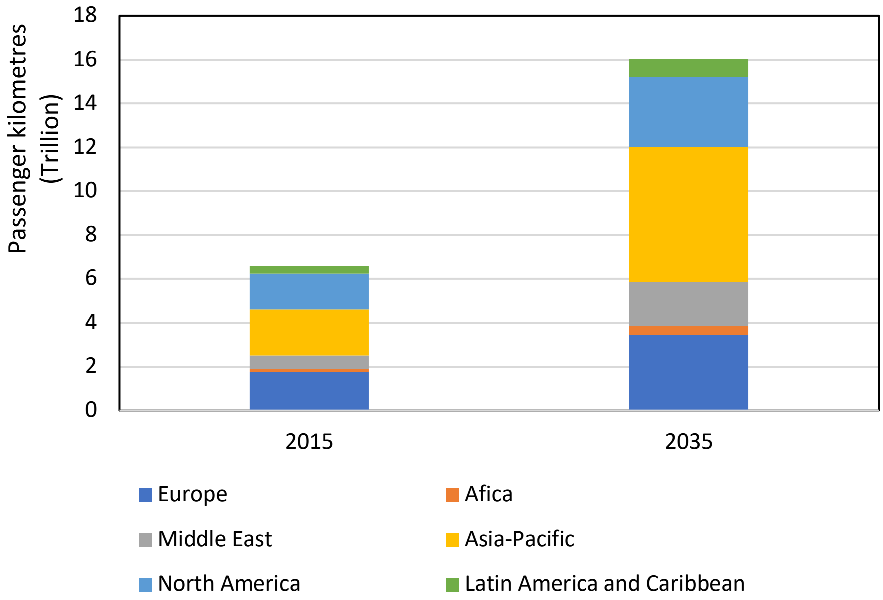

Figure 7 Passenger air transport by region in 2015 and 2035

(Source: ICAO 2015; Airbus 2035)

2.2.2.2 Air freight traffic

Air cargo transport increased 2.7% per year, slower than air passenger travel in the historical period that has been indicated in the Section 2.2.2.1, as shown in Figure 8. This is due to several crises in the world, including SARS in 2003 and the global financial crisis in 2008. This indicates that air cargo is more sensitive to changes in the world economy and 'special' events, as compared to passenger business. However, in all forecasts shown in Figure 8, there will be a similar growth trend for air freight transport and air passenger traffic up to 2035, which is approximately 4%–5%. By the end of 2035, FTK will increase to 432 billion (Airbus 2016), 494 billion (Boeing 2015), 440 billion (IATA 2014), 440 billion (ICAO 2016) or 459 billion (JADC 2016). Among all organisations, Boeing predicts the most positive future demand growth of air cargo because the increase of air freight business is 4.7%, and Airbus (Airbus 2016) only estimated the growth to be 4%.

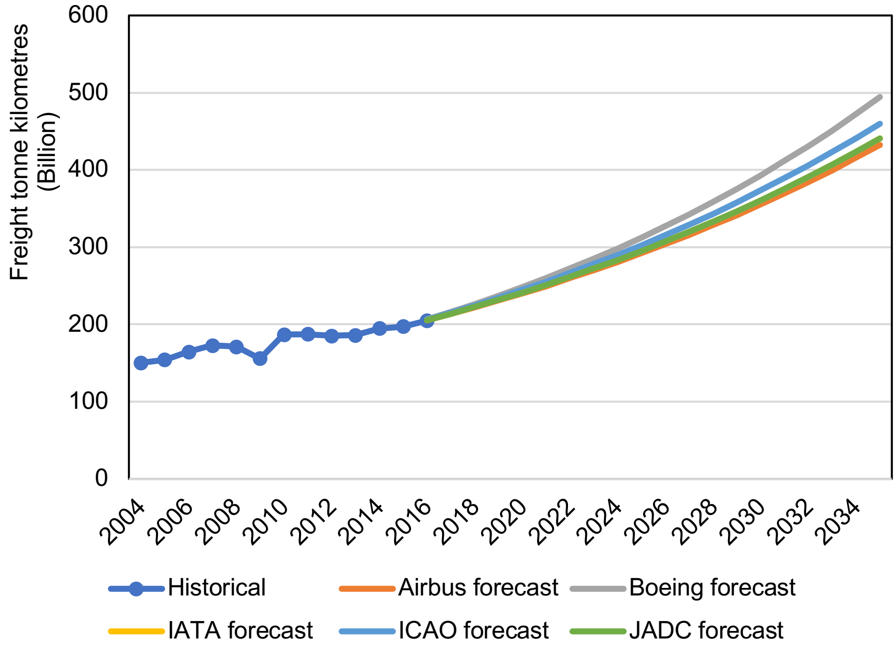

Figure 8 Projections of future air freight traffic volumes up to 2035 (Data source: Airbus 2016; Boeing 2015; IATA 2014; ICAO 2016; JADC 2016)

Moreover, Figure 9 presents a similar pattern of air cargo transport by region compared to air passenger travel. Asia–Pacific will remain the most significant market among all other areas in the sector of air freight transport, with an annual increase of 5.1%. By 2035, FTK of Asia–Pacific will grow to 211 billion and account for 45% of global FTK. Similarly, the most rapidly increasing market is the Middle East with an annual growth rate of 7.1%; its market share will ascend from 14% in 2015 to 23% in 2035, which is more than 1.5 times. On the other hand, the annual growth rate in Europe and North America is only 2.6% and 2.5%, respectively. Therefore, both the European and North American markets will contract during 2016-2035; specifically, FTK in Europe and North America will decrease from 22% in 2015 to 15% in 2035, while global FTK will decrease from 20% in 2015 to 14% in 2035.

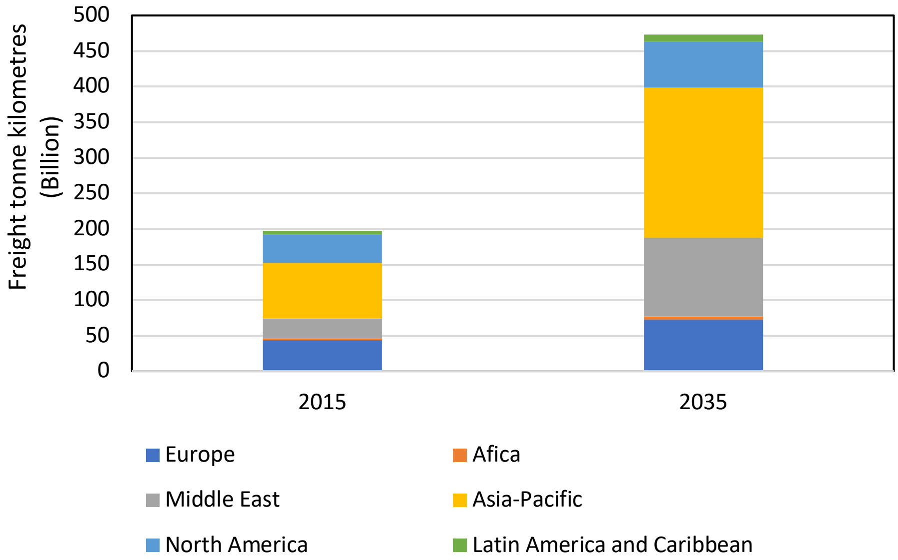

Figure 9 Air cargo forecasts by regions in 2035

(Data source: ICAO 2016)

2.2.3 CO_2 emissions projections

According to Lee et al (2001), much of the gains in fuel efficiency have been realised by 1980, with 5.4% annual improvements over the period of 1960-1980 (in terms of annual reductions of fuel or energy equivalent per seat kilometre). The IPCC report (2014b) also pointed out that fuel efficiency has been improved by 75% over the period of 1960-2000, whereas total fuel consumed by all aviation sectors, including passenger, freight and military, grew 3% annually during the same period. This is mainly due to aircraft efficiency improvements. However, the future innovation in aircraft efficiency is uncertain because the technology for aircraft has been relatively mature in recent years. Therefore, future projections of fuel consumption and aircraft emissions are highly uncertain because of different level of improvements in fuel efficiency. In addition, different air transport growth rate and level of operational improvements also influence projection results to some extent. In this chapter, we compared different emissions forecasts under the scenarios listed in Table 3. As shown in Table 3, there are 10 different scenarios in terms of levels of air transport growth, aircraft technology and operational improvement. ICAO scenarios draw upon the ICAO Committee of Aviation Environmental Protection (CAEP)

Modelling and Database Task Force (MODTF) Common Operations Database. Lee et al. (2009) calculate CO_2 emissions based on air transport growth (A1 and B2), operational improvements from scenarios of IPCC (2014b) and technology innovation (t1 and t2) from scenarios of Baughcum et al. (1999).

Table 3 Summary of future global CO_2 emissions scenarios illustrated in this section

Scenario	Air transport growth	Aircraft technology	Operational improvement
ICAO Scenario 1	Short-term demand adjusted to reflect economic downturn	No improvement in aircraft technology	No improvement in operational measures
ICAO Scenario 2	Short-term demand adjusted to reflect economic downturn	No improvement in aircraft technology	Necessary improvements to maintain current ATM efficiency levels
ICAO Scenario 3	Short-term demand adjusted to reflect economic downturn	Fuel efficiency improves by 0.95% per year for all aircraft entering the fleet after 2006 and prior to 2015. and 0.57% per year for all aircraft entering the fleet beginning in 2015 out to 2036	Moderate operational improvements of 0.5%, 1.4% and 2.3% in 2016, 2026 and 2036, respectively
ICAO Scenario 4	Short-term demand adjusted to reflect economic downturn	Moderate improvements in fuel efficiency of 0.96% per annum for all aircraft entering the fleet after 2006 out to 2036	Moderate operational improvements of 0.5%, 1.4% and 2.3% in 2016, 2026 and 2036, respectively
ICAO Scenario 5	Short-term demand adjusted to reflect economic downturn	Advanced fuel efficiency improvements of 1.16% annually for all aircraft entering the fleet after 2006 out to 2036	Advanced operational improvements of 1%, 1.6% and 3% by 2016, 2026 and 2036, respectively
ICAO Scenario 6	Short-term demand adjusted to reflect economic downturn	Optimistic improvements in fuel efficiency of 1.5% per year for all aircraft entering the fleet after 2006 out to 2036	Optimistic operational improvements of 3%, 6% and 6% by 2016, 2026 and 2036, respectively
Lee et al. A1t1	4.7% per year	Average of production aircraft will be 40%–50% better relative to 1997 levels	Optimal use of airspace availability
Lee et al. A1t2	4.7% per year	Average of production aircraft will be 30%–40% better relative to 1997 levels	Optimal use of airspace availability
Lee et al. B2t1	4% per year	Average of production aircraft will be 40%–50% better relative to	Optimal use of airspace availability

		1997 levels	
Lee et al. B2t2	4% per year	Average of production aircraft will be 30%–40% better relative to 1997 levels	Optimal use of airspace availability

As can be seen from Figure 10, there are 10 different scenarios based on research from ICAO and Lee et al; and, prior to 2010, there was a small difference between the result from ICAO and Lee et al due to their modelling approaches, especially their assumptions on aircraft technology. Based on 10 different projection scenarios, CO_2 emissions in 2050 has been calculated in a range of 1.79–4.53 billion tonnes between the most optimistic and conservative scenarios. As presented in Figure 10, CO_2 emissions from the air transport sector will grow to 3.45 billion tonnes under the baseline scenario of ICAO MODTF (ICAO S2), which is over six-fold in comparison with the 2006 level. However, with the improvements in fuel efficiency and air traffic management, CO_2 emissions in 2050 will be approximately 2.6 billion tonnes according to ICAO S3, ICAO S4, ICAO S5 and Lee et al. A1t1, and Lee et al. A1t2. For the most optimistic scenario of ICAO (ICAO S6), CO_2 emissions will be 2.3 billion tonnes in 2050, which is still higher than estimations of Lee et al. B2t1 (1.79 billion tonnes) and Lee et al. B2t2 (1.85 billion tonnes).

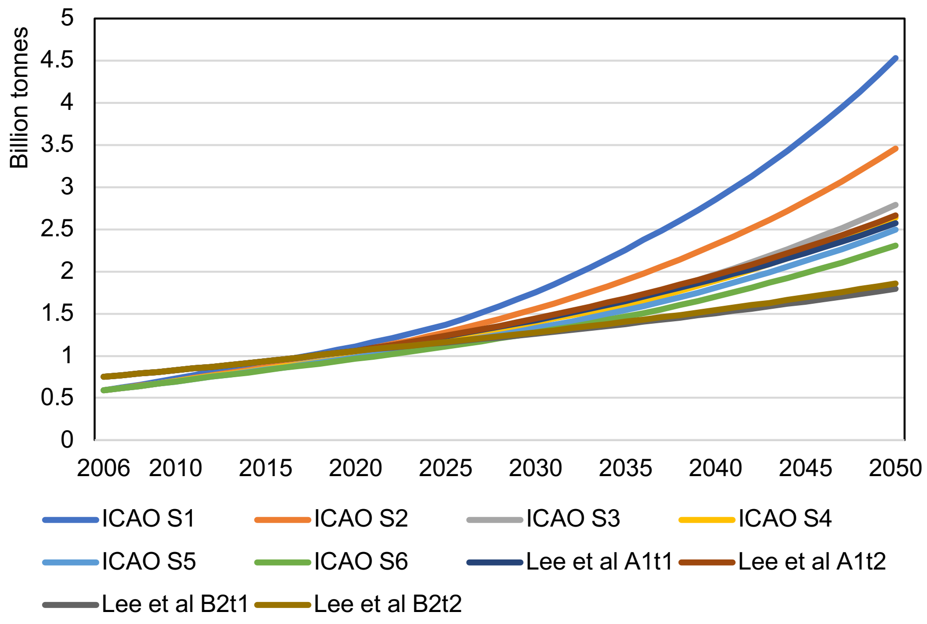

Figure 10 Aircraft CO_2 emissions projections up to 2050

(Source: ICAO 2009; Lee, et al. 2009)

2.2.4 Regulatory objectives and goals

It is of significance to reduce the emission of air pollutions from the aviation sector while maintaining the growth of the economy. To achieve the objective, the international airline industry has established a series of goals to eliminate the climate impacts. The goals include:

- Increasing fuel efficiency by 2.0% annually until 2032
- Capping the air emissions from the aviation sector during the period 2012–2032; and
- Halving CO_2 emissions until 2032.

In order to achieve these objectives, all countries should work collaboratively under the lead of ICAO. Note that these goals are adopted by carefully analysing the global situation of the air emissions and climate change while keeping the growth rate of the economy. In particular, the emissions of aviation sector have been taken into account under EU ETS ever since 2012. In 2009, IATA launched the goal of achieving stable emissions of carbon during the period from 2012–2032, even though the aircraft industry would continue to increase. To achieve IATA's objectives, a comprehensive analysis of different factors should be evaluated, such as the utility of alternative fuels, retrofits, offset mechanisms, infrastructure and operational measures, and fleet renewal. In the 37th session of ICAO in October 2010, Member States determined standards regarding the emissions of CO_2. The standards would be applied to make sure that new aircraft could meet a fundamental limit for the emissions of CO_2.

Based on the full support of IATA, a significant milestone was reached in July 2012 when the ICAO-CAEP agreed on the standards of new CO_2 as well as the Certified procedures adopted in Feb. 2013. Beyond IATA's targets, the international aviation sector for achieving carbon neutral growth while reducing the emission of CO_2 by 50% compared with the level in 2005. In the US, the EPA and ICAO are collaborating to develop regulations to reduce GHGs from the aviation industry. The agency also maintains public attention on the issue by regulating a 2-month period of public comments. The new standards will not be ready until 2017, while the implementation can only be carried out by 2018. However, the petition of "Reconsideration of Finding that Greenhouse Gas Emissions from Aircraft Cause or Contribute to Air Pollution That May Reasonable to Air Pollution That May Reasonably Be Anticipated to Endanger Public Health and Welfare" has been denied in December 2016. The most recent progress on international aviation emissions reduction has been made by the ICAO on their 39th Assembly, which is building the Carbon Offsetting and Reduction Scheme of the International Aviation (CORSIA) that would be launched in 2020.

2.3 CO_2 Emissions from China

2.3.1 Historical development of Chinese CO_2 emissions

As can be seen from Figure 11, China has surpassed the US and become the largest emitter in the world since 2005. By the end of 2014, CO_2 emissions from China reached 10,291 million tonnes, which is 13-fold of the level in 1960 that was 780 million tonnes (World Bank 2014). Also, we can learn from Figure 12 that CO_2 emissions from China account for 30% of the global total CO_2 emissions, which doubles the level of the US and is 20% more than the level of the EU. As the leading emitter in the world, China also needs to seek emissions mitigation measures to achieve its environmental sustainability although it has been excluded from the Kyoto Protocol. However, according to the Paris Accord, China has made an ambitious reduction target, which is to reach the peak of CO_2 emissions by 2030 and to lower emissions intensity (CO_2 emissions per unit of GDP) by 60-65% from the 2005 level (Centre for Climate and Energy Solutions 2015). To achieve China's abatement objectives, it is necessary to reduce CO_2 emissions from all energy-intensive sectors.

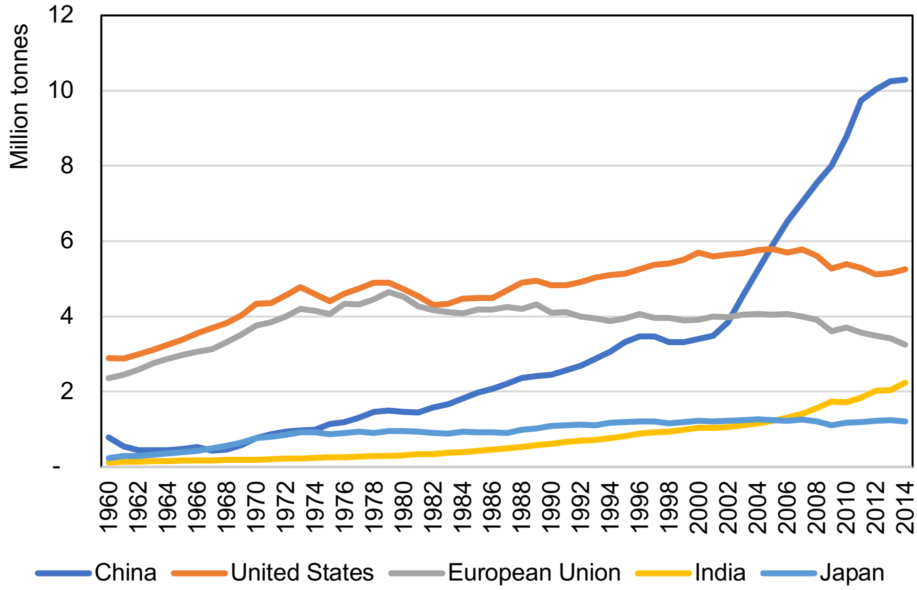

Figure 11 CO_2 emissions from top five emitters in the world between 1960-2014

(Data source: World Bank Database)

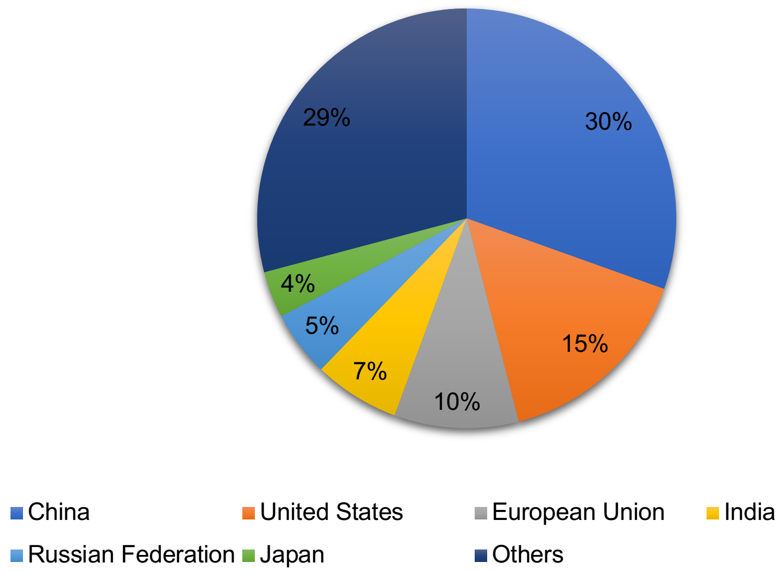

Figure 12 2014Global total CO_2 emissions by countries in 2014

(Data source: World Bank Database)

By looking at CO_2 emissions sector by sector in China, as illustrated in Figure 13, transport sector only accounts for 6% of total CO_2 emissions from China by the end of 2010, which means the Chinese aviation industry consists of an even smaller share of the total volume of CO_2 emissions. However, Cai et al. (2011) calculated CO_2 emissions from the transport sector based on their fossil-fuel consumption. They concluded that CO_2 emissions from the transport sector in China grew by 160% during the period of 1994-2007, which is higher than the growth of 118% of the total emissions of China's energy activities. According to their computation, there were 436 million tonnes of CO_2 emissions from the Chinese transport sector, and road transport held the largest share—86% and the aviation industry only consists of 5% of the total transport emissions in China. Although the air transport sector only contributes to a small share of the total CO_2 emissions in China, it increases faster than most of other Chinese industries.

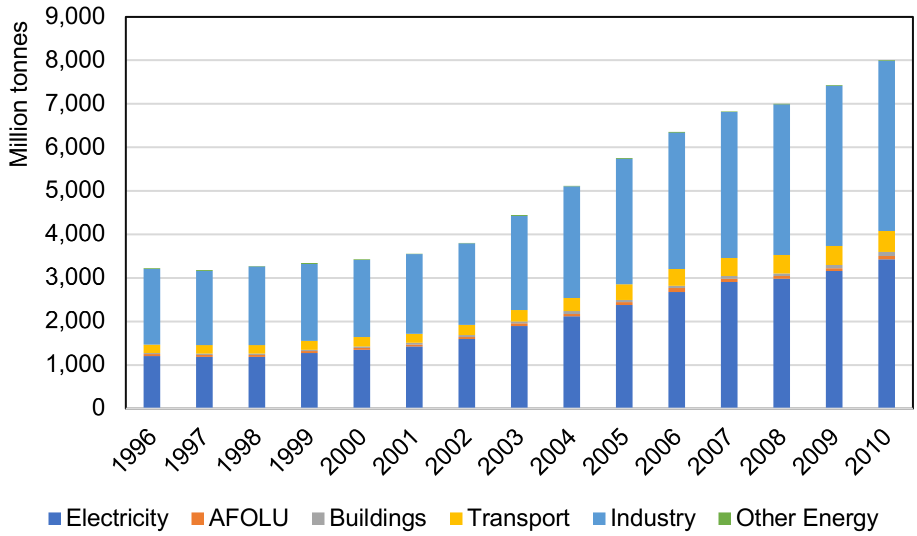

Figure 13 Total CO_2 emissions in China by sectors from 1996 to 2010 (Data source: Ji 2012)

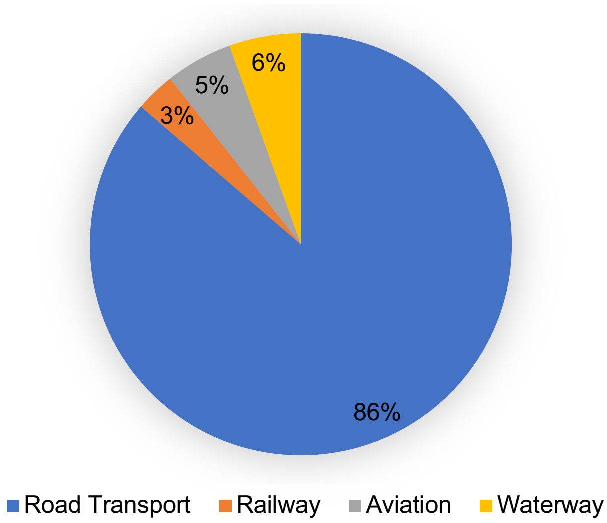

Figure 14 CO_2 emissions from the Chinese transport sector in 2007

(Data source: Cai et al. 2011)

2.3.2 Emissions from the Chinese aviation industry

As has been indicated in Section 2.1, China is the second largest air transport country in the world, but it has the fastest growth rate in the air traffic demand in both passenger and cargo transport. Figure 15 shows the result calculated by Zhou et al. (2016), which includes CO_2 emissions and fuel consumption from the Chinese air transport sector and the emission intensity and fuel intensity is calculated as the emissions or fuel consumption divided by the total turnover (including both passenger and freight). We can learn from Figure 15 that CO_2 emissions in the Chinese aviation industry increased by 600% between 1980 and 2013 from 1.07 Mt to 62.9 Mt, which is an average increase of 13.1% per annum. Similarly, He and Xu (2012) also calculated aircraft emissions from the Chinese civil aviation industry that it increased by 12.2% per year from 1960 to 2009, which is from 0.12 Mt in 1960 to 41.44 Mt in 2009. Both results presented the annual growth of CO_2 emissions from the air transport sector is much higher than the growth rate of total CO_2 emissions in China, which was 3.4% per annum (World Bank 2014). Also, it is higher than the growth rate of the whole of China's transport sector, which was 10.6% per year (Wang, Zhang and Zhou 2011).

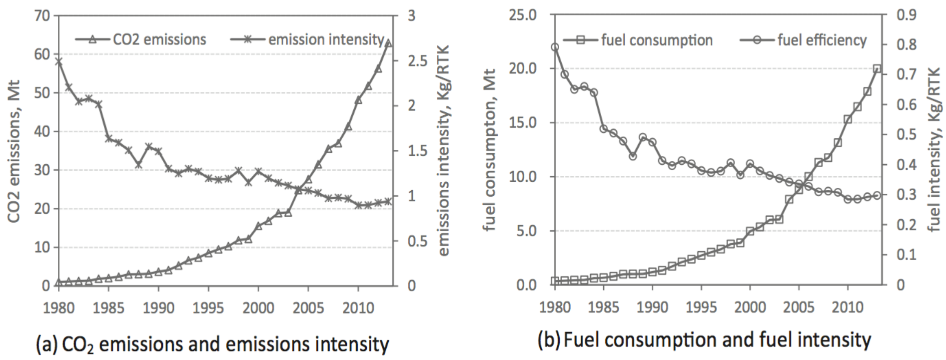

Figure 15 CO_2 emissions, emissions intensity, fuel consumption and fuel intensity of the Chinese aviation industry from 1980 to 2013

(Source: Zhou, et al. 2016)

As illustrated in Figure 16, the most significant air transport market in the world in 2036 will be the Chinese domestic air traffic with an increase of 360%, which is 2.4-fold of the growth rate of the US domestic air transport market. Also, there are five markets involves China in the top 20 traffic flows from 2017 to 2036, which proves Chinese airlines will play a major role in international aviation as well. Accordingly, CO_2 emissions from Chinese airlines are expected to increase rapidly if there is no huge technology improvements or mitigation instruments applied to the sector, which can be seen in Figure 17. Under the baseline scenario assumed by Zhou et al. (2016), they forecasted the Chinese civil aviation industry would emit 120.57 million tonnes CO_2 in total by the end of 2030, which doubles the level of 2015.[7] Therefore, it is necessary to explore mitigation measures for the Chinese air transport sector. Especially, President Trump of the US announced his decision to withdraw from the Paris Agreement, which means China will take the lead in global GHG emissions reduction. To achieve China's commitment under the Paris Agreement, the Chinese government needs to abate CO_2 emissions from all energy-intensive sectors, particularly, the aviation industry.

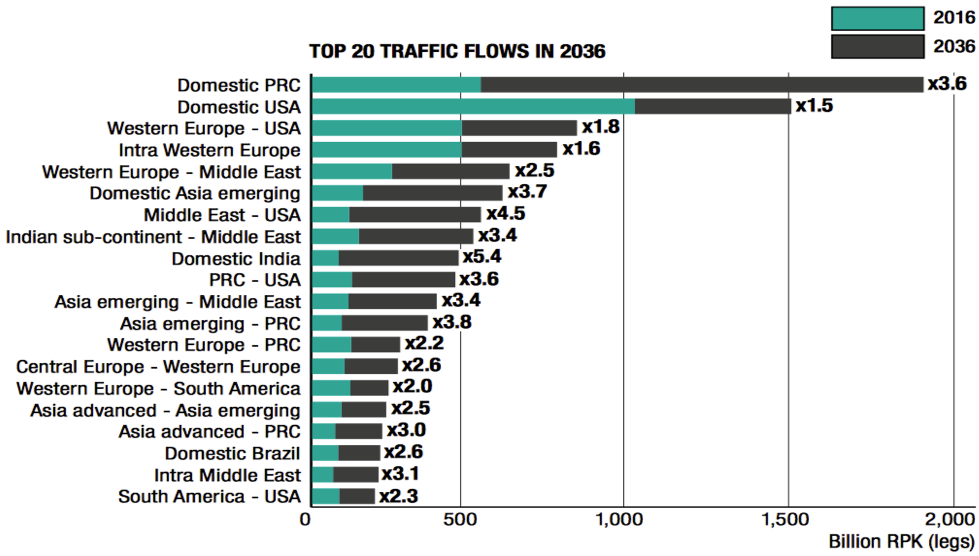

Figure 16 Top 20 traffic flows in 2036

(Source: Airbus 2017)

7 The baseline scenario carried by Zhou et al. (2016) assumes fuel efficiency will improve by 1.5% per year from 2015 to 2030 and the air trafftic in China will increase by 6% per annum. In 2015, all aircraft operated by Chinese airlines use conventional jet fuel in 100%; and, in 2020, 2025, and 2030, conventional jet fuel will account for 98%, 95%, and 90% of total fuel consumption, respectively. Therefore, biomass-based energy will be adopted at 2%, 5%, and 10%, individually in 2020, 2025 and 2030.

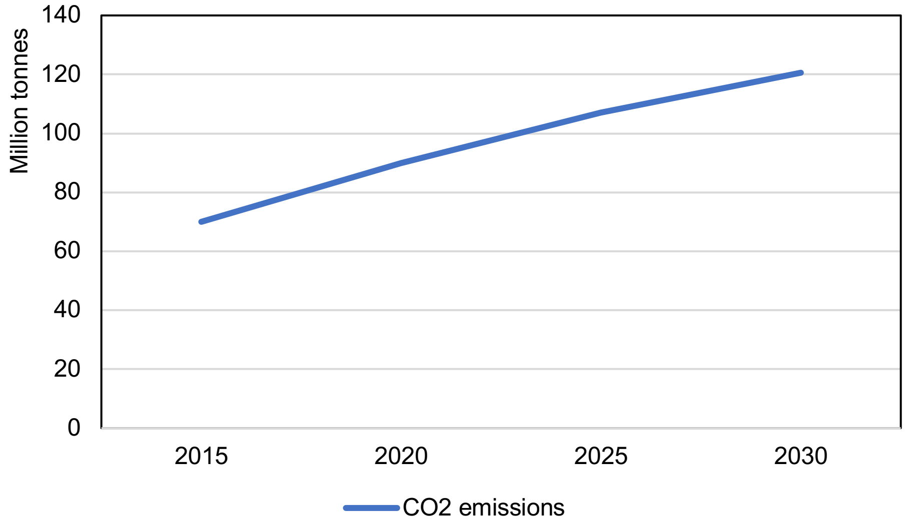

Figure 17 Baseline scenario of CO_2 emissions from the Chinese air transport sector up to 2030

(Data source: Zhou et al. 2016)

2.4 Conclusions

This chapter summarised the development of the airline industry for passenger and freight transport, both of which increased heavily during the previous 30 years. Traffic data showed a growth of passengers more than threefold between 1985 and 2015, while FTK rose four times during the same period. These increases occurred despite several 'special' events that changed the global economy, such as the First Gulf War, SARS, 9/11, the global financial crisis and the economic recession. Moreover, air traffic in Europe and North America has slowed due to market maturity, whereas Asia–Pacific becomes the largest air transport market all over the world.

In the meantime, the aviation market in the Middle East also has expanded rapidly. Regarding future developments of the world and regional economy, the demand for air travel, both passenger and freight, will continue to grow massively. The market share of Europe and North America will continue to contract while the market share of Asia–Pacific and the Middle East continue to increase. Although different methodologies have been investigated, an annual growth of 4%–5% of both passenger and freight air transport are found for years up to 2035.

Based on different expected growth rates of the global airline industry, several 2050 scenarios were illustrated for future aviation CO_2 emissions. ICAO MODTF scenarios are projected based on ICAO's estimations about future GDP development and different levels of improvement in both fuel efficiency and air transport operation. ICAO forecasts CO_2 emissions of the airline industry will grow to 4.53 billion tonnes if no improvement in both aircraft technology and air traffic management. On the other hand, CO_2 emissions will be only 2.3 billion tonnes with positive improvements in fuel efficiency and air traffic management. Lee et al. (2009) constructed their scenarios by linking potential GDP growth and operational improvements from IPCC; and then, included potential fuel efficiency improvements from research by Baughcum et al. (1999). The most conservative scenario on GDP growth and technology improvements by Lee et al. (2009) predicted CO_2 emissions from the aviation sector will be increased to 2.66 billion tonnes, which is consistent with most ICAO MODTF scenarios. The most optimistic scenario is that aircraft CO_2 emissions will ascend to 1.79 billion tonnes only, which is approximately 1.4 billion tonnes less than the most optimistic ICAO MODTF scenario.

In addition, by looking at historical CO_2 emissions from China, we could understand better that why emissions abatement in China is so significant for the world. China has been the largest emitter in the world since 2005 and its emissions from the aviation sector will also be the largest source by 2036 due to its highly increased air transport turnover. Based on the baseline scenario of Zhou et al. (2016), CO_2 emissions from the Chinese passenger airline industry will reach 120.57 million tonnes in 2030. Although the share of passenger airline direct emissions is only a small proportion of China's total emissions, the rapid growth of passenger aircraft emissions cannot be neglected. Therefore, it is essential to reduce CO_2 emissions from the Chinese passenger airline industry.

A range of possibilities for improvements in fuel efficiency and air transport operation has been included to project future CO_2 emissions. However, there is uncertainty as to which scenario can be achieved in the future. Therefore, technology innovations will be discussed in Chapter Three, which presents available technologies for the aviation industry in reducing aircraft emissions. The study also will offer a better understanding of whether improvements in technology innovations and air traffic management can meet regulatory objectives and goals stated in this chapter.

Chapter 3 Aircraft Emissions Abatement: Industry Developments

As addressed in the previous chapter, air traffic demand is projected to grow massively up until 2050, and CO_2 emissions from aircraft may increase to 4.53 billion tonnes under ICAO's forecasts. To achieve the environmental sustainability of the aviation industry, various methods have been explored over the last five decades. In this chapter, several technologies and operational measures are discussed as to their effects in reducing aircraft fuel consumption and corresponding emissions.

3.1 Overview

As addressed in Chapters 1 and 2, the aviation industry has been proliferating since the 1950s. According to IPCC's Fifth Assessment Report (IPCC 2014a), the temperature has risen from 0.65°C–1.06°C between 1880 and 2012. This has affected biological and socio-economic systems, which are anticipated to become significantly more relevant to humanity in the medium- to long-term future. Statistics show GHG emissions from various sources have increased greatly since 1970. Looking sector by sector, transport seems to account for a small share of global GHG emissions at 13% (IPCC 2014). This leads to the argument that aviation accounts for an even smaller proportion, which raises the question as to whether it is necessary to include it on the 'target list'. IPCC's Fifth Assessment Report indicates that approximately 960 million tonnes of CO_2 emitted from aircraft in total in 2010, including commercial, military, general aviation and related operations (IPCC 2014a). However, this amount is based on global population participation; aviation contributes to a considerably larger share in industrialised countries. Furthermore, other human activities push individual emission levels as fast and as high as air travel. For instance, a return trip between London and Beijing will cause CO_2 emissions of about 712 kg per traveller[8] or 14% of the average per capita emissions of global CO_2 emissions from all sectors. Thus, emissions from the aviation industry should not be neglected anymore because air travel has enormous potential to contribute to unsustainable development.

Government-sponsored research and development can be a valid driver of innovation in the aviation sector (Government Accountability Office 2008). Current research and development programmes in the US include the Federal Aviation Administration's (FAA) Continuous Lower Energy Emissions and Noise programme and the National Aeronautics and Space Administration's (NASA) Environmentally Responsible Aviation project. Moreover, expanded federal research and development support for the aviation industry in the US would have domestic and global impacts, mainly due to U.S.-based Boeing's position as one of the worlds' two dominant commercial aircraft manufacturers, along with European Airbus (McCollum, Gould and Greene 2010).

In addition, increased government spending on infrastructure could also play a role in mitigating GHG emissions. In the case of aviation, there are a couple of strategies beyond the direct control of airlines and strongly dependent on government regulation and support, such as airport expansion and advanced CNS/ATM[9] systems. Meanwhile, the Single European Sky Air Traffic Management Research (SESAR) programme will continue to progress in Europe, and incentives may be needed to motivate all aircraft to comply with SESAR requirements and adapt to its usage (Dray, et al. 2010). Airport congestion also could be reduced by greater regulation of aircraft arrival and departure times, possibly via pricing or auctioning strategies (Janic 1999). ICAO (International Civil Aviation Organisation) is a United Nations specialised agency, established by States in 1944 to manage the administration and governance of the Convention on International Civil Aviation (Chicago Convention). It

[8] The emissions result is calculated from the ICAO Carbon Emissions Calculator, available at https://www.icao.int/environmental-protection/CarbonOffset/Pages/default.aspx.

[9] CNS/ATM systems means communications, navigation, and surveillance systems, employing digital technologies, including satellite systems together with various levels of automation, applied in support of a seamless global air traffic management system (ICAO 1998). (ICAO 1998)

traditionally has been responsible for the development of policies affecting the aviation sector. For example, ICAO has implemented standards for emissions of conventional pollutants, to limit noise from aircraft and to set fuel quality standards (Annex 16, Volume II of the Chicago Convention). ICAO staff and public and private sector experts participated in the development of IPCC's Special Report on Aviation (IPCC 1999) and worked with other experts on methodological issues related to modelling and reporting of GHG emissions from aviation.

This chapter first addressed how aviation fuel efficiency improved during the historical period and then introduced what can be expected from improvements in aircraft technology and air traffic management in improving fuel efficiency that substantially reduces aircraft emissions. Several promising techniques that may increase fuel efficiency are discussed below. Furthermore, this chapter describes options in flight operations and network optimising to improve fuel efficiency. Finally, this chapter concludes on whether the aviation development in technology and air transport management can achieve the carbon emissions reduction objectives.

3.2 Aircraft Technology Innovation History and Fuel Efficiency

3.2.1 History and future fuel efficiency

Figure 18 presents the overall trend of average fuel efficiency per passenger kilometre from 1960–2014; it indicates that aircraft fuel efficiency has improved by 45% since 1960, with an annual increase of 1.26%. Aircraft fuel efficiency improved dramatically since 1966 and plateaued during the 1970s. Then, the fuel consumed per passenger kilometre decreased by 2.55% between 1981 and 1990 due to aircraft technology innovation. Next, the growth rate of fuel efficiency slowed down between 1991 and 2014 to 0.95% per year, because the technology of aircraft design was relatively mature.

According to the ICAO and IATA objectives for fuel efficiency improvements, future projections can be seen in Figure 18. From ICAO's forecast, the fuel consumed per passenger kilometre will decrease by 2% per year, while the fuel efficiency in passenger kilometre in 2050 will be 24.16 (1968 = 100). Furthermore, IATA (2014) predicts that future increases of fuel burned per passenger kilometre will be 1.5% per year; consequently, aircraft fuel efficiency will be 29.02 in 2050 based on the effectiveness in 1968 equals to 100.

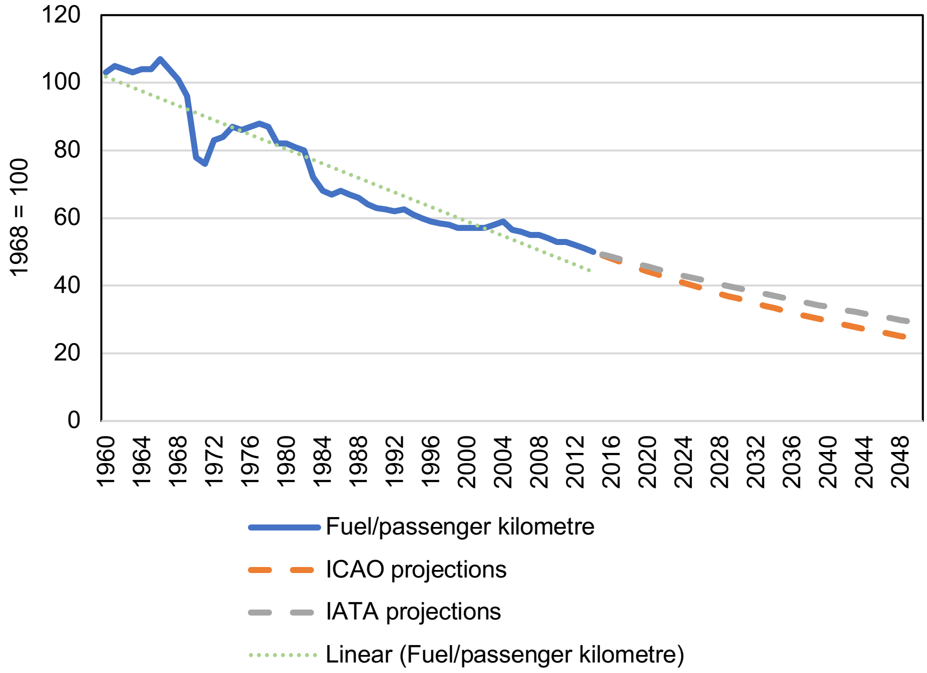

Figure 18 Average fuel efficiency for new commercial jet aircraft between 1960 and 2014; future projections up to 2050

(Data source: Kharina and Rutherford, 2015)

3.2.2 History technology innovation

As discussed in the previous section, fleet fuel efficiency has improved greatly over the historical period of 1960–2014 due to aircraft technology innovation in several aspects, including structures, aircraft systems, aerodynamics, propulsion systems integration and manufacturing techniques (ICAO 2010). The improvement in different generations of aircraft is complicated because each aspect takes effectiveness concurrently. Three factors are most significant in increasing fuel efficiency.

Firstly, manufacturers could explore ways to reduce the aircraft's weight to improve the payload under the same thrust and fuel consumption. Improving the aerodynamics system of aeroplanes can reduce drag and thrust. Improving performances and fuel economy of aircraft engines in turn will improve fuel efficiency. Figure 19 shows how aircraft manufacturers reduced the weight of aeroplanes by developing new structures and applying new materials in aircraft design. In 1974, Airbus delivered the A300, the first twin-engine wide-body jet airliner, to the commercial aviation market. This aircraft improved performance and fuel efficiency by adopting an under-wing engine, which allowed for the wings to be located further forwards and reduced the size of the vertical stabiliser and elevator (Bowen 2010). In the 1980s, the A310 came on to the market as a derivative of the A300, with a shortened fuselage, renewed wing design and lesser vertical tail.

Airbus also manufactured the A320, A330 and A340, all based on the A300 to compete with a similar type of aircraft—the B737 and B777 from Boeing. A380 is the first double-deck and four-engine ultra-high-capacity aircraft (UHCA), launched by Airbus in 2004, which beat the Boeing 747 to become the largest passenger aeroplane in the world. The most notable innovation for this aircraft is that 20% of the fuselage adopts lightweight, but strong, composite materials (Marks 2005), such as the main structure of the centre wing box, wing ribs, and rear fuselage (Airbus n.d.). The A380 applies Glass Laminate Aluminium Reinforced Epoxy (GLARE) to its topside and rear fuselage, which reduces the aircraft weight and improves its capability of anti-erosion and air resistance (Vlot and Gunnink 2011).

In 2011, a new generation aircraft—the B787—was delivered to the market. It is more energy efficient than the previous generation—the B767—at 20%. The B787 improves engine efficiency by 40%, increases aerodynamic efficiency and uses more lightweight composite materials (Boeing 2014). Similarly, another revolution made by Airbus is the A350XWB (Extra Wide Body), with its adaptive wing design that facilitates improvements in aerodynamic efficiency by optimising wing loading, reducing drag and lowering fuel burn (Airbus n.d.). Moreover, the A350XWB benefits from the implementation of advanced materials, including carbon composite, titanium and aluminium alloys. As a result, it has 25% lower operating costs, fuel burn and CO_2 emissions compared to previous generation aircraft.

In summary, technology innovation for improving fuel efficiency in recent decades has placed the focus on reducing aircraft weight by adopting new materials, increasing aerodynamics efficiency by designing new structures, and improving aircraft engine performance and efficiency. Therefore, we can expect future technology innovation to continue these efforts, a topic that will be discussed in the following section.

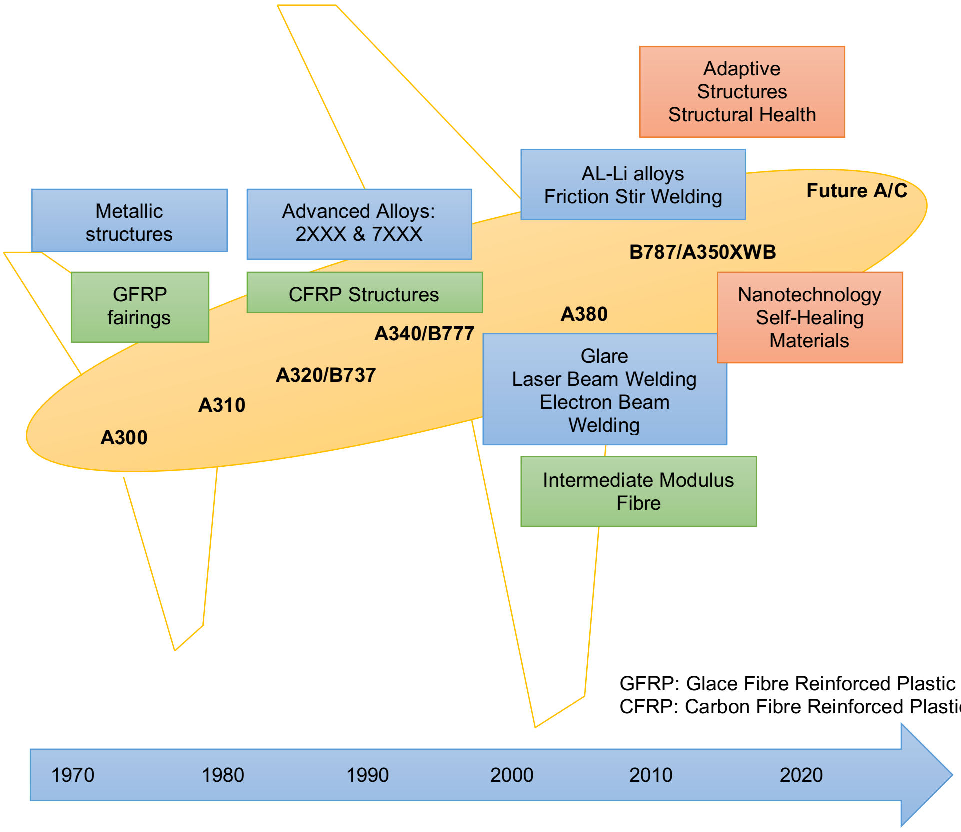

Figure 19 Airframe technology innovation

(Source: ICAO 2010)

3.3 Future Aircraft Technology Innovation

The current technology for the aviation sector can be seen as almost mature because most aviation innovation has occurred in previous decades (Boeing 2015). However, due to the sustainable development within the industry, new changes in improving environmental sustainability are needed. The literature on aeronautical engineering suggests several options for reducing aircraft emissions, which includes UHCA, wing design, high by-pass ratio turbofan engines, new materials and using alternative energy. In this section, each technology is examined separately and discussed for its potential for fuel efficiency improvements.

3.3.1 Aircraft related technologies

A traditional way to reduce fuel consumption and substantially reduce aircraft emissions is to design a UHCA. Currently, the largest passenger carrier aircraft is the A380, which can host over 800 passengers in an all-economy layout (Airbus 2017). In comparison, if there is a UHCA that can carry more than 1,000 passengers, it may reduce fuel consumption by 10% per seat kilometres theoretically (Gössling and Upham 2009). However, the aircraft will have a huge disadvantage, which is that it will exceed the 80 * 80 restrictions (Keith-Lucas 1968) that the largest aircraft an airport can handle. Therefore, even though such an aircraft could be designed successfully, all airports' in the world cannot meet their operating requirements.

There are several critical issues for the A380 that have not been solved yet, which will be a problem of the 1,000-passenger aircraft too. First, the A380 would cause turbulence due to its large aircraft size during take-off. As a result, small and medium aircraft must wait to take-off for at least three minutes after the departure of an A380; large aircraft also must wait at least two minutes. In addition, the length and tolerance of the runway in most airports are hard to afford the Landing and Take-Off (LTO) of an A380.

Second, there is the 'square-cube law' issue. In the aviation sector, the square-cube law presents the relationship between aircraft weight and stresses to the aircraft structure (Weisshaar et al. 1993). Even though advanced composite materials have been applied to the A380, there are still small fractures on the wings due to tremendous pressure. Thus, a UHCA that is larger than A380 would have the same problems mentioned previously, which means a manufacturer cannot merely make the aircraft larger unless there is more infrastructure work in airports and other new materials with the same or lighter weight but stronger is developed. On the other hand, if we retain the same aircraft size and simply upgauge[10] the cabin, it will also reduce emissions per passenger; there will be lower emissions per passenger kilometre when there is higher aircraft capacity utilisation. Still, such a strategy will reduce in-flight comfort and may lead to a lower load factor[11] because no one is willing to pay for a less comfortable experience when he/she is spending a similar amount.

Another aircraft design idea to decrease emissions is the fixed-wing aircraft, also called the blended wing body (BWB). Westland Dreadnought built the basis of the theory in 1924. By using new materials, this configuration would have a significantly higher lift-to-drag ratio than a conventional craft, which would improve fuel efficiency. It may mitigate CO_2 emissions per seat kilometre by 20% (Bowers 2000). Even though there are no new materials applied to the aircraft, the design itself can reduce fuel efficiency by 10.9% in comparison with a conventional wide-body (Warwick 2016). Furthermore, the shape of BWB creates larger payload areas for both passenger and freight aircraft, which, substantially, increases fuel efficiency per unit (passenger kilometre/tonne kilometre) under the same amount of fuel consumption. According to NASA simulation and Russell et al. (2010), BWB could reduce noise by 15 dB compared to Boeing 777 and 22–42 dB below Stage 4[12] level depending on the configuration.

However, there are several potential risks with this kind of aeroplane. First, the difficulty of aircraft rolling will be increased, and the comfort of passengers will be reduced when the aeroplane is turning. This is because the configuration of BWB aircraft tends to distribute passengers or cargo away from the vertical axis. Second, the evacuation of passengers during an emergency will be a challenge because there is no window in the design system. Third, it is hard to design the cylindrical fuselage due to the issue of cabin

[10] 'Upgauge' refers to adding more passenger seats within the same aircraft (Office of Inspector General 2001).

[11] Load factor is a ration describing total number of passengers over total number of available seats on each flight.

[12] Stage 4 is a classification of noise reductions for quieter aircraft from the FAA.

pressure, although the cylindrical fuselage can afford more air pressure than if it were oval or rectangular.

The application of new materials is another way to save aircraft fuel burning by reducing weight. The most valuable innovation is applying composites on aircraft. Composites are multiphase materials that are structured by several elements. The most common composites used in civil aviation are glass fibre reinforced plastics, also called fibreglass. Although it has a-triple specific strength of aluminium alloy (most popular material used in aircraft), its particular stiffness is only 50% of that of aluminium alloy, which leads to a limited application (Kasen 1975).

In addition, in recent years, carbon composite came to be another significant material applied to reduce aircraft weight. Timmis et al. (2015, Tunteng 2012) conducted a life cycle assessment of the implementation of carbon fibre reinforced polymers (CFRP) on the Boeing 787. According to their analysis, the composite aircraft has more fuel economy than the conventional aluminium-based aircraft during its lifetime, which could contribute 20%–25% of industry CO_2 abatement goals. Beck et al. (2009) similarly found that composite aircraft are more fuel-efficient than aluminium-based aircraft during their in-use phase, although the production and disposal of aluminium use fewer resources and produces lower emissions than composite materials. The result indicates, during the whole life cycle, composite aircraft would have less environmental impacts due to its lightweight.

In term of engine innovations, propfan engines should be the most effective one at present. It is an aircraft engine innovated by turbofan and turboprop, but different from both. The most apparent advantage of propfan engines is greater propulsive efficiency and fuel economy. In comparison with current high by-pass ratio turbofan engines, this kind of engine will reduce fuel burning by 20%; and by comparing engines of Boeing 707 and DC-9, it could save fuel burning by 60% (Dallara 2011).

3.3.2 Aviation fuel

As a generic name, 'aviation fuel' applies to the gas engines, whereas 'jet fuel' applies to a turbine to power aircraft. Ever since the manufacture of the first jet-powered aircraft in the early 1940s, two significant operation standards can be summarized as Jet A1 (used globally in the world except for the US) and Jet A (used in the US). In aviation, the composition of jet fuel has been a dilemma over time, balancing cost and performance. The former refers to the availability of sufficient raw materials and requirements to process, while the latter represents engine-friendly technologies, propulsion properties and safety. However, a rare emphasis has been placed on environmental impact (Stephenson 2012). Jet fuels can be optimized by the technical requirements of the engines and the operational conditions.

In the transition to a sustainable industry, the following fuels and energy sources have been considered in aviation: biodiesel, ethanol, methanol, Fischer–Tropsch (FT) synthetic kerosene, nuclear, liquefied H_2 and liquefied biomethane. According to Saynor et al. (2003), methanol, ethanol, biodiesel and nuclear are unsuitable for jet aircraft due to their low energy density, limited volumes and uncertain quality; in addition, these are inherently too dangerous in the event of an accident or terrorist attack. On the other hand, Hydrogen, FT kerosene and biodiesel can be considered alternative energy sources, which could contribute to fuel saving and emissions reductions. However, these three all have their problems if we want to put them to use in air transport. The costs of producing H_2 and FT kerosene are considered to be relatively high. Engines and airframes suitable for using hydrogen are not likely to be seen anytime soon. The related proportions of different hydrocarbon constituents can be determined by the bulk property of jet fuel, namely, fluidity, energy content, density and combustibility. Other significant parameters are the behaviours of cold and corrosively flows, fuel stability and lubricity. However, there are also many minor factors that need consideration in the fuel, i.e. compounds of nitrogen hetero and oxygen, and sulphur. Those elements tend to minimize the enhancement of the combustion property while reducing the environmental impacts.

A variety of approaches have been established for producing alternative power for aircraft as jet fuels to replace waste and bio-based materials for different types of conversion techniques. An approach can be established as the feedstock by using the conversion process as the resulting fuel. Note that the alternative power for aircraft would substantially vary in chemical composition. Many approaches could create synthetic paraffinic kerosene (SPK) with no aromatics, but others may develop compounds of aromatic as well. Significant consequences are found in the blending grade of conventional, fossil-based jet fuels. Based on the costs of high infrastructures for the conversions, dubious competition, and industrial algal cultivations for the algae-based bio jet fuels and compared to other types of high-value goods based on the same feedstock, namely, the productions for the nutraceuticals or cosmetics industries, it is undetermined that conventional plant oil is better than competitors or other types of advanced bio-based jet fuels.

A report from Argonne National Laboratory shows that alternative bio-jet fuel pathways can reduce life-cycle GHG emissions by 55-85% compared with petroleum-based jet fuel but there are no emissions reductions for direct emissions (Elgowainy, et al. 2012). de Jong et al. (2017) also indicated there would be a large-scale abatement of life-cycle GHG emissions. To be more specific, FT pathway shows the highest GHG emission savings (86-104%) of the pathways considered, followed by Hydrothermal Liquefaction (77-80%), and pyrolysis (54-75%).

Because no issues are specifically related to land use, however, algal oils have a significant interest in the aviation sector. Differences between conventional routes and novel routes have been identified. Those differences consist of the utility of microorganisms. However, none of the differences has been established in commercial scales, especially the progress and announcements produced by many biofuel companies in the US. American Society for Testing and Materials evaluates these fuels (Stevenson et al. 2000, 2004.).

For example, a project has been granted to the $ProBio_3$ in France for investigating the microbial conversion of specific carbon substrates based on the renewable resources and the industrial by-products. Based on a long-term perspective, the first type of 'solar' jet fuel was produced in 2014 by the emergence of novel techniques (Marker, et al. 2005). This jet fuel is based on CO_2, solar energy and water under the project of SOLAR-JET in Europe. Currently, the technique is still in the laboratory, though it can be applied to reality on a large-scale as an alternative fuel for sustainable productions. Even though the innovation and research scenes while coming to the bio-fuel productions for sustainable aviation, one of the significant challenges for airlines can be finding a sufficient supply of bio-based fuel. To overcome the obstacles while eliminating the vulnerability in the entire supply chains of biofuel production, biofuel producers and airlines have started launching commercial partnerships. In particular, it has been announced in January 2016 that United Airlines would purchase more than 15 million gallons of renewable jet fuels more than a period of three years (United Airlines 2015).

With the technological developments, the global aviation sector could continue to increase the growth of the aircraft as the fastest growing sector in transportation. Together with the rapid increase in aviation activities, the environmental effects have become a significant concern. A total of three scenarios have been established based on different inputs: load factors, fuel prices and economic growth. Those scenarios have led to a number of projected traffic patterns (Zeng and Pyle 2003). The goals of the European Advanced Biofuels Flightpath is to ensure the consumption and commercialization of up to 2 million tonnes of producing paraffinic bio-based fuels sustainably in the aviation sector by 2032. It is shown that slow financial growth is expected to occur under the EU in the central scenario, followed by a slight and gradual recuperation during the period 2012–2032 at a minimum of 2.7% (Wilcox, Shine and Hoskins 2012).

As stated above, most technology innovation cannot be achieved in recent years or even decades, which means technology measures in efficiency improvement may not be able to keep up with air travel demand growth. Substantial airport investments and psychological resistance from both crew and passengers mainly obstruct the introduction of UHCA. Without new materials applied to reduce aircraft weight, it is impossible to design such high capacity aircraft because the wind tunnel[13] has reached its ultimate load (Xie et al. 2008). The BWB may reduce comfort and interrupt current optimised schedules because of lower cruising altitudes, and there are several unsolved safety issues. There are limitations to the hydrogen aircraft, as discussed previously, but there is another problem: building a new energy supply network worldwide. Therefore, we must pursue other measures to improve fuel efficiency to mitigate aircraft emissions.

3.4 Operational Measures

Operational measures can contribute to fuel efficiency improvement in several ways: flight route optimisation, navigation system improvement, flight management and capacity utilisation. This section discusses the improvements with each measure.

Changing flight routes can reduce aircraft emissions because the current flying distance is significantly farther than the direct route between departure and arrival airports. To achieve this objective, new communication, navigation and surveillance systems are required, as well as an air traffic management system. With modern technology, greater automation and the expansion of satellite navigation, IPCC (1999) quantifies a 6%–12% in savings of fuel consumption; however, this would take a very long period to achieve. Except for this caveat, these changes could result in more direct routing and reduced flight delay. ICAO (2000) stated these improvements could contribute to a 5% CO_2 emission reduction. Moreover, increasing airport capacity is very important because

[13] Wind tunnel is a tool used in aerodynamic research to study the effects of air moving past solid objects.

capacity constraints cause longer flight distances, which means more fuel consumption, especially when flights are required to circle before landing.

Another way to reduce fuel consumption is improving en-route airspace, which means better airspace division and aircraft separation reduction. These improvements could lead to a redesign of air traffic control sectors due to better traffic flows. Gössling and Upham (2009) introduced the term 'highway', meaning a way of isolating traffic 'on a certain route in a single tube-shaped sector, reducing both crossing points and the need to pass the control of the aircraft between controllers at each environmental sector boundary'. This will positively contribute to controller workload. In the meantime, it could dynamically change the size of control sectors (European Commission [EC] 2003).

Optimising the route network could respond to changes in demand and in aircraft technology, which contributes to CO_2 emissions abatement. EUROCONTROL proved this through its European ATS Route Network Version-7 project, which is planning the route network based on traffic flows instead of national boundaries (EUROCONTROL 2012). With improved communication, navigation and surveillance technologies, free routing will be introduced in the future to replace existing route structure, which means pilots will be responsible for maintaining aircraft separation (EUROCONTROL 2003).

As presented above, several operational measures could direct routing and improve fuel efficiency, thereby mitigating aircraft emissions. Nonetheless, increasing capacity and shortening journey times will not only save operation costs but also induce demand growth, thereby offsetting any environmental benefit.

3.5 Emissions Abatement in China

As a developing country, China is not obliged to reduce GHG emissions under the Kyoto Protocol. However, China still made its promise at the UNFCCC in Copenhagen to voluntarily reduce its energy intensity (the amount of energy consumed per unit of GDP) and CO_2 emissions (the amount of CO_2 emitted per unit of GDP) by 40%–45% by the end of 2020. As one of the leading emitting industries, the aviation industry carries great pressure.

As the most effective long-haul transportation method, air transport would still be the most popular choice for the public in the future. The development of the aviation industry is driven by national GDP and personal income, which means the amount of air transportation will heavily increase in the long term. According to previous studies, the growth rate of air transport continually higher than that of national GDP (the increasing rate of total RTK of civil aviation industry may double the growth of national GDP) (Liu and Dong 2009). Therefore, it could be projected that the amount of energy consumed in the aviation industry will heavily increase in the following years and even decades.

Since 2008, to meet the decarbonisation target, CAAC launched a project about how to reduce CO_2 emissions from the aviation industry. The opening report of the project addressed circumstances of energy intensity and CO_2 emissions in 2005 (base year of the decarbonisation project for Chinese aviation industry) and the significance to reduce them by 2015. It brought guidance in each aspect to save on energy use and to reduce CO_2 emissions, such as building a hierarchy of decarbonisation, reporting scheme and monitoring department, improving the fuel efficiency of aircraft operation and using aircraft Auxiliary Power Unit (APU)[14] to replace the airport ground power supply. Furthermore, aircraft carried by Chinese airlines are new and having higher load factor; unit fuel consumption per tonne kilometre of Chinese airlines and unit CO_2 emissions per tonne kilometre are lower than the international average rate. This means it is difficult for Chinese airlines to reduce fuel consumption and CO_2 emissions by simply improving fuel

[14] APU is an independent miniature power unit planted on middle or large aircraft to reduce dependency on the airport ground power supply. It is a device for aircraft power supply and air compression. Some APU could give additional thrust to aircraft. By using APU, aircraft do not need airport ground power supply or a ground cart to boost the aeroplane before take-off. In the meantime, because APU already powers the lights and air conditioner for both passenger cabin and control cabin, the engine power can be all used to accelerate and climb, which improves take off efficiency. APU could save fuel consumption and reduce airport noise because it could supply the power for lighting and air conditioner after landing instead of the main engine, which makes the main engine stop running quickly.

efficiency. Hence, it is very important to accelerate technology improvement in biofuels; otherwise, it is impossible for China to meet its CO_2 emissions abatement objective.

Although not optimistic about the Chinese aviation industry having huge progress on aircraft emissions due to current measures, airlines still made their efforts in reducing fuel consumption and CO_2 emissions. In 2015, the unit fuel consumption per tonne kilometre was 0.294 kg, which had decreased by 13.5% compared with that of 2005 as can be seen in the Section 5.4.4. The average unit fuel consumption during 2011–2015 was 5% lower than that of 2005–2010 (CAAC 2016). Under the leadership of CAAC, the aviation industry has launched 220 projects for energy saving and emissions abatement in 2015, which can be projected to reduce 900,000 tonne CO_2 emissions annually.

In operation measures, except for more aircraft that have been planted APU instead of using the airport ground power supply, temporary routes are massively to be opened up to deal with air transportation congestion and to reduce fuel consumption and aircraft emissions. Electronic vehicles have been used in several pilot airports. Temporary routes[15] have been opened to deal with air transport congestion. Because more people are choosing to travel by air, the current airline networks and routes cannot afford the whole travel volume, which results in many flights not taking off on time due to traffic flow control or waiting a long time to land after arriving at destination airports. Therefore, opening up temporary air routes is a necessary measure to ease air traffic congestion.

However, when it comes to whether temporary routes could save fuel consumption and reduce aircraft emissions, aircraft operators and airport administrators have different opinions. Some acknowledge temporary routes do save travel time and fuel consumption, while others do not agree. This is due to different routes between the origin and the destination airports having diverse

[15] Air routes between two airports are quite fixed and even for the same airport pair the return flights could have different paths. In order to speed up the air traffic flow, airport management team may ask some flights to fly over some routes that does not open to passenger airlines normally or ask them to fly over other airports and take the route from that airport to the destination airport.

situations. Part of those temporary routes have shorter flying distance, which could save fuel consumption and reduce CO_2 emissions in the meantime of avoiding air traffic congestion. However, some routes between pair of airports are already the shortest flying routes, which means by flying temporary routes aeroplanes are going to consume more fuels and emit more CO_2.

In March 2015, the six biggest airports in China (Beijing Capital, Chengdu Shuangliu, Kunming Changshui, Changsha Huanghua, Harbin Taiping and Xiamen Gaoqi) gradually replaced their speciality vehicles[16] with electronic vehicles. At present, there are 18,000 speciality vehicles operating on all civil aviation airports ground in China and the number of these vehicles will gradually increase in each year. These vehicles burn both diesel and petrol, which accounts for 13% of total energy consumed by airports and which means speciality vehicles are the leading non-aircraft emitters within the aviation industry (CAAC 2015, Christiano and Eichenbaum 1989). In the following three years' pilot phase, these six airports will gradually purchase electronic vehicles to replace petrol/diesel-powered vehicles and implement respective electric charging infrastructure.

According to CAAC Statistics (2016), 33 airports have implemented APU instead of using airport ground power in 2015, which could reduce 300,000 tonne CO_2 emissions annually. In addition, 349,000 flights fly through temporary routes, which result in 1,1580,000 km less in total travelling distance, 62,500 tonne less in aviation fuels consumption as well as 197,000 tonne less in CO_2 emissions (CAAC Statistics, 2016). In addition, six airports launched a pilot project that is replacing speciality vehicles with electric vehicles, which contribute to future airports emissions abatement (CAAC Statistics, 2016). Although there have been some successes in aviation emissions abatement, China should not work the problem out by itself or just rely on operation measures. To save fuel consumption and reduce CO_2 emissions more efficiently, China

[16] The speciality vehicles mentioned here includes tractors, passenger step, shuttle buses, parking cars, baggage cart, hydraulic lift, luggage carriers, forklift and VIP shuttle.

needs to play in a larger scope, which is to co-operate with other countries on a global level and to adopt diverse instruments. Therefore, it is quite significant for Chinese aviation to respond to outside mitigation policies (i.e. EU ETS, CORSIA) and to study how to connect with other countries or regions to reduce CO_2 emissions and save on energy consumption.

3.6 Conclusions

This chapter reviews past aircraft technology innovation and its influences on fuel efficiency improvements, which indicates technology development has reached maturity. Some promising technologies have been discussed, including UHCA, wing design, composite materials, engine improvements and alternative fuels. According to the previous literature, nearly 50% of CO_2 emissions reductions can be expected through technology innovations. However, the development of those technologies discussed in this chapter cannot be achieved anytime soon, which means related organisations must look for alternative mitigation measures. In the meantime, upgauging aircraft cabins can abate another 20% of emissions per seat kilometre. Nonetheless, as has been indicated in the analysis above, the upgauge in the cabin may reduce the in-flight comfort of passengers, which may lead to a drop in demand for those airlines with more tight spaces. Regarding operational measures, improving air traffic management and optimising route-networks may result in a further reduction of 6%–12%.

Nevertheless, the amount of CO_2 emissions from aircraft will not be kept at the current level by all those measures discussed in this chapter. Notably, total CO_2 emissions will double by the end of 2050 as compared with 2015, even under the most optimistic scenario in technology developments, air traffic operation and aircraft capacity utilisation, as illustrated in Chapter Two. Therefore, without radical improvements in aircraft technologies, the serious impacts of climate change will not be avoided in the following decades. Therefore, we need to pursue other measures to abate aircraft emissions to achieve the overall emissions reduction objectives. In terms of China, as has been discussed in Section 3.5, even though there are several technologies applied to the Chinese aviation industry and improvements in ATM, the air transport sector still cannot meet their regulatory targets in CO_2 emissions abatement, which also proves the necessity of implementing policy options to the industry.

Chapter 4 Aircraft Emissions Abatement: Policy

This chapter discusses the different types of climate policy options that can be implemented in the aviation industry. Three categories of policies have been summarised: regulatory, economic and voluntary. Each category has been explored specifically and their possibility in applying into the aviation industry has been discussed. In addition, the first international aviation emissions trading scheme—EU ETS—has been investigated in its mechanism and challenges. Finally, the mitigation progress from the authority of international aviation—ICAO—is discussed, which indicates how global co-operation will be in the near future. Investigating all of these leads to the conclusion that there are multiple challenges in implementing different policy options in the aviation industry; therefore, applying different policy options in different cases (countries or regions, domestic or international) is necessary to find the most suitable one.

4.1 Overview

As presented in Chapter Three, a range of mitigation options could be applied to eliminate aircraft emissions, including aircraft-related technology developments, improved air traffic management, infrastructure use and more efficient operation (McCollum, Gould and Greene 2010). According to the current state of development, the technological and operational potential for reducing international GHG emissions from aircraft is considerable; however, the rate of improvement under business-as-usual (BAU)[17] conditions is unlikely to be sufficient to eliminate the projected growth in emissions from steadily increasing demand (International Energy Agency [IEA] 2008). For this reason, policy options, such as regulatory approaches, economic instruments and voluntary schemes, must be explored to accelerate the aviation emissions abatement.

[17] BAU conditions means there are no significant mitigation policies in the aviation industry.

Domestic regulations could take the form of emission, aircraft or engine efficiency standards, limits on the carbon intensity of fuel, or possibly the inclusion of aviation in a comprehensive cap-and-trade regime. In the US, the EPA has been petitioned to regulate GHGs from aviation transport under the Clean Air Act (2007). In legislation recently debated in Congress, domestic GHG cap-and-trade programmes would cover all transportation fuels, including all jet and marine fuels, sold in the US; thus, both domestic GHGs and a portion of international aviation GHGs would be covered under the proposed system (Pew Center on Global Climate Change 2008). Other countries have recently begun to develop policies to regulate GHG emission from domestic aviation under their national programmes. New Zealand, Australia and the EU have already taken steps to include domestic flights in their local GHG cap-and-trade programmes. The EU has acted to expand its GHG trading system to include emissions from the aviation sector beginning in 2012 (Lee et al. 2009).

Because aviation is recognised as a major contributor to global emissions, mitigation policies in the industry have been discussed in multiple international climate policy frameworks. Under the commitment of the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol, most developed countries have agreed to eliminate aircraft emissions from domestic flights; however, emissions from international flights are still out of scope. This situation remains with the renewal of the Kyoto Protocol up to 2020.

Nonetheless, policymakers and stakeholders are still pursuing international aviation emissions abatement even though it is not included in previous climate policy frameworks. The Paris Agreement still made no explicit statement about emissions from international aviation, although it did make a more ambitious target on the increase of temperature, to which all Parties to the Paris Agreement commit to limit the ascendant of temperature at 1.5°C instead of the target at 2°C (European Federation for Transport and Environment 2016). The new target from the Paris Agreement requires efforts from all sectors, including international aviation. ICAO has also explored a number of policy options including: encouraging voluntary programmes; developing and evaluating designs for an emissions trading programme for aviation emissions and issuing draft guidance for incorporating international aviation emissions into national emissions trading schemes; analysing the possible use of a fuel tax or charge; examining the potential for improved operational measures to reduce fuel burn; and exploring the possible design and use of emissions or efficiency standards (McCollum, Gould and Greene 2010).

From an economic viewpoint, the implementation of MBMs could be considered among other instruments because they are characterized by reaching environmental targets quite cost-efficiently (Scheelhaase and Grimme 2007). Both carbon tax and carbon emissions trading are market-based instruments that depend fundamentally on the efficient working of the market system for their success (Ekins and Barker 2001). The carbon control through MBMs will achieve a given level of emissions mitigation at a lower cost than regulations (Baranzini, Glodenberg and Speck 2000). Among MBMs, those that can raise revenue and recycle it through the economy will have lower costs than those that do not raise revenue; which evidently supports carbon taxes and auctioned emission permits over grandfathered emission permits (Goulder 2000).

In 2007, the 36th Assembly of ICAO established a Group on International Aviation and Climate Change (GIACC) to develop a programme of action for pursuing advance efforts to address GHG emissions from the aviation sector. Member States discussed a range of policy options and issues related to reconciling the concept of ‘common but differentiated responsibilities’ contained in the UNFCCC against the concept of non-discrimination contained in the Chicago Convention under which ICAO operates (ICAO 2007a). This issue specifically arose in the context of the EU ETS, which designed to apply to all airlines flying into or out of EU airports.

During the 38th Assembly in 2013, ICAO agreed to establish a global MBM for the international aviation industry by 2016, to can be implemented by 2020 (ICAO 2013), in response to the EC’s (2008) inclusion of aviation in the EU ETS. Regarding this decision, the EU also revised the ETS system in October 2013 as follows: 1) 'all emissions from flights between airports in the European Economic Area (EEA, covering the 28 EU Member States plus Norway and Iceland) would continue to be covered'; 2) 'from 2014 to 2020, flights to and from countries outside the EEA would benefit from a general exemption for those emissions that take place outside EEA airspace. Only emissions from the part of flights taking place within EEA airspace would be covered'; 3) to accommodate the special circumstances of developing countries, flights to and from third countries which are not developed countries, and which emit less than 1% of global aviation emissions would benefit from a full exemption (MEMO/13/906 2013). During the 39th Assembly in 2016, ICAO raised its global international aviation mitigation scheme. CORSIA, a voluntary mitigation scheme for all Member States at its pilot and first application phases (2021–2023, 2024–2026) and a mandatory scheme for all Member States except for least developed countries (LDCs), small Island developing countries (SIDCs) and landlocked developing countries (LLDCs) (ICAO 2016).

4.2 Mitigation Policies

There are three policy options for emissions reduction generally: regulatory approaches, economic instruments and voluntary schemes (Robberts 2004). Regulatory approaches are frequently used to limit negative environmental impacts from human activities through enforcing sanctions. MBMs are instruments that use markets, price and other economic variables to provide economic incentives for polluters to eliminate or reduce negative environmental impacts. Different from regulatory approaches and MBMs, voluntary approaches are schemes in which firms commit to improve their environmental performance as part of their corporate responsibility (OECD [Organisation for Economic Co-operation and Development] 2000). These three policy options are discussed below.

4.2.1 Regulatory approaches

Regulatory approaches are normally defined as the enforcement of standards, also referred as command-and-control (CAC). CAC is ‘the direct regulation of an industry or activity by legislation that states what is permitted and what is illegal’ (McManus 2009). CAC is a controversial, but effective, regulation approach in emissions mitigation. Most leading emitters in the aviation industry have adopted this kind of method to limit emissions from airlines and maintain certain levels of pollutants. For instance, China has always used CAC as regulations for aircraft emissions, setting its target of reducing 22% of aircraft emissions by 2020 in comparison with that of 2005 (CAAC 2011). These regulations often raised extra financial burdens on the airlines involved but remain in widespread use in most countries and industries.

Debates about overall emissions limits for aviation raise the difficult issue of regulation methods: if emissions limits were to be implemented in the future, ICAO could potentially administrate them. As ICAO already has an international governance role, is well positioned to ensure that emissions limits are compatible with existing policies, and could ensure that any detrimental impact on international transport is mitigated (Gössling and Upham 2009). However, the regulation of any future overall emissions limits for aviation would be complex.

Firstly, the national emissions targets imposed by the Kyoto Protocol have been determined on a common but differentiated responsibilities (CBDR) basis, and emissions limits applied to international aviation may need to be established on the same basis; otherwise, the principle of CBDR could be violated. Additionally, countries that are not parties to the Kyoto Protocol would presumably not be allocated aviation emissions limits; their international air carriers could, therefore, gain a competitive advantage (Faber et al. 2007).

Secondly, the specification of emissions limits by country may not prove to be feasible, and alternative allocation methods may be devised based on routes flown, nationalities of passengers, or ultimate destinations of cargo (Faber, Boon, et al. 2007). Moreover, the scope of emissions limits would require careful consideration because aircraft have other climate impacts besides those of CO_2 emissions: the effects of NOx emissions on ozone and methane, the production of aerosols, and formation of linear contrails and contrail-cirrus clouds. Given that the level of scientific understanding of some non-CO_2 climate effects of aviation is low, emissions limits or reduction targets may initially focus solely on CO_2 emissions, for which scientific understanding of the issue is more advanced (IPCC 2007).

4.2.2 Market-based environmental policies

4.2.2.1 Environmental taxes

Environmental taxation was conceived primarily as a policy instrument to compensate for polluters' environmental damage; hence, it is consistent with the 'polluter pays principle'. Both producers and consumers should be responsible for the environmental damage, which means they both need to pay the environmental tax. However, most countries provide certain tax relief for their energy-intensive industries to avoid international competition, which is inconsistent with the 'polluters pay principle' (Ekins and Speck 2000).

Arthur Pigou made the first proposal of environmental taxes, called a Pigouvian tax, which is levied on any market activity that generates negative externalities (Sandmo 2008). In relation to environment taxes, Pigouvian tax argued that the tax should be set equal to the abatement cost. According to Pearce and Turner (1992), environmental taxation will fail to restore the environmental damage caused by production if products are under-priced and do not cover full social costs (particularly environmental damage costs). In the early stage of environmental taxation implementation, several studies showed environmental taxation not only affects the environment but also competitiveness and revenue distribution, as environmental taxes may result in competitiveness losses and 'double dividend' in industries.

To compensate for the negative impacts of environmental taxes, the implementation should be accompanied by a general reform of the fiscal system, especially removing energy subsidies (Baranzini, Glodemberg and Speck 2000). By incorporating environmental impacts into prices, environmental taxes directly address the failure of markets to take these impacts into account and they leave the flexibility for consumers and businesses to reduce their environmental damage in a better way (OECD 2011). However, environmental taxes have been used less frequently than CAC approaches, probably due to the powerful protest from industry interest groups.

In comparison with CAC approaches, there are a number of advantages to environmental taxation. Firstly, it provides a clear and continuous incentive for mitigation activities to reduce the tax burden (Weishaar 2014). Environmental taxation has a fixed price for emissions, which reduces the uncertainty and risks of investments in innovation of abatement technology. This lack of price volatility would definitely boost the innovation in mitigation technology. Secondly, it would raise government tax revenue if the tax is not a cost-covering tax. The government may prefer this kind of tax because it could shift away from the tax burden of high-income taxes or high non-wage labour taxes (Ekins 1999). The government also can adjust environmental taxes to achieve sharper reduction targets or alternatively to ease the tax burdens of energy-intensive industries. Furthermore, environmental taxes do not distort competition within the same jurisdiction because they are not giving comparative advantages to any undertakings; this means both existing and new entrants face the same legal framework.

Despite the strengths stated above, there is still a range of issues associated with the use of environmental taxes, some of which are similar to the problems of the CAC approaches. While the tax burden is known to undertakings, the exact position of the marginal damage curve is uncertain; thus, it is difficult to set Pigouvian taxes accurately. If the carbon tax rate cannot be set at the Pigouvian level, it may lead to carbon leakage because the inaccurate setting of carbon-related environmental taxes may result in some companies shifting their production abroad. Environmental taxes also may lead to changes in industries' risks perception, which may slow the abatement technology innovation because they could achieve their reduction target by such taxes.

In practice, from the long-term goal of mitigating climate change, technology improvements are the most effective way to reduce GHG emissions, especially for the aviation sector. Moreover, the effectiveness of environmental taxes highly depends on the elasticity of demand. As presented above, environmental taxes are price-based instruments; hence, they are only effective in changing consumption and production patterns in a cleaner process if demand is price elastic. Otherwise, taxes are ineffective in limiting the negative environmental effects of an industry that are not price elastic. Bailey (2002) examined the Packaging Waste Directive—issued by the EC—to indicate the effectiveness of MBMs in reducing pollutions is severely constrained by price-inelastic commodities. In addition, a fixed tax rate for all industries is not fully consistent with the idea of the Pigouvian tax, which means companies with lower energy intensity may not be burdened by environmental taxes. There are not enough incentives for them to achieve the overall emissions reduction goal. Thus, discriminatory taxation is preferred over the fixed tax rate because it can be adjusted according to the nuances of each industry and region, which could facilitate the effectiveness of environmental taxes in reducing GHG emissions.

(1) Carbon taxation

A carbon tax, as an environmental tax, is designed to reduce CO_2 emissions from the production and consumption of fossil fuels to achieve the objectives of mitigating global climate change (Hoeller and Wallin 1991). Compared to other political instruments, the carbon tax has been considered a successful measure with low administrative costs and high emissions reduction efficiency (Helm 2005). Carbon taxation originated in north European countries in the 1990s, facilitating the tax reform in those countries because they implemented several environmental taxes and energy taxes prior to the establishment of the carbon tax.

Different countries may have different purposes to implement carbon taxation. Some national governments aim to stimulate the CO_2 emissions abatement by adding a tax to fossil fuel production and consumption industries; other governments aim to raise tax revenue to improve energy use efficiency. According to the OECD, as an economic incentive instrument, the carbon tax base should be capable of affecting industries' behaviours and the tax rate has to be high enough to internalise total social costs of pollution or achieve the objective of environmental impacts mitigation. On the other hand, if the purpose of establishing a carbon tax is to raise funds for programmes of energy-use efficiency improvements, the set of tax rate needs to be proportionate to the required amount.

(2) Aviation fuel taxation

In relation to aviation, fuel taxation is one of the most important instruments to mitigate aircraft emissions because emissions from this industry are highly related to fuel consumption. However, Article 24 of the Chicago Convention has exempted aviation fuel from taxing (ICAO 2006). Nonetheless, ICAO also adopted a resolution at the 16th Meeting of its 149th Session that allows individual countries to apply their own fuel taxation on domestic flights (ICAO 1996); hence, some Member States applied fuel taxes on their domestic flights, such as the US and the Netherlands.

As the largest air transport market in the world, the US has been ranked first place in total RTK of air transport among the Member States in ICAO, which means the US has been always the largest emitter in the aviation industry. In particular, the total RTK from US airlines on both domestic and international flights in 2015 was 170,585 million tonne-kilometres, which accounts for 21% in total RTK performed by all Member States (ICAO 2016). Therefore, the US is obliged to reduce aircraft emissions, especially after committing to the Paris Agreement. At first, the US Federal Excise Tax (FET) was reformed, which is to apply FET to jet fuel nationwide with a tax rate of \$0.219/gallon for general aviation and \$0.044/gallon for commercial aviation (Stone and Borean 2014). International flights remain untaxed due to the complexity of implementing a fuel taxation on them. To apply fuel taxes on international aviation, a new legal framework is needed, and this process involves tremendous negotiations for different existing bilateral or multilateral air service agreements (ASAs) (Mendes and Santos 2008).

Another issue associated with fuel taxes is whether the tax can be applied in consistent with worldwide. If fuel taxes cannot be implemented globally, it may distort the competition among different airlines. To be more specific, it may provide an incentive for airlines to move their hub into uncharged zones or using untaxed fuels in a taxed area to avoid this kind of policy (Korteland and Faber 2013). Therefore, ICAO has been working on other political measures to reduce aircraft emissions from international flights.

(3) Other taxes

In addition to fuel taxes, there are other forms of environmental taxes for the aviation industry. One option is imposing value added tax (VAT) on international airline tickets, which are currently VAT-free. This aims to use price elasticity to control air travel demand and then reduce aircraft emissions. Another option is the air passenger duty (APD), which has been applied in the UK. The APD is currently implemented to 'a fixed wing aircraft from any UK airport that: weights 5.7 tonnes or more, is fuelled by kerosene, and carries passengers whether they've paid for the flight or not' (HM Revenue & Customs 2015). From the UK government's perspective, the APD contributes to aircraft emissions reduction; the government raised the APD in 2007 to achieve a higher abatement target. However, Cairns and Newson (2006) have questioned the efficiency of this instrument in reducing aircraft emissions. They also argued this kind of instrument has created a discrimination between the UK and other EU countries under the One Single Sky Agreement (OSSA). Even during the Brexit process, the UK has made a clear statement that the aviation industry remains at BAU conditions[18] (EurActiv 2016), which means the discrimination under the OSSA still exists in the current stage.

4.2.2.2 En-route emissions charges

Compared to environmental taxation, en-route emissions charges may be more suitable for the aviation industry with less complexity. Emissions charges are proportional to the kilometres travelled, and they face less legal obstacles because they do not preclude binding agreements (Wit, et al. 2005). As the instrument is territory-based rather than fuel-based, it may not incur economic distortions as being discussed for fuel taxation.

An aircraft emissions charge was firstly adopted by Switzerland in 1997 and Sweden in 1998, which applied to emissions from aircraft based on what types of engine carriers adopted. This initial implementation led to the establishment of a Europe-wide harmonised approach by European Civil Aviation Conference (ECAC) working group during 2000-2003 (ECAC 2003). Following the launch of the guideline, London Heathrow Airport and London Gatwick Airport also adopted emissions charges for NO_x and HC emissions from aircraft in 2004 and 2005, individually. Moreover, Germany started to apply an emission charge at Frankfurt, Munich, Cologne Bonn and Hamburg airports from 2008 to 2010 (Scheelhaase 2010). Emission charges based on the guideline made by ECAC treat aircraft discriminately due to their engine types; therefore, they provide economic incentives to airlines to replace their older fleet with fuel-efficient ones. Although all such measures have certain effects on local problems and circumstances, global effects need a different approach (Fleuti 2007).

4.2.2.3 Subsidies

Subsidies are another economic incentive instrument. Unlike taxes, subsidies follow the 'pay to polluters principle' rather than the 'polluter pay principle'. It is easier for government authorities to administer subsidies than CAC approaches (Gössling and Upham

[18] British aviation businesses, large and small, are split over the consequences of Brexit.

2009). However, it may be difficult to remove them once such a system is established, especially for the agriculture and energy sectors in developed economies. Subsidies can be implemented through two different processes: a) subsidies can be paid to polluters by switching their production process in a cleaner way or b) subsidies can be paid to polluters by the quantity of emissions reduction. However, subsidies are considered unfair because of the need to pay polluters rather than vice versa (Robberts 2004). Nevertheless, subsidies may contribute to emissions reduction by stimulating the adoption of new and cleaner methods. On the other hand, subsidies require monitoring and enforcement in case of excessive claims by polluters.

In relation to aircraft emissions abatement, subsidies could be used to accelerate aircraft-related technology innovation and development, as well as the use of alternative fuels. However, no subsidies are applied in the aviation sector globally at present, although the effectiveness of alternative fuel on emissions abatement has been acknowledged (HM Treasury 2008). Generally, subsidies and privileges within the aviation industry and climate policy should be removed instead of creating new ones (Peeters, Gössling and Becken n.d.).

4.2.2.4 Emissions trading

Dales (1968) first brought up emissions trading; tradable permits (emission allowances) are allocated to polluters by policymakers and polluters can trade their allowances in a secondary market if they achieve their abatement goal or purchase allowances to reach their target. Emissions trading has been used for emissions reduction over decades, such as the US EPA's sulphur dioxide (SO_2) emissions trading programme and the Regional Greenhouse Gas Initiative (RGGI), pilot emissions trading cities in China and most notably the EU ETS. The emissions trading scheme functions through a simple process: a) the total amount of emissions is defined for a specific region; b) emission allowances (permits) are set to lower than that amount or equal to it and allocated among all polluters in this region via grandfathering or benchmark methods;

and, c) polluters can trade their permits in a secondary market for their own purposes.

(1) Existing emissions trading schemes

Several emissions trading schemes have been built successively, as shown in Figure 20. The first emissions trading scheme is the UK ETS, built in 2002, which was a voluntary emissions trading system created as a pilot scheme to the EU ETS. New South Wales Greenhouse Gas Abatement Scheme (NSW GGAS) in Australia closed on 30 June 2012 due to a carbon tax launched in NSW on 1 July 2012. This action avoided duplication and minimized emissions abatement costs. West Climate Initiative (WCI), formed in 2007, initially involved Arizona, California, New Mexico, Oregon and Washington. In the following years, new states entered the mechanism and other states dropped out. By the end of 2011, the major entity of the WCI was California; therefore, the launch of the Californian emission trading scheme resulted in the incorporation of these two mechanisms.

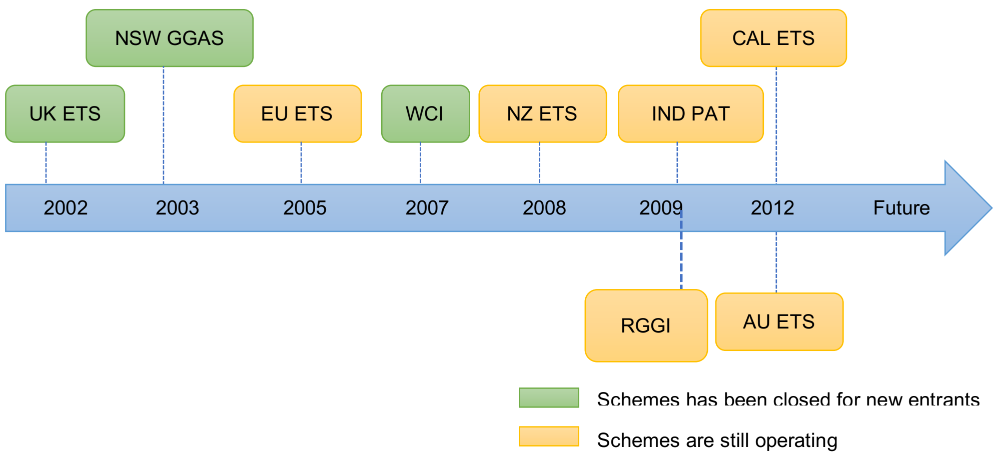

Figure 20 Main emissions trading schemes all over the world

Moreover, the following schemes still operate nowadays. The EU ETS is the first multinational mandatory cap-and-trade mechanism, which composites the largest carbon trade market in the world. This will be discussed in section 4.3.

The New Zealand Emissions Trading Scheme (NZ ETS) is a mandatory mechanism established in 2008. It includes forestry, stationary energy, industrial production, liquid fossil fuel, agriculture and waste, which consist of 50% of total emissions of New Zealand (Ministry for the Environment 2017). The most distinctive characteristic is no ‘cap’ in the NZ ETS and it involves land-use sectors in its trading system, which includes deforestation lands and agricultural lands (Jiang, Sharp and Sheng 2009).

In terms of the carbon quota allocation, the NZ ETS adopts an output-based approach to grant free emissions allowances to participants (Lennox and van Nieuwkoop 2010). Because agriculture was included in the NZ ETS, it was granted free allowances of 90% of the level in 2005. Some industries were allocated with the same amount of carbon quotas, including indirect discharges of electric consumption, direct emissions from stationary energy and direct emissions of non-energy-consumption industry process. From 2013, NZ ETS introduced auctioning into the allocation. Except for forestry, agriculture, industry process and fishery can still get free allowances. Stationery energy, waste and liquid fossil fuel must obtain their permits through auctioning. The NZ ETS allows participating companies to reserve their remaining allowances for the following trading period, and it also allows participants to neutralise their emissions with CERs from Clean Development Mechanisms (CDM) projects. In particular, there are no limits on the total volume of reservations and CERs.

Formed in 2009, RGGI is the first mandatory MBM in the US that targets fossil fuel-fired electric generators. RGGI is a regional programme designed to reduce CO_2 emissions of the power sector in north-eastern states, which include Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island and Vermont. Allowances are allocated for the Member States through auctioning at a uniform price. There were 14 auctions during the first phase (2009–2011) of RIGGI, which sold 395 million tonnes of CO_2 with 0.92 billion USD in revenue. Because there was an increase in the use of GAS and a decrease in the energy demand due to the economic recession, the total emissions were lower than the set cap (Murray and Maniloff 2015). During its second phase (2012–2014), the carbon price had been at a very low level (no higher than 1.93 USD), although the total cap of all Member States was reduced to 165 million tonnes and 145 million tonnes in 2012 and 2013, respectively. To optimise the mechanism, the total amount of allowances was cut to 91 million tonnes, and there would be an annual decrease of 2.5% of the cap up to 2020 (Legrand 2013).

As the third-largest emitting country, India has adopted a series of mitigation policies, and the most notable one is India's Perform, Achieve and Trade Scheme (IND PAT). Compared to the traditional ETS, the IND PAT is an MBM without total emissions reduction targets but rather set abatement objectives based on industries' energy intensities. The IND PAT was proposed in 2009 and started to operate from 2012. During its first trading period (2012–2015), the IND PAT set a mandatory reduction goal for 478 high energy-intensive factories and electric generators, which covered 60% of total emissions in India (The Institute for Industrial Productivity 2012). In total, the first phase of the IND PAT targeted to abate 26 million tonnes of CO_2 emissions, which equalled emissions from the burning of 6.6 million tonnes of petroleum. Due to the requirement of the PAT, industries needed to improve their fuel efficiency by 1%--2% per annum. The IND PAT is different from traditional emissions trading because its intention is to improve energy efficiency and not to direct control of the GHG emissions.

The IND PAT set an average Specific Energy Consumption (SEC) based on the fuel efficiency between 2007 and 2010, and it set emissions abatement target based on the SEC. If participating companies can achieve or exceed the SEC, they could obtain Energy Saving Certificates (ESCs); otherwise, they must pay penalties. Then, PAT participants can trade their ESCs on the market or reserve for following trading periods. However, Bhandari and Shrimali (2017) reviewed the PAT's operation and pointed out that the target is not strict enough in improving energy efficiency, which may lead to lack of investments in long-term energy efficiency improvements. Their results showed the PAT market may not form, and there are many equity issues that remain under-addressed.

The California Cap-and-Trade Scheme (CAL ETS) began to operate in 2012 and involved all major industries in California, USA, including oil refining, electric generating, industrial facilitating and fuel transporting (California Air Resource Board 2017). During 2013–2014, the CAL ETS firstly covered the electric supply industry and industrial sectors, which consists of 35% of total emissions in California. In 2015, the coverage expanded to gas suppliers and other energy retailers, accounting for a proportion of 85% of the total emissions.

There are three trading phases: a) 2013–2014, during which 90% of allowances were free allocated; b) 2015–2017, which 100% of allowances would be free allocated to high-leakage companies, 75% of allowances would be free granted to medium-leakage corporations and 50% of quotas would be free allocated to low-leakage enterprises; and c) 2018–2020, during which the allocation for high-leakage firms will remain at the level but the allocation for medium- and low-leakage companies will decrease to 50% and 30%, respectively (Dahan et al. 2015). In 2013, allowances from the CAL ETS were mainly free granted to electric firms (excluded electric generators), industrial enterprises and gas retailers. Their free quotas progressively decreased annually in the following years.

Moreover, the set of the cap differed across sectors. For industrial enterprises, the benchmark of free allocation is based on their output and emission intensity. Electric corporations could get their free allowances based on their long-term procurement plans. In terms of gas suppliers, the free quotas were set based on their historical emissions. Other permits are auctioned quarterly through a single round with a uniform price. Therefore, the allocation method of the CAL ETS is quite similar to that of the EU ETS; however, the CAL ETS created the double auction for investor-owned utilities (IOUs). To be more specific, although all public utilities could get full free allowances, investors of those utilities cannot use their quotas directly to neutralize their emissions but instead must put them into the carbon market and use all their revenues from the auction market to serve taxpayers (Sohpe et al. 2014).

The application of the double auction has several advantages. Firstly, it could improve the efficiency of the transaction and ensure the revenue would be used to serve taxpayers. Secondly, the double auction ensures the fairness in competition by avoiding any distortion in energy markets. Finally, the double auction optimizes the auction market by involving more participants.

Australia started to operate the carbon pricing mechanism (CPM), which requires the largest 500 polluting companies in the country to pay for all emissions from their productions at a fixed price (Caripis, et al. 2011). The mechanism involves emissions from the electric industry, stationary energy, waste, sewage disposal, and industrial productions, which covers 60% of the total emissions of Australia. The CPM targeted to reduce CO_2 emissions by 5% by 2020 in comparison to the level of 2000. Except for the fixed charges, there were industry assistance provisions that would grant free allowances to companies engaging in emission-intensive trade-exposed activities (EITE). Free allowances could be traded with other participants privately or even sold back to the government; however, no matter how permits were obtained (purchased at the fixed price or free allocated), they cannot be reserved for the next trading period.

This was originally designed to transfer the CPM to a truly cap-and-trade scheme that cooperates with the EU ETS after three years. However, the Australian government accelerated the process by starting the emissions trading since 1 July 2014. The acceleration aimed to achieve the reduction target committed by Australia under the second phase of the Kyoto Protocol and the UNFCCC (Jotzo and Betz 2009). In the meantime, flexible carbon prices under the ETS reduced the abatement costs of Australian companies. The acceleration facilitated responsible entities and middlemen entered the global carbon markets, which allowed them to learn more about related risk management products and reserve emissions permits.

Nevertheless, after the ruling party changed, the Emission Reduction Fund (ERF), which does not require the polluting enterprises to pay for it, replaced the CPM, but the government-sponsored them to reduce carbon emissions. The Australian government funded 2.55 billion AUD in the financial year of 2014–2015. The supervision authority would purchase reduction permits from participants through auctioning (Clarke, Fraser and Waschik 2014).

After reviewing different existing emissions trading schemes, emissions trading can easily achieve abatement targets predetermined by regulators in comparison with regulatory approaches, because it requires a predetermined ‘cap’ (overall level of emissions). With trading emission allowances, companies can decide who is really going to abate to achieve the reduction target at the least cost. Specifically, polluters, who would incur high reduction costs, could achieve their abatement goal by purchasing emissions permits from other companies that have already reached their targets rather than actually reduce emissions; of course, this would incur a cheaper cost. Instead of the fixed rate of environmental taxation, emissions trading is considered fair because the market decides the price of tradable permits. There are a number of weaknesses of emissions trading as well.

Firstly, the excessive permits would result in a slower process of using alternative fuel or technology innovation for emissions abatement. If companies’ emissions are always lower than the cap of allowances, then participants do not have an additional enthusiasm to accelerate the innovation process of technology. Secondly, the volatility of permit prices creates uncertainty of the market. The price would go up along with economic growth or strict benchmark and vice versa. For example, the failure of EU ETS in its first phase proved the excessive allowances lead to the price of allowances drop by 60% in 2006 (Carbon Trade Watch 2011). In addition, permits trading would raise polluters’ costs, which could lead to the transfer of their production to overseas, a region that does not have strict reduction goal. This is referred to as ‘carbon leakage’.

Thirdly, another problem is ‘windfall profit’, which is when polluters raise revenue while remaining at the same level of pollution. This is due to the free allocation of emissions permits or transferring extra costs from purchasing emissions allowances on consumers for inelastic demand sector. As the emissions trading scheme is a purely MBM, it does not raise revenue for governments unless the tradable permits are auctioned.

4.2.3 Voluntary approaches

In the absence of direct regulatory approaches or economic incentives, companies should take voluntary measures to meet their environmental liability. From the polluters' perspective, they would benefit from such voluntarily co-operation with regulators on emissions reductions because it may result in less strict regulatory policies in the future. On the other hand, if a strict regulatory policy is launched in the future, they still believe they would benefit from gaining competitive advantages compared to other companies that do not undertake voluntary approaches. Except for purchasing CERs from CDM projects regulated under the Kyoto Protocol, there are numerous carbon offsetting organisations that offer various projects to neutralise demanding companies' carbon footprints. They engage more often in the trade of verified emissions reductions (VERs) and non-verified emissions reductions (NVERs) from non-CDM projects. VERs involves an external auditing process, which improves its creditability in the market; in contrast, NVERs are usually assessed with self-developed standards, which are not always reliable (Taiyab 2006).

In relation to aircraft emissions abatement, the carbon offset is the most common way used by airlines. A carbon offset is a mitigation measure that allows people paying specific organisations or companies to neutralise their carbon footprints by planting trees or investing in other environmental protection programmes. Multiple airlines have already introduced carbon offset programmes, such as Japan airlines, UA, Virgin Atlantic and Shenzhen Airlines. In comparison with other airlines, the carbon offset programme from Shenzhen Airlines is designed for passengers to exchange saplings using their mileage rather than paying for it.

However, this offset has been questioned for its creditability on carbon reductions. Firstly, the effectiveness of voluntary carbon offset schemes may vary due to different approaches and strategies, especially measurement, time-bound and monitoring. Secondly, there is a limitation on voluntary schemes if they rely on self-regulation. To overcome this problem, companies or organisations should pursue external monitoring and verification instead of self-regulation. Thirdly, there may be a large gap between a company's performance and the public's expectation, which would lead to reputational risk. Therefore, even if airlines are willing to adopt voluntary carbon offset schemes, they still need to be cautious to avoid exposure to the risks stated above.

4.2.4 Policy comparison

As discussed above, several economic instruments can be applied to reduce GHG emissions and mitigate climate change, which enabled the comparative analysis of different policies. Except for recognising the lesser efficiency of regulatory approaches, Conrad and Schröder (1993) conclude the best policy is an emissions tax and the second-best policy is an abatement subsidy by comparing impacts on the economy under alternative environmental policies. Parry and Williams III (1999) used a numerical general equilibrium model to compare the costs of different mitigation policies in a second-best setting with a distortionary tax on labour, including a carbon tax, two energy taxes, and both narrow-based and broad-based emissions permits and performance standards. In their analysis, carbon taxes and tradable permits outranked other instruments if the revenues from these two policies can be used to reduce other distortionary taxes.

By modelling the distributional and efficiency impacts of emissions taxes and permits on various industries, Bovenberg, Goulder and Gurney (2005) reached the conclusion that profits can be maintained in both upstream and downstream industries by freely allocating less than 50% of pollution permits and auctioning the rest. In addition, Goulder and Parry (2008) claimed there is no single economic instrument superior to others in all settings; however, a strong case has been made that environmental taxes and tradable permits are particularly efficient in raising government revenues. As can be seen from the modelling result of a top-down DEMETER simulation, subsidies would have relative expensive costs in directing toward renewable energy sources while carbon taxes could achieve more stringent mitigation objectives in a cost-efficient way (Gerlagh and van der Zwaan 2006). Because emission taxes and emissions trading could fail to induce efficiency when environmental damage is strictly convex and there are relatively few companies, Kennedy and Laphante (2008) did not recommend any of them strongly. Although there are enormous researches compared to different economic policy measures in reducing GHG emissions, we have to consider both a full range of instruments that have been mentioned above and a full range of costs (efficiency, administrative and political) before choosing the best option for any particular implementation (Pezzey 2003).

4.3 First International Aviation Emissions Trading Scheme: EU ETS

The EU ETS involves all EEA countries (the EU Member States plus Iceland, Norway and Liechtenstein) covering more than 11,000 power plants and energy-intensive factories (EC 2003); the aviation industry has been included in it since 2012. Forty-five per cent of total emissions produced by EU countries is included in the EU ETS (EC 2008). During its first trading period (2005–2007), 90% of permits were allocated to participating companies through grandfathering; if they do not purchase enough allowances to meet their target, each enterprise should pay a fine of 40 EUR per tonne of CO_2 emissions. The scheme also did not allow firms to save extra allowances at a relatively lower price for later use; the excessive quotas would be cleared at the second trading phase.

In the following trading period (2008–2012), permits were still mainly allocated free; however, the cap dropped by 6.5% (EC n.d.). The global economic recession during that period led to the failure of the EU ETS because the allowances largely exceeded the total amount of emissions produced, and the carbon price rushed down to the bottom. Although the EU ETS did not achieve its responsibility, there were some improvements in the mechanism itself, which is that the EU ETS started to accept Emissions Reduction Units (ERUs) and Certified Emission Reductions (CERs) to neutralise no more than 13.4% of participants' total emissions (EC 2011). In particular, the air transport sector was included in the EU ETS at the end of this trading phase (2012).

Then, more improvements came in the third trading phase (2013–2020). Firstly, the EU-wide cap replaced the national allocation plan. Secondly, the reservation of excess allowances remained from the second trading period and could be used in the third phase. Thirdly, from 2013, all CERs purchased to use in the EU ETS had to come from LDCs (EC 2013). The most important change was that the allocation of carbon quotas was granted to participants through auctioning rather than free allocation. In particular, electric generators needed to purchase all permits through auctioning. Energy-intensive factories needed to buy 20% of their required allowances by auctioning, and this proportion will increase to 70% by 2020 (EC 2014a). When it comes to the aviation industry, 15% of required carbon quotas need to be purchased through auctioning (EC 2014b).

4.3.1 The inclusion of the aviation industry

Also, this is the first international emissions trading scheme for the aviation sector. It has been a long discussion and debate process since first raised by the EC's Communication in 2005 (EC 2005). This Communication introduced the importance of including aviation in emissions trading and offering a basis for discussion with other European institutions and stakeholders on internalising the environmental costs of aircraft emissions mitigation (EC 2005). Following the launch of this Communication, the first proposal of including the aviation industry in an emissions trading system was made in 2006, while an Aviation Directive was issued later in 2008.

This Aviation Directive addressed that all flights from, to and within the EEA had been included in the EU ETS since 2012. Each airline would be required to hold a number of permits proportionate to the CO_2 pollution generated by its fleet, with permits acquired through a transaction following an initial, partially free distribution among the carriers. For fairness in competition, all flights departing from and arriving at EEA airports would be included in the trading scheme, including international (non-EEA) airlines. This approach raised a series of reactions because a number of countries, such as the US, China and many other developing countries, do not have a mandatory emission reductions obligation under the Kyoto Protocol. Even the European Court of Justice (ECJ) ruled on in favour of its legality, though there still are many debates around whether the EU Aviation Directive complies with principles or rules from the following: WTO, international treaty obligation as Article 2(2) of the Kyoto Protocol to the UNFCCC, international customary law, Chicago Convention and Open Skies Agreement. Pressure from these countries resulted in the suspension of the inclusion of aviation in the EU ETS from October 2012 for one year to allow for the possibility of the development of an MBM to reduce aircraft emissions.

In response to this, ICAO promised during its 38th Assembly that it would build a global aircraft emissions reduction scheme by 2016 and implement it in 2020; and before that, all Member States could adopt their own regional or domestic measures independently (ICAO 2013). Therefore, to allow time for international negotiations, the EU ETS would only include flights within the EEA countries and exempt low emissions flights for the period 2013–2016. After the 39th Assembly of ICAO, the EC revised its scheme again, intending to include all international flights flying to and departing from EU airports in the EU ETS. All legislative works are expected to finish by the end of 2017, which will allow the emissions trading of international flights to start in before March or April 2018) (EC 2017). In the meantime, all airlines need to report their 2017 emissions to the EC. As the ICAO pronounced the launch of the CORSIA for international aviation emissions abatement, intercontinental flights are still suspended from the EU ETS.

4.3.2 Legal challenges

In light of the controversies between the EU Aviation Directive and international legal frameworks, past literature specifically analyse whether the EU Aviation Directive complies with principles or rules from the following: WTO, international treaty obligation as Article 2(2) of the Kyoto Protocol to the UNFCCC, international customary law, Chicago Convention and Open Skies Agreement between the US and the EU. On the other hand, not only do the airlines outside the EU territory strongly oppose the EU Aviation Directive (Deng 2012) but also many other non-EU countries are protesting it with regard to their interpretation of the international legal system. Nearly 30 countries, including China, India, Japan, Russia and the US, attended a meeting in India in September 2011 and adopted a joint declaration describing the EU's scheme for aviation emissions as 'discriminatory' and a violation of international law (Bridges trade Bio.Res. 2011). In the US, Congress considered a bipartisan bill to equivalent effect awaits Senate approval after being passed by the House of Representatives on 24 October 2011 (House-Transportation and Infrastructure 2011). The bill is supported by the US Secretary of State, who has warned the EU that the US would be 'compelled to take action' if the EU did not abandon its scheme (EU Tells Clinton It Won't Abandon Carbon Limits for Airlines 2012). However, due to the launch of the CORSIA, both EU and US have showed their support for this exclusive international market- based mechanism of global aviation emissions abatement. India has described the EU scheme as an illegal unilateral trade measure and threatened to take action before the WTO (Rajamani 2011). In reaction to the EU scheme, India has also suggested adopting a decision at the UN Climate Change conference in Durban that prohibits unilateral trade measures.[19]

In terms of China's reactions, the government states that the mitigation of emissions from the international aviation industry should

[19] Proposals by India for the inclusion of additional agenda items in the provisional agenda of the 17th session of the Conference of the Parties (UN Doc. FCCC/CP/2011/INF.2/ADD.1, 7 October 2011).

be accomplished under a multilateral agreement rather than a unilateral measure like the EU ETS (Tunteng 2012). As a rising power country, China also wants to be in a rule-making position instead of a rule-taking position. At this point, China will not allow other countries or organisations to make decisions on their own. In addition, China has blocked US$4 billion worth of orders from Airbus (Wall 2011), and both China and India have prohibited their national carriers from complying with the EU's scheme (Kotoky 2012). The airlines have also taken the dispute directly to the EU. In 2010, a consortium of US airlines, supported by IATA and the National Airlines Council of Canada, initiated a legal action in which they argued that the EU violated its obligations under the customary international law and various international agreements, including the Chicago Convention.[20]

Against the background of this partially failed litigation strategy to include all EU and non-EU international flights into the EU ETS, on 22 February 2012, 23 countries adopted a 'Moscow' Declaration denouncing the EU's aviation scheme and threatening a range of measures in response.[21] Pressures from these countries resulted in a one-year suspension from October 2013 to allow ICAO to pursue a global MBM for eliminating aviation emissions.

4.3.2.1The EU Aviation Directive and the UNFCCC

In the on-going negotiations of the long-term future of the UN climate regime, some countries propose strengthening the role of UNFCCC with regard to emissions from international aviation and maritime transport (Kulovesi 2011). In respect of the principle of Common but Differentiated Responsibilities and Respective Capabilities (CBDRRC) under the UNFCCC, the EC argues that it does not apply to the EU Aviation Directive because the Directive applies only for the businesses active in the EU market rather than

[20] Case C-366/10, Air Transport Association of American Airlines, Inc, Continental Airlines, Inc, United Airlines, Inc v. The Secretary of State for Energy and Climate Change, OJ (2010) C260/9 (including the claims).

[21] Joint Declaration of the Moscow meeting on inclusion of international civil aviation in the EU-ETS, 22 February 2012, adopted by Armenia, Argentina, Republic of Belarus, Brazil, Cameroon, Chile, China, Cuba, Guatemala, India, Japan, Republic of Korea, Mexico, Nigeria, Paraguay, Russian Federation, Saudi Arabia, Seychelles, Singapore, South Africa, Thailand, Uganda and the USA, available at: http://images.politico.com/global/2012/02/120222.pdf.

states and their climate policies. Moreover, given the exemption of small developing-country airlines from the scheme, those developing countries airlines with frequent flights to the EU can be assumed to have a greater economic capability, 'so that including them in the emission allowance trading scheme is permissible' and 'also proportionate' in light of the principle of common but differentiated responsibilities[22] (Kulovesi 2011).

However, Nollkaemper's (2012) paper addresses the counter-measure, the EU Aviation Directive, taken by the EC to apply to all states, irrespective of their particular obligations under the Kyoto Protocol, and notably also irrespective of the principle of common and differentiated responsibilities—which may make the proportionality argument more difficult. Furthermore, from the study of Scott and Rajamani (2011), the principle of CBDRRC establishes a common responsibility on both states and businesses. They point out the EU's Aviation Directive not only takes the form of a unilateral decision to include international airlines in the emissions trading scheme; but also applies for an exemption for flights from non-EU countries if they have equivalent measures for mitigating emissions from the aviation industry. The emphasis on equivalence would seem to suggest that equal treatment, not differentiation, would be the guiding principle in this respect (Scott and Rajamani 2012).

Although Scott and Rajamani indicate the EU's Aviation Directive is inconsistent with the principle of CBDRRC, they believe they can put forward two concrete proposals to achieve this end. The first proposal is designed to ensure that the EU's Aviation Directive respects the principle of CBDRRC calls upon the EU to differentiate from non-EU countries in terms of the conditions that apply for gaining exemption from the ETS. Specifically, different countries should be required to make different emissions reduction

[22] See also Eckhard Pache, *On the compatibility with international legal provisions of including greenhouse gas emissions from international aviation in the EU emission allowance trading scheme as a result of the proposed changes to the EU emission allowance trading directive*, Legal Opinion Commissioned by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safely (2008), available at <www.bmu.de/files/pdfs/allgemein/application/pdf/aviation_emission_trading.pdf>.

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commitments; the EU should differentiate not only between developed and developing country blocks but also between individual developing countries. The second proposal is the differential treatment of operators who are flying different routes, which will be consistent with the Chicago Convention.

Recently, however, the proposed revision of the EU ETS does prepare to give the flights from and to developing countries a full exemption if they emit less than the 1% global aviation emissions (MEMO/13/906 2013). In that case, all the arguments around the violation of CBDRRC may not be able to be applied to the revised EU ETS.

4.3.2.2 EU ETS and the WTO

It is worth reviewing whether the aviation scheme is compatible with the EU's WTO obligation: specifically, under the General Agreement on Tariffs and Trade (GATT) and the General Agreement on Trade in Services (GATS). This is due to the discussion of the EU Aviation Direction under the WTO rules; it not only will investigate the scheme from EU under a global perspective but also will inspire new arguments centred on whether we should pursue rewriting the WTO rules or reinterpreting of current rules. The latter possibility exceeds the scope of this research, so it will not be discussed here.

From the overall conclusion, the EU's scheme is likely to violate a number of GATT and GATS obligations, but virtually all violations can be justified on the environmental ground under the general exceptions in these agreements. The EU ETS does not constitute a duty, charge or tax because the 'price' paid for an allowance is not fixed by the state in advance but depends on free market forces (2008/101/EC). It makes no difference whether the measure is applied to fuel consumption, products, or some other activity or subject matter. It would follow, therefore, that the measure should not be considered a fiscal measure for the purposes of GATT (Bartels 2012). This is quite different from imposing a finance charge on an activity, as the airlines gain a tradable property right in exchange. The point is that the compulsory purchaser retains something of value—indeed, in the case of emissions allowances, this value could increase significantly on the open market.

For this reason, too, the EU ETS should not be considered a tax or a charge within the meaning of GATT, more precisely Article III: 2 GATT. As a quantitative restriction, it seems reasonable to conclude that the EU ETS has restrictive effects—no matter how small—on the importation of products into the EU, within the meaning of Article XI: 1 GATT. As an internal measure, the EU's scheme applies to flights transporting imported products, it would seem to be regulated by Article III: 4. In terms of the most favoured nation obligation, both internal measures and measures imposed on importation are subject to the most favoured nation obligation established in Article I: 1 GATT. It is difficult to see how the internal aspects of the EU's scheme (in relation to intra EU flights) would violate this provision. It is possible that Article I: 1 GATT might apply to the EU's scheme insofar as it affects international aviation. The EU's scheme also involves goods in transit in two ways: firstly, in relation to products that transit across the EU and secondly in relation to products that have been in transit before they arrive in the EU as a final destination. On the other hand, the Aviation Directive could lead to great distances transit through other countries to avoid liability for the full CO_2 emissions from the point of departure, which would not be compatible with the requirement in the GATT Article XX[23] chapeau that measures not be applied in ways that lead to arbitrary or unjustifiable discrimination (Meltzer 2012).

According to Bartels (2012), it is possible that a WTO Panel would lack jurisdiction to determine whether there is a GATS violation until ICAO remedies have been exhausted. Besides, based on the Article I: 1 GATS, this would seem to be sufficient for there to be a failure to accord an 'advantage' to all 'like services' and 'service suppliers'. Furthermore, if the EU granted an 'equivalent measures' exception to some countries only, there would also be a violation of

[23] 'Subject to the requirement that such measures are not applied in a manner which would constitute a means of arbitrary or unjustifiable discrimination between countries where the same conditions prevail, or a disguised restriction on international trade, nothing in this Agreement shall be construed to prevent the adoption or enforcement by any contracting party of measures.' (WTO, Analytical Index of the GATT, p562)

the requirement to grant such an advantage 'immediately' and 'unconditionally' to all WTO members (Bartels 2012). Article XVI GATS applies to measures setting a maximum number of suppliers or various elements of services, whether in their form or in their effect.[24] The EU's scheme does not, however, set any maximum limits, even if it has a restrictive effect on the supply of services. Bartels concludes that Article XVI GATS, therefore, does not apply. While Kulovesi's (2011) argument reasonably makes that WTO rules are not directly relevant for the EU scheme on international aviation emissions. Moreover, even if the scheme encounters the legal difficulties described, its GATS-illegal aspects may be justified under Article XIV GATS (Bartels 2012).

4.3.2.3International aviation emissions regulation

Another legal question raised by the EU Aviation Directive is whether the EU has the power to regulate airlines with regard to emissions produced outside the EU because it may difficult to calculate emissions for an international flight into two parts (emissions produced within the EU and outside the EU), given restrictions under international law as to the extent to which states are permitted to regulate activities taking place outside their territorial jurisdictions.

The inclusion of aviation emissions in the EU ETS reflects the EU's traditional desire to lead the global battle against climate change by its own example (Kulovesi 2011). In addition, it already provided that the Community would identify and undertake specific actions to reduce GHG emissions from aviation if no such action were agreed within ICAO by 2002 in the Sixth Community Environment Action Programme (Decision No 1600/2002/EC). Therefore, regional action like the EU ETS surely has political legitimacy (Nollkaemper 2012).

Furthermore, one of the most inflammatory questions in the legal challenge is whether the EU ETS has created an extraterritorial rule in a way that violates international law. From the perspective of

[24] WTO Appellate Body Report, US—Gambling, WT/DS285/AB/R, adopted 20 April 2005, at para, 309.

the Centre for International Sustainable Development Law (CISDL) working paper, the EU Aviation Directive has been accused of breaching international customary law because it applies the ETS to those carriers operating outside the EU territory and thereby subjects the territory of other countries and the high seas (Tunteng 2012). However, the Advocate General makes a plausible legal argument that the EU is in fact not regulating the conduct of foreign aircraft outside the territory of its Member States when requiring aircraft operating from airports within its jurisdiction to surrender emission allowances corresponding to the length of the entire flight. Kulovesi (2011) upheld the above perspective because the EU ETS only applies to businesses active in the EU market, not states and their policies, which means there are no extraterritorial rules that would interfere with the sovereignty of other states.

Still, according to the newly revised proposal of the EU ETS, emissions taking place outside the EEA will be excluded from 2014–2020. This indicates the EU has no intention to regulate airlines with regard to emissions out of their jurisdiction but only to include the aviation in the ETS for advancing the progress of aviation emissions abatement.

4.3.2.4 The Chicago Convention

Although all EU Member States signed the Chicago Convention, the EU has not signed it and thus is not bound by the Convention; this indicates that all the rules under the EU ETS cannot be interpreted under the principles of the Chicago Convention (Bogojevic 2012). Still, there are many arguments concerning whether the EU Aviation Directive is compiled with here.

The international legal regime for civil aviation is based on the principle of non-discrimination, as found in Article 11 of the Chicago Convention. Kulovesi’s (2011) study points out that the legal design of the EU ETS leaves developing country airlines with some other options, e.g. they could use CDM credits instead of purchasing allowances from EU auctions, which means the EU’s Aviation Directive breaches Article 11 of the Chicago Convention. For this reason, the new proposal of the EU ETS also exempts the emissions from flights to and from developing countries.

There are many pieces of literature indicating that the EU breaches the Chicago Convention because the scheme imposes either an illegal charge or an illegal tax on aircraft operators. According to Article 15 of the Chicago Convention, any imposition of a charge other than for the use of airports and air navigation facilities is prohibited. At this point, Tunteng (2012) states that the EU does violate Article 15 of the Chicago Convention because the Directive requires aircraft operators to pay for their emissions.

Nonetheless, there is a big difference between a charge or a tax and an emissions trading scheme. From this perspective, the EU Aviation Directive does not charge or tax non-EU airlines because the EU ETS is an MBM rather than an environmental charge or tax. In addition, ICAO 'could scarcely' make recommendations on guiding principles for emission trading schemes if they fell within activities prohibited under Article 15 of the Chicago Convention.[25] Therefore, the EU ETS, as a pure MBM, does not violate Article 15 of the Chicago Convention (Kulovesi 2011).

4.3.2.5 The Open Skies Agreement

The parties to the EU/US Open Skies Agreement agreed to pursue emissions trading measure 'within the framework of ICAO'.[26] The analysis and interpretation of the European Court of Article 15(3) of the Open Skies Agreement, in conjunction with Articles 2 and 3(4) of the same agreement, establishes that the EU ETS is not prohibited under the Open Skies Agreement, but, however admirable it may be, it leaves important questions unresolved (Tunteng 2012). The view that the non-discriminatory application of the EU ETS ensures 'fair and equal opportunity for the airlines of both Parties to compete in providing the international air transportation governed by the Open Skies Agreement' (EC 2007, p6) is not likely to be shared outside of the EU at this moment.

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[25] *Case C-366/10, Opinion of Advocate General Kokott*, 6 October 2011, paragraph 4 (Herainafer: Advocate General Kikott's opinion).

[26] IATA and the NACC, supra note 17, para (7), (34) and (40).

4.3.2.6 The Kyoto Protocol

Tunteng (2012) indicates the EU breaches international treaty obligation as Article 2(2) of the Kyoto Protocol, which provides ICAO exclusive responsibility for reducing GHG emissions in the international aviation sector and thus the EU as a signatory of the Kyoto Protocol must work through ICAO. However, the ECJ held that Article 2(2) under the Kyoto Protocol could not be taken into account when assessing the validity of the Directive. In addition, Kulovesi's (2011) study also indicates Article 2(2) of the Protocol does not seem to support the view that parties to the Protocol have conferred on ICAO and the authority to address aviation emissions and have prohibited any other multilateral or unilateral measures. In addition, the Protocol is not unconditional or sufficiently precise so as to confer rights on individuals. The ECJ finds inadmissible the claim that the EU ETS is contrary to the Kyoto Protocol in that it creates pollution control for aviation outside of its international legal frameworks.

To avoid all these legal challenges and clutter negotiations with different parties, the EC suspended its inclusion of international flights for one year (2013) and reached an agreement in 2014 to wait for the MBM established by ICAO. However, in response to the 39th Assembly of ICAO, the EC attempted to include international flights into the EU ETS again. Therefore, all these conflicts have brought up to the inclusion in the second time; however, it may have less pressure for the EC this time because there may be other linkages between the EU ETS and other equivalent instruments of countries outside the EU (e.g. linking EU ETS and CORSIA).

4.3.3 Impacts from EU ETS

4.3.3.1 Environmental impact

The environmental impact of an emission trading scheme directly depends on the cap, because this corresponds to the number of allowances issued (Boon, et al. 2007). Therefore, the more allowances issued, the smaller the environmental effect and vice-versa. By including aviation in the EU ETS, the expected CO_2

emissions reductions attributable to the cap on aviation sector, baseline growth assumptions and the geographical scope are listed in Table 4.

Table 4 Absolute and percentage annual reductions: stabilisation at 2005 emissions levels compared to BAU emissions levels

Geographical coverage	Reducing by 2015		Reducing by 2020	
	%	Mt CO_2	%	Mt CO_2
Intra EU flights	36%	31	45%	44
EU–All departing flights	36%	77	46%	115
EU–All arriving and departing flights	36%	122	46%	183

(Source: EC 2006)

However, it is clear that the mitigation in other sectors is much larger than in the aviation sector, which can be explained that the emissions abatement is generally expensive in the aviation sector. Therefore, most airlines would prefer to purchase emissions allowances from other sectors rather than to implement expensive mitigation measures for their aircraft (International Centre for Trade and Sustainable Development 2011). In contrast, at higher allowances prices on the market, it becomes less attractive to purchase allowances on the market and more reductions are achieved within the sector (Boon et al. 2007). By comparing the emission reductions under the full auctioning and that under the EC's legislative proposal, based on different allowances prices, the impact of higher allowances is nearly linear. This is because the demand effect is more or less the same in 2020 as in 2012 due to autonomous developments between 2012 and 2020 (Bredin and Muckley 2011). Furthermore, the differences in emission reductions within the sector between the different policy options are relatively modest in comparison to the BAU emissions. The lower the share of costs passed through the lower the reduction can be achieved within the sector (CE Delft 2007).

With the ICAO's establishment of CORSIA, EC also revised their application scope and developed a new impact assessment based on the assumption that CORSIA would be in operation from 2021 without any exceptions. According to their impact assessment (EC 2017), all policy options would reduce overall aviation emissions; however, policies neither in the period of 2017-2020 nor for post-2020 could prevent an increase in aviation emissions. Nonetheless, airlines are required to offset their emissions out of the cap with EU allowances or equivalent international credits, which means this would result in emissions reductions from other sectors. Table 5 presents how many CO_2 emissions are required to be offset during each policy option. As we can see from the table below, for the period of post-2020, option 3 would result in the smallest emissions reductions in other sectors that are included by EU ETS; this is because airline companies could offset their carbon footprints from other international credits but not only by the EU allowances.

Table 5 Environmental impacts of including international aviation into the EU ETS & GMBM

Period	Policy Options	Aviation emissions coverage (CO_2 in Mt per annum)	Emissions reductions from other sectors (CO_2 in Mt per annum)
2017-2020[27]	Option 0	327.84	117.37
	Option 1	80.08	25.1
	Option 2	199.36	71.67
Post-2020[28]	Option 0	393.26 (EEA related)	206.2 (EEA related)

[27] For 2017-2020 phase, option 0 means the EU ETS will return to full scope which includes all international flights from/to EEA airports. Option 1 remains the scope that was adopted during 2013-2016 that only includes international flights flying between EEA countries. Under option 2, all emissions from intra-EEA international flights and all departing flights from EEA countries to third countries would be covered, while emissions from arriving flights from third countries would be exempted.

[28] For post 2020 phase, all options except for option 0 consider that the Global Market Based Mechanism (GMBM) will be in operation from 2021 onwards. Option 0 is the same with the one for 2017-2020 phase. Option 1 includes all intra-EEA flights into the EU ETS and all extra-EEA flights would join the GMBM (CORSIA). Under option 2, extra-EEA flights would still be included into the GMBM and EU ETS for intra-EEA flights would be revised

Option 1	400.45 (EEA related)	49.3 (EEA related)
Option 2	400.82 (EEA related)	49.5 (EEA related)
Option 3	403.86 (EEA related)	14.4 (EEA related)

Apart from the environmental benefits from the CO_2 emissions mitigation, there are other environmental effects in air transport volumes and air transport technologies. The inclusion of intra-EU flights could affect the air transport volumes and may also cause the re-routing of trade and passenger flows (Tuinstra, et al. 2005). These will only have a modest impact on the demand of air transportations, as the cost of purchasing allowances is not high enough to induce airline network reconfigurations at the current stage (Albers, Bühne and Peters 2009). In the short to medium term, aircraft operators have a range of measures for stimulating their operations and fleet from the instance ICAO Circular 308 by considering the extra costs from the EU ETS (ICAO 2003), i.e. the retrofit of winglets could reduce drag and therefore reduce fuel burn and emissions (Lawrzecka 2011). In the long term, fleet renewal and changes in engine and combustor designs are of greater importance for the overall impacts in particular concerning NOx emissions and noise. In addition, the cost of purchasing allowances could further strengthen the economic incentive for airlines to reduce fuel burn (Brueckner and Zhang 2010).

4.3.3.2 Impact on airline performance

On any routes covered by the EU ETS, airlines can be expected to operate similar types of aircraft that are appropriate to the route's missions in terms of aircraft capacity and stage length. Fuel consumption per flight by route will only differ between airlines according to the fuel efficiency of the aircraft used, operational practices, and the extent to which more passengers and freight are carried. Thus, airlines will incur a similar additional operating cost per flight performed once incorporated into the EU ETS. Specifically, a more efficient airline will incur a lower cost, and a less efficient airline

according to the GMBM and no free allowances would be issued anymore. All intra-EEA and extra-EEA flights would be covered by the GMBM.

will incur a higher one (Hasselt, et al. 2009). In addition, the impacts on the profit margins are generally small due to the small operating cost, especially for non-EU carriers. This is because the EU market only constitutes a small share of their total markets (Boon et al. 2007).

Given that the EU ETS will cover all aircraft operators on all covered routes, most studies assume that aircraft operators fully pass on the costs of participating in the scheme to consumers. A price increase to consumers would be expected to have some impact on the air services demand. If costs are passed through, there will be some loss of demand, the size of which depends on the price elasticity of demand. If all costs are variable, the airlines can reduce costs in proportion to the fall in demand, keeping their profit margin, but losing some absolute level of profit due to the reduction in the scale of the operation (OXERA 2003). Not all costs are variable, however; if all costs are fixed, the airlines cannot reduce costs in the face of reduced demand, resulting in a relatively large loss (Boon et al. 2007).

According to the impact assessment from the EC (2006), fully passing on costs to customers would mean that by 2020 airline tickets for a return journey could increase by 4.6 EUR to 39.6 EUR, depending on the journey length. This assumes coverage of all departing and arriving flights and a high allowance price of 30 EUR. This would have only a small effect on forecasted demand growth from BAU levels of 142% to a minimum of 135%. Ernst & Young (2007) indicate in their report that full-service airlines might not decrease their supply on less profitable routes as a response to the increases in costs of purchasing allowances. These flights are often part of their ‘hub-and-spoke’ system and support their long-haul routes; therefore, these airlines cannot afford losses in passengers on short-haul flights. However, Ernst & Young (2007) also considers that low-cost airlines might stop some of their less profitable routes due to increased costs and decreased profits.

This small impact on growth reflects that the demand for the aviation industry is not very price sensitive. This is partly because, according to data on the socio-economic distribution of air transport users, increased ticket prices would be borne predominantly by the wealthier segments of the population (EC 2006). The ticket price increase also depends on the allowance price. Price increases vary from 1.1 EUR on a short-haul round trip, with an allowance price of 15 EUR, to up to 60 EUR for a long-haul flight, with an allowance price of 45 EUR. Note these results are very sensitive to the load factor in which the price increase per ticket decreases proportionally if the load factor increases over 70% (CE Delft 2005). Increased costs for consumers have a tendency to dampen their demand for the goods or services, and this will result in a decrease of emission as capacity is reduced to match demand. This holds only if the reduction in demand is large enough to reduce the number of flights. Thus, small increases in ticket prices lead through changes in demand to relatively small decreases in RTK (only 3.8% even airlines pass all extra costs on consumers), which means the EU ETS will not have a significant impact on the growth of demand for aviation (Anger and Kohler 2010).

Considering the revised proposal of the EU ETS, flights from and to countries outside the EEA could get a general exemption or even full exemption (MEMO/13/906). Although aircraft operators may have received free allowances for intercontinental flights, they have to return them in case they apply for the exemption. Because airlines have probably passed through the opportunity costs, they have an opportunity cost windfall (Nelissen and Faber 2012). If 50% (100%) of the EEA-related opportunity costs that airlines expected to receive for their compliance with EU ETS on their intercontinental routes for free have been passed through to the airlines' clients, then all relevant airlines taken together have made a windfall profit of approximately 436 EUR (872 EUR) million in the period January–October 2012.

4.3.3.3 Impact on the competitiveness between EU and non-EU airlines

The competition between airlines would not be significantly affected because all airlines would be treated equally. The main difference between airlines is the length of a journey undertaken, the age of the aircraft used, and the payload carried. Therefore, carriers travelling shorter distances, using older aircraft or carrying fewer passengers or less freight, would be affected to a greater extent than more fuel-efficient carriers (EC 2006).

In general, any effect on the competitive positions of airlines is expected to be small, unless the price of the allowances increases very substantially above current levels. However, the impact of the ETS on EU carriers and non-EU carriers will be different, because of their hub airports (Malina et al. 2012). The reduced demand caused by the cost passed through in airfares is larger for indirect flights via EU hubs than for direct flights and is smaller for indirect flights via non-EU hubs. Of the major EU hubs, transfer traffic at London Heathrow seems to be affected most substantially, a function of its geographical location on the edge of Europe and its wider catchment area across Europe (CE Delft, MVA Consultancy 2007). In addition, previous studies have shown there are grounds for believing that EU carriers may be disadvantaged in some markets relative to non-EU carriers because there is only a share of non-EU airlines' business included in the ETS when the whole business of EU airlines participating into the scheme (Boon et al. 2007). This implies that opportunities for redeploying aircraft with different fuel efficiencies will be less for EU airlines because non-EU airlines could redeploy their less efficient aircraft to routes not affected by the ETS (Schaefer et al. 2010).

In terms of the competition among EU airlines, the ability to cause distortions in this relates to the allocation method of allowances and type of service provided. Although a modest decrease in demand will not have significant impacts on competitiveness between airlines, it still may vary by route, business model and company (EC 2006). Morrell (2007) and Scheelhaase and Grimme (2007) studied the impacts of the EU ETS on selected airlines in the short term. Both of these studies found the impacts are likely to be greater on low-cost airlines. Under unfavourable conditions, cost increases up to 3% of traffic revenues are estimated for a low-cost carrier, compared to less than 1% for a full-service carrier (Scheelhaase and Grimme 2007).

Meanwhile, Frontier Economics (2006) argues that low-cost airlines facing increasing costs from the EU ETS (for allowance prices of 27–40 EUR and price elasticity of demand of -1.5) will have a decline in demand of 7.5%–12%. This may not hold because the lower end of the price range is likely to be more inelastic (CAA 2005). Frontier Economics (2006) assumes that full-service airlines have a proportion of price-inelastic business traveller and act mainly as feeders for long-haul services. On the other hand, Mason (2005) shows that business class travellers are not all price inelastic and that a proportion of them have switched from flying with full-service airlines to using more flexible services provided by low-cost airlines. Therefore, the impacts on full-service airlines might be larger than estimated in the studies examined.

4.3.3.4 Impact on the competitiveness between EU and non-EU countries

The macroeconomic impacts of incorporating aviation into the EU ETS on the EU are argued to be insignificant (EC 2006). Impacts on GDP in the EU are projected to be from -0.002% to +0.026% over the 10-year trading period. The decrease in GDP and employment in the aviation sector are assumed to be offset by increased income and employment generated from substitute activities. It should be stressed that macroeconomic impacts depend on the revenues generated and how these are used (Ekins and Barker 2001).

According to the EC’s new impact assessment (2017), there are two assessment trading periods, and each has several different policy options. For most cases, there would be distortions between EEA and non-EEA destinations due to different policy scenarios. There is only one policy option, Option 3 in post-2020 phase, will not lead to competition distortion for the international aviation market because all international flights are included in the CORSIA.

Table 6 Impacts on competition due to different policy options of EU ETS

Period	Policy Options	Tourist located within EEA	Tourist located outside of EEA
2017-2020	Option 0	No distortion between EEA and non-EEA countries because all flights arriving/departing in the EEA are covered.	May not travel to EEA countries because flights to and from those destinations are covered.
	Option 1	Potential preference for travelling outside of the EEA as all flights from and to third countries are all exempted.	No distortion for traveling to EEA countries because all flights between EEA countries and third countries are not covered.
	Option 2	May prefer travelling outside of the EEA because only one way is included into the EU ETS while both ways are included for flights among EEA countries.	May not travelling to EEA destinations because the return flight is covered by the EU ETS.
Post 2020	Option 0	No distortion between EEA and non-EEA countries because all flights arriving/departing in the EEA are covered.	May not travel to EEA countries because flights to and from those destinations are covered.
	Option 1	May prefer travelling outside of the EEA because GMBM may have cost advantages over the EU ETS.	No distortion between EEA countries and other countries that covered by the GMBM; however, there may be potential preference for travelling to those destinations that exempted from the GMBM.
	Option 2	May prefer travelling outside of the EEA because GMBM may have cost advantages over the EU ETS.	No distortion between EEA countries and other countries that covered by the GMBM; however, there may be potential preference for travelling to those destinations that exempted from the GMBM.
	Option 3	No competition distortion between international destinations that are covered by the GMBM; however, there may be preference to travel to domestic destination because	No competition distortion between international destinations that are covered by the GMBM; however, there may be preference to travel to domestic destination because

	domestic flights are exempted from the GMBM.	domestic flights are exempted from the GMBM.

(Source: EC 2017)

4.4 Future Development of International Co-operation on Aircraft Emissions Abatement: The Progress of ICAO

Economic activities in the aviation sector are quite endogenous. The increase and decrease of aviation activities significantly affect economic contraction and growth, as well as other aspects. On average, the growth of aviation activities has an approximate annual rate of 2.5% while incorporating nearly 1% improvements of fuel efficiency every year (Hamelinck et al. 2013; Herndon et al. 2005).

The Kyoto Protocol provides that developed countries shall pursue the limitation or reduction of international aviation emissions working through ICAO[29]. However, the progress of ICAO has been always extremely slow.

There is no efficient global MBM for aviation emissions trading promoted by ICAO since they adopted a major objective in 2004, which was 'to limit or reduce the impact of aviation GHG emissions on the global climate'.[30] In 2007, ICAO established a special Group on International Aviation and Climate Change to produce an ICAO programme of action on climate change (ICAO 2007), which was endorsed by ICAO's High-level Meeting on International Aviation and Climate Change in October 2009 (ICAO 2009). At the 37th ICAO Assembly, Member States committed to a global annual average fuel efficiency improvement of 2% through to 2020 and an aspirational goal of a global fuel efficiency improvement rate of 2% per annum from 2021–2050.[31] In addition, Member States adopted a medium-

[29] Article 2(2), Kyoto Protocol, supra note 11.

[30] International Civil Aviation Organisation, 'Environment Branch' (2011) <http://www.icao.int/env/>

[31] Resolution A37-19, supra note 9, para. 4

term aspirational goal of maintaining global net CO_2 emissions from international aviation at 2020 levels.[32]

Furthermore, ICAO has invited the Member States to submit voluntary national action plans outlining their CO_2-reduction policies and activities by June 2012.[33] There is in principle agreement between the ICAO Member States that the most desirable policy design is an MBM, including emissions trading schemes (Havel and Gabriel 2011). Consequently, ICAO has developed a framework of guiding principles for the development and design of MBMs by the Member States.[34] Although the 2004 ICAO Assembly endorsed the further development of an open emissions trading system for international aviation, the 2007 ICAO Assembly opposed the application of emission trading schemes to aviation emissions without ‘mutual consent’. The ICAO Assembly in 2010 made little progress concerning MBMs, deciding to continue exploring the possibility of a global scheme, develop a framework for MBMs and develop guiding principles for MBMs.[35]

As a brief overview of Kulovesi, ICAO has launched a number of initiatives on climate change, but it has not been able to agree on any binding measures to control the growth of GHG emissions from aviation (Kulovesi 2011). As we can see from its working paper, CISDL concludes there are two major obstacles that explain why things take so long—over a decade, in fact: ICAO only makes these aspirational targets and guiding frameworks instead of an international regulation agreement. Actually, there has been a general political reluctance to negotiate under ICAO since the failure of the UNFCCC to include international aviation emissions in the Kyoto Protocol (Yamin and Depledge 2004). Another one is the conflict between the principle of common but differentiated responsibilities contained in the UNFCCC and the Kyoto Protocol

[32] Ibid, para 6.

[33] Ibid, para. 9-10.

[34] Resolution A 37-19, supra note 9, para. 14 and Annex.

[35] ICAO Assembly Resolution A37-19, supra note 36, paragraphs 13-18 and Annex. Paragraph 15 of the Resolution includes a de minimis threshold for MBMs, which is international aviation activity of 1 per cent of total RTK. The resolution indicates that aircraft operators from states below the threshold should qualify for an exemption from national, regional, or global market-based measures.

and the principle of non-discrimination contained in the Chicago Convention (Faber and Brinke 2011).

In response to the EU's one-year suspension, however, ICAO finally agreed on their 38th Assembly in October 2013 to develop an MBM for aviation emissions abatement by 2016 that can be implemented by 2020 (ICAO 2013). Until then countries and group of countries, such as the EU, should be able to deploy interim measures.

ICAO has promised to build a global emissions trading scheme by 2016 and apply it in 2020. However, instead of emissions trading, ICAO announced its progress in building an MBM scheme in the form of CORSIA (ICAO 2016). As shown in Table 7, this is a voluntary scheme during its pilot phase and first phase because of the difficulty in the Member States agreeing which will go first. Several proposals were made, including states with high aviation activity and high gross national income per capita; states with high aviation activity according to ICAO's scale of assessment; or that developed countries should go first. In the second phase of CORSIA, all states will be included except for those explicitly carved out, which also is listed in Table 7. In addition, inclusion or exemption of a state should be based on its international aviation activity. However, such exemptions may weaken the environmental effectiveness of CORSIA and lead to competition distortion in different markets.

Apart from deciding which Member State goes first, the 39th Assembly also decides how to set carbon offset requirements. Still, there is great debate on how to choose carbon offset targets: a few countries addressed that the amount of carbon offset should be decided by each Member State itself, which is consistent with the Paris Agreement, which is nationally determined. Most countries thought there should be non-discrimination, just like the Chicago Convention, which means there should be an international decision on how much to offset.

A few states also claimed that it should be decided after the pilot phase. Hence, a dynamic approach has been decided on the Assembly, which is allocating offset targets based on 100% of global growth factor at first and then moving to individual growth factors in later stages. This is also presented in Table 7, which can be seen that participants only need to offset their carbon emissions based on global growth factor during the pilot phase, phase I and the first three years of phase II. During 2030—2032 under phase II, each airline should offset its carbon emissions based on at least 20% of the individual growth factor and 80% of the global growth factor. Furthermore, at last three years of phase II, participating airlines are required to neutralise their carbon emissions at least based on 70% of individual growth factor and 30% at most of global growth factor.

Table 7 CORSIA implementation phase

Implementation	Participant	Offset requirements	
Pilot Phase (2021–2023)	States that have volunteered to participate in the scheme. States participating in this phase may determine the basis of their aircraft operator's offsetting requirements	% Sectoral * (an aircraft operator's emissions covered by CORSIA in a given year * the sector's growth factor in the given year) + % Individual[36] * (an aircraft operator's emissions covered by CORSIA in a given year * that aircraft operator's growth factor in the given year); where the % Sectoral = (100% - % individual)	100% sectoral and 0% individual, though each participating State may choose during this pilot phase whether to apply this to: a) an aircraft operator's emissions covered by CORSIA in a given year, or b) an aircraft operator's emissions covered by CORSIA in 2020
Phase I (2024–2026)	States that voluntarily participate in the pilot phase, as well as any other States that volunteer to participate in this phase, with the calculation of offsetting requirements with ICAO		100% sectoral and 0% individual

Phase II (2027–2035)	All states that have an individual share of international aviation activities in RTKs in year 2018 above 0.5% of total RTKs or whose cumulative share in the list of States from the highest to the lowest amount of RTKs reaches 90% of total RTKs, except for LDCs, SIDs AND LLDCs		From 2027–2029, 100% sectoral and 0% individual; from 2030–2032, at least 20% individual; from 2033–2035, at least 70% individual

As discussed above, carbon offsets have several limitations; however, CORSIA has overcome some of them. Since the global market has been regulated under ICAO, each airline participating in CORSIA will be applied with one offset strategy; there is no difference in environmental targets, strategies, indicators and performance. One organisation regulation also solves the problem of effectiveness limitation caused by self-regulation. In addition, because ICAO monitors the carbon offsets of each airline, this decreases the possibility of exposing airlines to reputational risk.

Even so, CORSIA still has its own limitations. The credibility of carbon offsets has been traditionally questioned because air travel passengers do not believe the proposed trees would have any real impact on climate (Brouwer, Brander and van Beukeing 2008). Therefore, the real effect of CORSIA still requires testing in the future. On the other hand, although all participating states committed to reduce aircraft carbon emissions under the same requirements, specific measures for each airline may be different, which may lead to different effectiveness in performance. The EU conducted a consultation addressing the public's concern about the policy option developed by ICAO (EC 2016). Hence, ICAO may change its policy option after the pilot phase or in a later stage to pursue a more effective approach on aircraft emissions abatement.

4.5 Possible Policy Options for the Chinese Passenger Airline Industry

4.5.1 Emissions trading in China

As we presented in Chapter 2, China is the largest emitter in the world. Although the Chinese leadership insists on the CBDR principle in international negotiations, China has implemented ambitious regulatory objectives for improving fuel efficiency and switching from coal to cleaner energy in homeland. Except for building CDM projects, China established seven pilot emissions trading schemes in the province of Guangdong and Hubei, and the cities of Beijing, Tianjin, Shanghai, Chongqing and Shenzhen in 2011. After years' efforts, the Chinese government have learned their lessons from its pilot schemes and other regional ETS (i.e. EU ETS), which led to an intention to build a nation-wide ETS in China in 2016 and start to operate in late 2017. In this section, we explore the historical developments of emissions trading in China.

4.5.1.1 Clean Development Mechanism

'The Clean Development Mechanism, defined in Article 12 of the Protocol, allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO_2, which can be counted towards meeting Kyoto targets' (UNFCCC 2006). The implementation and progress of CDM accelerate the form of global carbon markets; and, there are more and more developed countries and developing countries are involved in the mechanism. As the largest developing country and carbon supplying country, China has played actively under the CDM that contributes to the mitigation of climate change. In 2007, the State Department established the National Leading Committee on Climate Changes (NLCCC) to research and formulate climate strategies, supervise

CDM projects, and deliberate international negotiation strategies (National Development and Reform Commission [NDRC] n.d.).

Nowadays, global carbon markets are continuing to mature, the trading price and volumes has been increased steadily; and, it is going be the largest international exchange market that surpasses the trade of crude oil (Li, Zhang and Dong 2014). Chinese companies have led a number of CDM projects that provide numerous CERs to developed countries, which accounts for over 80% of total CERs produced by all CDM projects. Although China holds a number of CERs that can be traded in international markets, Chinese companies do not have the bargaining power during the process. Foreign buyers tend to sign a long-term contract with Chinese enterprises to lock in prices, which limits Chinese companies' rights on hedging abroad and market risks elusion (Wang 2010).

4.5.1.2 Pilot ETS to national ETS

As has been addressed in Chapter 2, China made an ambitious commitment under the Paris Agreement, which is to reach the emission peak in 2030 and subsequently to reduce afterwards. In order to achieve China's ambitious target, it is necessary to adopt emission abatement measures domestically other than CDM projects. In 2011, the NDRC established seven pilot schemes in Guangdong, Hubei, Beijing, Tianjin, Shanghai, Chongqing and Shenzhen to build experiences and identify challenges that should be resolved before the establishment of a nation-wide emissions trading scheme. Since the operation of these pilot schemes, there are several problems that have been identified: lack of market liquidity and structural imbalances of participants (Li 2015). However, these pilot schemes also accumulated experiences and build a solid foundation for the establishment of a national emissions trading scheme.

Seven pilot emissions trading schemes across Eastern, Middle and Western of China includes multiple high CO_2 emissions industries, such as electricity, steel, chemical engineering, mining, etc., which account for most of the total national CO_2 emissions. As showed in Table 8, except for emission-intensive industries at the national level, each pilot emissions trading scheme included industries having local features into the ETS. For example, Guangdong province included the textile industry in its ETS and Hubei province involved the automobile manufacturing industry in its ETS. Therefore, the national emissions trading scheme should consider the industry structure before including any industry into it. In particular, Shanghai and Chongqing included the aviation industry[37] in their ETS, which provide valuable experiences to the national aircraft emissions trading.

Table 8 Industries covered by pilot emissions trading scheme

City	Industry
Beijing	Companies have an average emission that larger than 10,000 tonnes during 2009-2011 within the industry of thermal power generation, cement, petro chemistry, and service industry; Companies would like to join the ETS voluntarily.
Shanghai	Companies have emissions larger than 20,000 tonnes in any year of 2010-2011 within the industry of steel, petro chemistry, chemical engineering, nonferrous metals, electricity, building materials, textile, papermaking, rubber, chemical fibre; Companies have emissions larger than 10,000 tonnes in any year of 2010-2011 within the industry of aviation, port, airport, railway, hospitality, financial service.
Tianjin	Companies have emissions larger than 20,000 tonnes in any year since 2009 within the industry of steel, chemical engineering, petro chemistry, oil and gas exploitation, and civil architecture.
Shenzhen	Companies in electricity, enterprise and public institution, large-scale public buildings, industries, and public transport sector; Companies would like to join the ETS voluntarily.
Guangdong	Electricity, cement, steel, petrochemical industry, ceramics factory, textile, nonferrous metals, plastic plant, papermaking, hospitality, and financial service.
Hubei	Building materials, chemical engineering, electricity, metallurgy, food and beverage, petroleum, automobile manufacturing, chemical fibre, medicine and papermaking.
Chongqing	Electricity, steel, nonferrous metals, building materials, chemical engineering, and aviation. Industrial companies have emissions larger than 20,000 tonnes in any year during 2008-2012.

According to the NRDC (2016), the first phase of Chinese national emissions trading scheme will cover petrochemical,

37 The aviation industry here only refers to both passenger and freight airlines registered in the pilot city.

chemistry engineering, building materials, steel, nonferrous metals, papermaking, electricity and aviation industries. Enterprises within these sectors would join the national ETS if they consumed the energy of 10,000 tonnes of coal equivalent during any year during 2013-2015. From previous experiences of pilot ETS, mechanisms for enforcing compliance with an ETS are still weak in China (Zhang, et al. 2014), which requires further efforts to be made for the operation of the national ETS. In addition, the cap setting is essential for an ETS to be a success. As we can learn from the failure of the second phase of the EU ETS, over-set cap led to a huge decrease in carbon prices, which almost paralysed its operation. Hübler et al. (2014) explored design options of a Chinese ETS, which concluded higher national economic growth slightly increases abatement costs under the intensity target in 2020; however, the result is sensitive to the assumptions of the national GDP growth under the fixed reduction target in 2030. Then, the NDRC combined benchmarking and historical emission intensity reduction methodologies together to free allocate allowances to participants (Tong 2016). The proportion of the free allocation will be reduced in following years and correspondingly, the percentage of auctioned allowances will be increased. As the Chinese ETS is in a start-up stage, the Chinese government need to learn lessons from previous experiences of pilot schemes in China and other regional/international ETS.

4.5.2 China's perspective on EU ETS

There have been heated discussions about how China should face EU ETS since the European Parliament included all international flights flying to or departing from EEA airports into their emissions trading scheme in 2012. Some scholars believe China should build an independent emissions trading scheme and include the aviation industry to negotiate exemptions from EU ETS. Although this could not avoid increasing costs for Chinese airlines, the revenue from emissions trading can be used by each Chinese airline to launch their own carbon emissions abatement project.

According to Article 25a of the Aviation Directive (EC 2008), however, airlines can only get one-way exemptions from EU ETS, even if they already participate in domestic emissions trading scheme. Furthermore, there are multiple difficulties in building a domestic emissions trading scheme, such as allowances allocation, emissions computation, monitoring, certification and exercise. In particular, if the emissions trading scheme includes all flights (including non-Chinese airlines) flying to and departing from Chinese airports without any bilateral or multilateral agreements like the EU ETS, the ETS in China would face the same problems, questioning and opposition, just like the EU ETS. However, if the emissions trading scheme does not include flights carried by non-Chinese airlines, not only would it not help Chinese airlines to obtain exemptions from EU ETS but also it would lead to Chinese airlines losing their competitive advantages because of increased costs.

As discussed above, China has strongly opposed to include flights from and to third countries into EU Aviation Directive. From China's perspective, there is no difference between emissions trading and carbon taxation. Firstly, whether emissions trading or carbon taxation, they all aim to control and reduce CO_2 emissions, but emissions trading directly uses cap and control, while carbon tax uses taxation as a leverage to control CO_2 emissions. On the other hand, although it looks like the allowances price of CO_2 emissions trading is decided by a market mechanism, so the local governments still can control it through controlling free allowances allocation.

Rather than applying carbon taxation directly, EU ETS is just another form of tax with the coat of a purely MBM which is carefully designed by European Parliament. The reason for this action is that the EU wants to avoid legal risks in the meantime of gaining competitive advantages. Although the carbon emissions trading or 'carbon taxation' is not a fuel taxation, aircraft emissions are calculated based on aviation fuel consumptions. This can be seen as 'carbon taxation' and fuel taxation apparently are the same thing if emission permits are auctioned. This definitely violated bilateral agreements about the exemption of aviation fuel tax.

Moreover, EU ETS would lead to competition distortion, which could bring advantages for their airlines in international flights completion. Because EEA countries are improving their regional transportation networks, regional flights may gradually be replaced by high-speed railway; therefore, EEA airlines can allocate their allowances saved from regional flights to their international flights, which leads to them having more competitive advantages. Furthermore, non-air transport industries in EEA countries can also benefit from the inclusion of the aviation industry in EU ETS. This is due to these companies having excessive free allowances since their emissions have dropped under their historical volumes, which is the result of the global financial crisis and economic recession in 2008. By including the aviation industry in EU ETS, airlines from EEA countries can trade their free allowances to outside participants to gain extra revenues that can be invested in their own technology innovation projects. This, in turn, would give them more free allowances to sell in the secondary market and more profits by selling the technology to other countries.

4.5.3 Possible options for Chinese international aviation

From China's perspective, it is highly unlikely that it will co-operate with the European Parliament on the EU ETS, which means China must figure out how to reduce its energy intensity and CO_2 emissions in another way. Although China does not have mandatory obligations for emissions abatement under the Kyoto Protocol, it still needs to develop and implement mitigation policies as a leading emitter. China, as one of the major Member States of ICAO, contributes to the negotiations of building an international aircraft emissions mitigation scheme—CORSIA.

This is a voluntary scheme and is not mandatory for each ICAO Member State. It offers them more time to prepare and integrate their own mitigation policies with those of CORSIA. Notably, CORSIA is a scheme following the 'polluters' pay principle', which is considered acceptable. However, as discussed above, voluntary approaches have limited effects on emissions abatement, and it is quite difficult to quantify emissions saved by carbon offsets. Consequently, China still needs to develop and implement its own mitigation policies to achieve the reduction target it made in previous years.

Except for technological and operational measures, China must pursue other effective options to reduce aircraft emissions domestically, such as emissions trading (has been proceeded) or carbon taxation. Despite the scale of challenges, there are multiple options for China to reduce emissions in its the aviation industry.

Firstly, China may apply carbon taxation to domestic flights. This could result in ticket price increase and then lead to a demand drop; this means aircraft emissions could be reduced due to demand drop. Revenue from carbon taxation would fund government’s technological innovation, which could further contribute to aircraft emissions abatement. Secondly, China could build a domestic emissions trading scheme to replace schemes built in pilot cities and include domestic flights into the trading scheme. Instead of carbon taxation, economic incentive from the MBM could stimulate motivations of airlines to reduce aircraft emissions. They could use the revenue from emissions trading to invest in their own emissions mitigation projects to obtain more emissions allowances to sell for gaining more profits. Otherwise, China may also include international flights carried by Chinese airlines only to reduce more aircraft emissions in the meantime while avoiding violations of existing international agreements.

Moreover, Chinese airlines could adopt voluntary approaches (carbon offsets) for both domestic and international flights. These approaches could be integrated with CORSIA, which could contribute to emissions abatement for the global aviation industry. For emissions mitigation of international flights, China as a major player in international negotiations is highly likely to cooperate with other countries under the lead of ICAO.

4.6 Conclusions

As recognised in previous chapters, even though the aviation sector consists of a small share of the total global CO_2 emissions, the growth rate of aircraft emissions is relatively fast compared to other sectors. This increased pressure is the reason why policymakers are seeking different measures to abate aircraft emissions, so as to mitigate the environmental impacts of the aviation industry on global climate. Several policy options have been discussed in this chapter, including regulatory approaches, MBMs (environmental taxes, emissions trading, emissions charges and subsidies) and voluntary approaches (carbon offsetting, commitments to achieve carbon neutrality and other corporate responsibility initiatives). In reviewing multiple research, this chapter concludes that carbon taxation and emissions trading are more cost-effective among all policy instruments reviewed in this chapter, though there are several challenges in building such mitigation policies, especially for the international airline sector.

Chapter 5 Aircraft Emissions from the Chinese Aviation Industry

There has been spectacular economic growth in the Chinese aviation industry in recent decades. However, not much research has focussed on the consequent increase of the CO_2 emissions from Chinese aviation industry that have grown by an average of 16% per annum since 1986. Several drivers of emissions in the Chinese aviation industry have been discussed in previous chapters, i.e. RPK, price elasticity, average ticket price and fuel efficiency. This chapter aims to estimate the role of Chinese aviation industry in international emissions mitigation and particularly the potential role of both domestic and global aviation mitigation instruments. To conduct such analysis, this study first examines the historical drivers of the emissions in Chinese aviation industry and secondly provides a benchmark baseline scenario in the absence of any significant policy.

5.1 Introduction

In recent decades, the Chinese economy has grown rapidly, with an average GDP increase of 11% per annum (National Statistic of China 2012). Along with rapid economic growth, multiple industries in China have been dramatically developed, especially aviation. Since the Chinese government introduced industrial reform policies in the 1980s, the aviation industry in China has developed into one of the largest air transport networks in the world (ICAO 2013). A variety of studies have focussed on the relationship between the tremendous growth of Chinese airline industry and its industrial reform since the 1980s.

However, there is limited research regarding the aviation emissions of Chinese airlines. There has been much discussion about reducing global aircraft emissions, especially the necessity of including China and other developing countries in global aviation emissions reduction mechanisms. Nowadays, a range of mitigation options could be applied to eliminate aircraft emissions, namely aircraft-related technology development, improved air traffic management, better use of infrastructure, more efficient operations, economic/ MBMs and regulatory measures (McCollum, Gould and Greene 2010). According to the current state of development, the technological and operational potentials of reducing international GHG emissions from aircraft are of great possibility; however, the rate of improvement under the BAU [38] scenario is unlikely to sufficiently eliminate the projected growth of emissions that caused by steadily increasing demands (IEA 2008). Therefore, in order to achieve regulatory objectives, economic instruments are of urgency to accelerate aviation emissions abatements regarding environmental taxation, emissions trading, or carbon offsetting, for example.

From an economic perspective, the implementation of MBMs could be considered among other instruments because they are cost-efficient to reach the environmental targets (Scheelhaase and Grimme 2007). Both carbon taxes and carbon emissions trading are market-based instruments, which fundamentally depend on the efficiency of the market system for their success (Ekins and Barker 2001). Among MBMs, raising and recycling revenues through the economy reduces costs than those that cannot raise revenues. This evidently supports the permits of carbon taxation and auctioned emission over grandfathered emission (Goulder 2000).

As a major emitting country, however, China still has no mandatory obligation to mitigate its CO_2 emissions, because it faces an increase of CO_2 emissions as a consequence of its rapidly developing economy (Dai and Wang 2011). China currently accounts for 30% of global CO_2 emissions as we presented in Section 2.3.1. According to the outlook of China's energy and carbon emissions, the CO_2 emissions in the transport industry are projected to increase from nearly 1,000 Mt in 2000 to about 5,000 Mt by 2050 (Zhou et al.

[38] BAU in this chapter means the airline industry in China will continue to grow along with the increase of GDP, population and air ticket price. There is no significant technology improvements and emissions reduction schemes up to 2030. However, the fuel efficiency will be improved by 1% per annum.

2011). To face and resolve the problem, the Chinese government has established a target of reducing its CO_2 emissions by 15% between 2016 and 2020 in the ‘The Thirteenth Five-Year Project’ (State Department of China 2011).

Among all the CO_2 emission sources, aviation is a significant one that also causes other potentially climate change-inducing substances such as PM (particulate matter) because it has an annual ascendant of 13% that much faster than the growth of total national CO_2 emissions (Zhou, et al. 2016). Therefore, the aviation industry is a critical issue for the Chinese environment, which is expected to progress dramatically in the medium- and long-term. At present, the air transport sector is responsible for 2.5%–3% of global anthropogenic CO_2 emissions (IEA 2013); and aircraft emissions are expected to grow around 3%–4% per year (IPCC 2007). It is, therefore, a necessity to establish policies to mitigate the climate change caused by the international aviation industry. In ‘The Thirteenth Five-Year Project’, the Chinese government has emphasised CO_2 emission, in particular requiring a reduction of at least 4% of CO_2 from the aviation industry during 2016–2020 in comparing with the level in 2011-2015 (CAAC 2017). This target was ambitious, given the level of historical growth in aviation: low-carbon substitute fuels are not well developed, and efficiency gains are difficult to achieve by technological means.

This chapter seeks to investigate the drivers behind the Chinese aviation industry’s CO_2 emissions and emphasise the consequence of lacking emissions mitigation schemes. To achieve such research objective, this study consists of following tasks:

- Examining the historical drivers of emissions in the Chinese aviation industry, and then providing a benchmark baseline scenario in the absence of any significant policy;
- Summarizing related research in the historical development and aircraft emissions of Chinese aviation industry;
- Describing the historical developments of the Chinese aviation industry in both domestic and international

passenger transport market, focussing on the trend in passenger travel, emissions, revenue and the price elasticity of demand;

- Using this analysis to develop a benchmark BAU scenario for emissions and energy demand; and
- Discussing the implications of this analysis for the need to develop domestic mitigation mechanisms and join global MBMs.

5.2 Literature Review

Since the People's Republic of China was founded in 1949, the country's aviation industry has developed in several stages, especially after the Chinese economic reform in 1978. The reform significantly boosted the economy and led to significant progress in the aviation industry. During the 37 years of economic growth since the reform, the Chinese aviation industry has achieved remarkable progress. Based on RTK, China has become the second largest aviation network in the world (ICAO 2013), following the US. There are five stages to the development of the Chinese aviation industry: before 1949, 1949–1978, 1979-1986, 1987–2001 and 2002–present (Dougan 2002).

Prior to 1949, the industry was under the control of the air force and government because of territorial airspace and security issues. It engaged only in limited commercial operations in a highly centralised and planned economy. During 1950–1978, the entire airline industry in China experienced enormous economic loss, because only high-level government officials were eligible to fly prior to 1980 (Zhang 1998).

Therefore, the most significant evolution of the Chinese aviation industry began in the late 1970s, when China gradually moved away from a centrally planned economy. The airline industry started being market-oriented rather than operating according to centralised decision-making powers. From 1987–2001, further reforms established six major airlines under the supervision of CAAC. The airlines created a number of regional airlines linking provincial capitals with key gateway cities in China, which broke the monopoly while creating a competitive marketplace (Zheng and Connell 2011). In addition, international routes operated by Chinese carriers expanded significantly during this period, which can be seen from the RPK for international flights (CAAC 2002). To be more specific, only 22 foreign cities from 19 countries allowed Chinese airlines to fly between them and China in 1986 (CAAC 1992). This number increased to 65 foreign cities from 29 countries in 2014 (CAAC 2015). In terms of the total number of air routes, its expansion is extraordinary which increased from 287 (260 for domestic flights and 27 for international flights) in 1986 (CAAC 1992) to 3,142 (2652 for domestic flights and 490 international flights) in 2014 (CAAC 2015). This is mainly due to Chinese industrial reform since 1997, including the deregulation of airfares, entry and exit, and privatisation (Zhang and Round 2008). Furthermore, the infrastructure construction also expanded rapidly during this period. According to the National Bureau of Statistics of China (NBSC), the number of civil aviation airports increased from 82 in 1985 to 206 in 2015.

There are several studies about China's transport emissions but research about aircraft emissions only, especially for international flights, is still rare. Wang, Zhang and Zhou (2011) calculated CO_2 emissions of transport in China from 1985–2009 and identified main drivers for transport emissions growth. In 2009, road transport had the largest emissions share in China's transport sector; civil aviation only consisted of 2.1%. Six factors could influence CO_2 emissions growth: emission coefficient effect[39], transportation services share effect[40], transportation modal shifting effect[41], transportation intensity effect[42], per capita economic activity effect and population effect. From their analysis, per capita economic activity, transportation modal shifting and population growth are the critical factors that could

[39] Emission coefficient effect is the impact of different energy sources on transport CO_2 emissions.
[40] Transport services share effect explains how low energy consumption transport services could contribute to CO_2 emissions abatement.
[41] Transport modal shifting effect means the impact of travellers shifting their transport mode from less energy consumption intensive modes, like railway, to more energy consumption intensive modes, such as highway and aviation, on CO_2 emissions.
[42] Transportation intensity was measured a transport service-GDP ratio (km/CNY).

contribute to the increase in transport sectors CO_2 emissions in China.

Cai et al. (2012) adopted vehicle kilometres travelled into their estimation method, which proposed a more accurate estimation of CO_2 emissions from China's transport sector in 2007. They concluded that CO_2 emissions from road transport have a larger share of the total CO_2 from the whole transport sector than IEA's estimation, which means other transportation modes have smaller shares. To be more specific, aircraft emissions only account for 5.14% of the total transport emissions.

He and Xu (2012) calculated the annual CO_2 emissions of aircraft during 1960–2009 and analysed the emissions intensity. Their conclusion indicates the share of aircraft emissions of the total transport sector and total fuel combustion industries are both low, which are 6.6% and 0.25%, respectively. However, the share increased gradually year by year during the investigated period. Loo and Li (2012) focussed on passenger transport instead of both passenger and cargo, and they adopted distance-based and fuel-based methods to calculate CO_2 emissions. From their results, in 2009, aviation was the second largest source of passenger transport emissions. Zhou et al. (2016) calculated CO_2 emissions from the Chinese aviation industry during 1980– 2013 and found out that such emissions increased rapidly over the investigated period even as emissions intensity kept descending. Their results show that although emissions from the aviation industry consist only a small share of total emissions from the whole country (approximately 0.66%), this share will undoubtedly grow profoundly since the expected massive growth of air traffic demand and the shrinkage of energy-intensive industries in China.

Civil aviation is growing faster than almost any other transport sector in China, and its energy intensity is significantly higher than that of rail or automobile travel. According to the data from the National Bureau of Statistics of China database, the average annual growth rate of total RPK in the transport sector is 7%, which is the same growth rate as the national GDP; however, the average annual growth rate of RPK in the civil aviation industry is 15%, which is double the increase of total RPK in the transport sector. The RPK increase in air passenger transport is also double the annual growth rate of road transport (7%) and railway (6%). In terms of freight transport, the increase of RTK in air transport (15% per year) still almost doubles the increase of the transport sector (8% per year). However, when it comes to the freight transport by railway, air cargo transport grows triple the rate of the railway, which has an average growth rate of 4% per year. The annual increase of road freight transport is the same as the growth in air cargo. As one of the most significant airline networks in the world, China, therefore, has responsibilities to eliminate CO_2 emissions from its aircraft. However, there is a lack of research focussed on historical aircraft emissions in China.

5.3 Methodology

5.3.1 Secondary data analysis

To conduct a historical analysis, it is impossible for researchers to collect first-hand data of previous years; therefore, this chapter adopts a secondary data analysis to study historical drivers for Chinese air travel demand growth and increasing emissions. Rather than using a primary data analysis, the research questions are answered using a secondary data analysis via data collected from public statistics (Boslaugh 2007). This chapter presents data on air travel demand data, ticket prices and revenues, fuel efficiency, etc. from the National Bureau of Statistics of China and CAAC statistics.

By investigating these data, this chapter can assess the historical drivers of increased air travel demand and emissions growth for both domestic and international flights carried by Chinese airlines. In particular, this chapter only includes international flights departing from and arriving at Chinese airports operated by Chinese airlines only. By looking at historical trends between 1986 and 2015, a baseline scenario can be projected on how future demand and aircraft emissions would grow without any carbon constraints. The methodology adopted for forecasting the future air travel demand is the vector error correction model, which will be explained in section 5.3.2.

5.3.2 Regression analysis

'The classical linear regression model is a way of examining the nature and form of the relationship among two or more variables' (Asterious and Hall 2007). In this chapter, we set the air travel demand (RPK) for both domestic and international flights carried by Chinese airlines to be the dependent variable. In terms of the explanatory variables, the model built up here includes average ticket price (revenue per passenger kilometre), GDP and population. Although there are various variables listed in Table 2, most of them cannot be involved in this model because this is not an origin-destination analysis due to the lack of data. However, because the population changes very slowly over the period of 1985-2015, the model will not include population as one of the explanatory variables. Therefore, to explore elasticities of air travel demand, following model is formulated:

$$\boldsymbol{D_t = exp\{\alpha + \beta_1 \log(ATP_t) + \beta_2 \log(GDP_t)\}} \quad (1)$$

where D_t denotes the air travel demand in RPK, ATP_t refers to the average ticket price, and GDP_t means the gross domestic product in China. In addition, the subscript t stands for the given year of the sample data. Both RPK and ATP data comes from annual year book-Statistics of Civil Aviation China, and GDP comes from NBSC. Besides, both average ticket price and national GDP have been deflated to 1978 price.

This model explores the relationship of each independent variable with the air travel demand in both domestic and international markets. Although the data for GDP is the same for both travel demand models, the average ticket price is different for domestic air travel and international air transport. The reason why we choose the RPK over the passenger numbers for the demand model is we want to catch the changes of average flight length because this is expected to increase over the time because new routes may open in the future or more people will travel long-distance than before, and; this would influence future projections. By studying the relationship between different air travel demand and each independent variable, we can forecast future market growth for both domestic and international air traffic. The demand assumes that the long-run relationship between the dependent variable and independent variables will continue in the estimated period. There will be a more specific explanation about the model and its related econometric analysis in section 5.5.

Based on the projection of future air transport demand, we could learn about how much fuel would be burned by multiplying the demand (RPK) and unit fuel efficiency (kg/RPK). Then, the total direct CO_2 emissions could be calculated based on this method, as presented in section 5.3.3.

5.3.3 Emission calculation: Two-tiered methodology

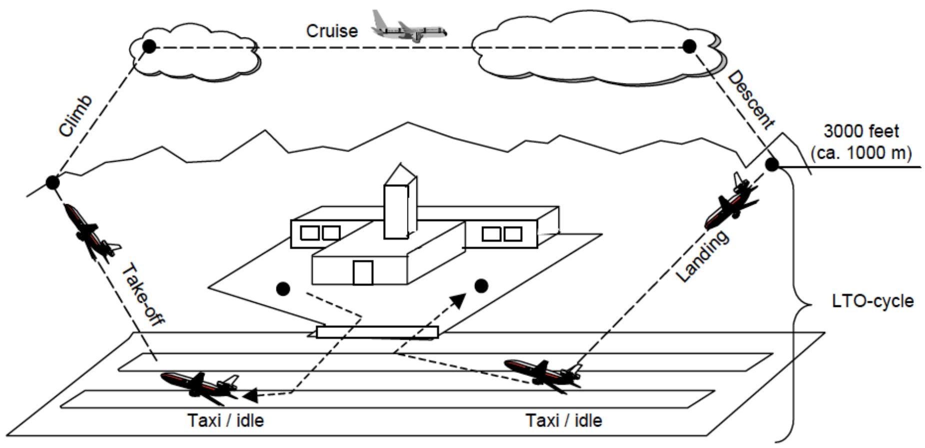


Figure 21 Flying Cycle

(Source: IPCC 1997)

Because there is no detailed and publicly available statistics regarding CO_2 emissions, the two-tiered methodology in the 'Greenhouse Gas Inventory Reference Manual' (IPCC 1997) has been selected as a framework for estimating and reporting the emissions from both domestic and international flights. The first tier is the simplest methodology, based only on an aggregate number for fuel consumption to be multiplied with average emission factors. The second 'Tier 2' methodology estimates emissions in two flying phases: the LTO and cruise phases. Although CO_2 emissions is a constant for both LTO and cruise phases, two-tiered methodology still gives a more accurate estimation. Also, if we consider applying the analysis of this thesis to other aircraft emissions (e.g. CH_4, NOx), we could just use the same model without revising emissions calculation process. For the observation of empirical analysis, this chapter chose all Chinese carriers operating in the domestic and international markets, which means emissions from non-Chinese airlines will not be calculated in here. The computation equation is:

$$\boldsymbol{CO_{2_t} = LTO_t \times EF_{LTO} + \frac{RPK_t \times FE_t - LTO_t \times FE_{LTO}}{1000} \times EF_{CRU}} \qquad (2)$$

where CO_{2_T} means CO_2 emissions from aircraft, LTO_t is the number of landing and take-off, EF_{LTO} refers to the emission factor during the LTO phase, RPK_t is the revenue passenger kilometres, FE_t denotes the fuel consumption per RPK, FE_{LTO} represents the fuel consumption per LTO and EF_{CRU} is the emission factor during the cruise phase, the subscript t means the given year.

The number of LTO can be calculated based on future passenger numbers, load factors and average aircraft capacity for domestic and international flights, respectively. The emission factor and fuel efficiency during the LTO phase is different for domestic and international flights. For domestic flights, the emission factor of CO_2 during the LTO phase is 2,680 kg/LTO and the fuel efficiency is 850 kg/LTO on the average fleet. When it comes to international flights, the emission factor of CO_2 during the LTO phase is 7,900 kg/LTO and the fuel efficiency is 2,500 kg/LTO on the average fleet. In terms of the emission factor during the cruise phase, it is 3,150 kg/ton for both domestic and international flights.[43] By considering the aircraft replacements and technology and operational development, this chapter assumes that fuel efficiency will increase by 1% per year, which is consistent with ICAO's improvement objective.

[43] All emission factors listed here are calculated based on the average fleet because we do not have the detailed data on RPK by each type of aircraft of Chinese airlines.

5.4 Historical Developments of Chinese Aviation in International Passenger Transport

In this section, we analyse the historical performance of Chinese airlines with respect to passenger transportation during the period from 1986–2015 using a time series analysis. Specifically, indicators are discussed, including RPK, transport revenue, price elasticity and income elasticity of demand, fuel consumption and efficiency, as well as CO_2 emissions. The purpose of examining those historical trends is to gain insights into the drivers of CO_2 emissions and establish parameters for a future baseline scenario.

5.4.1 Air passenger transport and CO_2 emissions

Figure 22 shows the historical RPK by Chinese airlines during the period 1986–2015. It can be seen that the growth between 1986 and 2015 was strong and steady with an average of 16.24% per year and 14.53% per year for domestic and international flights respectively.

Firstly, the air transport market started developing during the period of 1986-2002. In addition, the growth in the Chinese economy, wealth, and global tourism led to the increasing of travels for both international business and personal activities (Yang and Wang 2006). The drop in 2003 was due to the global epidemic of SARS. Because this disease emerged in south China and then spread to other regions of the country, both domestic and international transport of China was significantly affected during that period (Ruan, Wang et al. 2006).

Secondly, the demand for air flight transport started to grow heavily, especially after 2009. In particular, there are three growth periods for air passenger transport RPK: 1986–2003, 2004–2009 and 2010–2015. By the end of 2015, Chinese airlines carried 555,640 million passenger kilometres on domestic flights 171,420 million passenger kilometres on international flights. The share of international flights carried by Chinese airlines in total passenger flights operated by Chinese airlines has been steady since 1986, with an average market share of 22%. This is due to higher demand for domestic air travel instead of international, which can be seen from average growth rate presented above. On the other hand, this is because the data for international flights collected in this chapter is only carried by Chinese airlines, which is lack of passengers travelled by other international airlines.

As shown Figure 23, there is a slight decrease of annual changes in RPK from domestic flights, which indicates the growth of passenger transport on domestic flights may grow slower in the future than that of in history. On the other hand, a slight increase is found in the annual changes in RPK from international flights operating by Chinese airlines from 1986–2015. The linear forecast trend line indicates the minor ascendant might continue in the future. The demand for passenger air transport is mainly driven by population and personal income, which indicates that future air transport demand in passenger would slow down if the growth of population and income were to decrease.

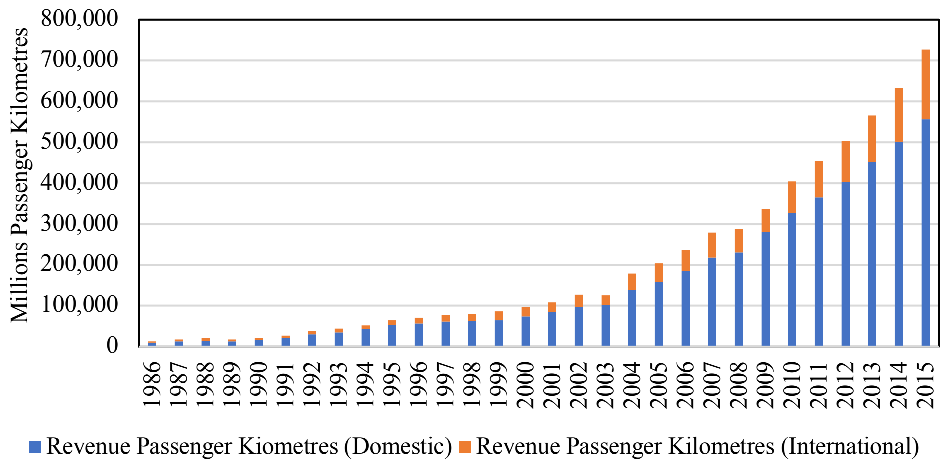


Figure 22 RPK for domestic and international flights and overall growth during 1986-2015

(Data source: CAAC 1992, 1998, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016)

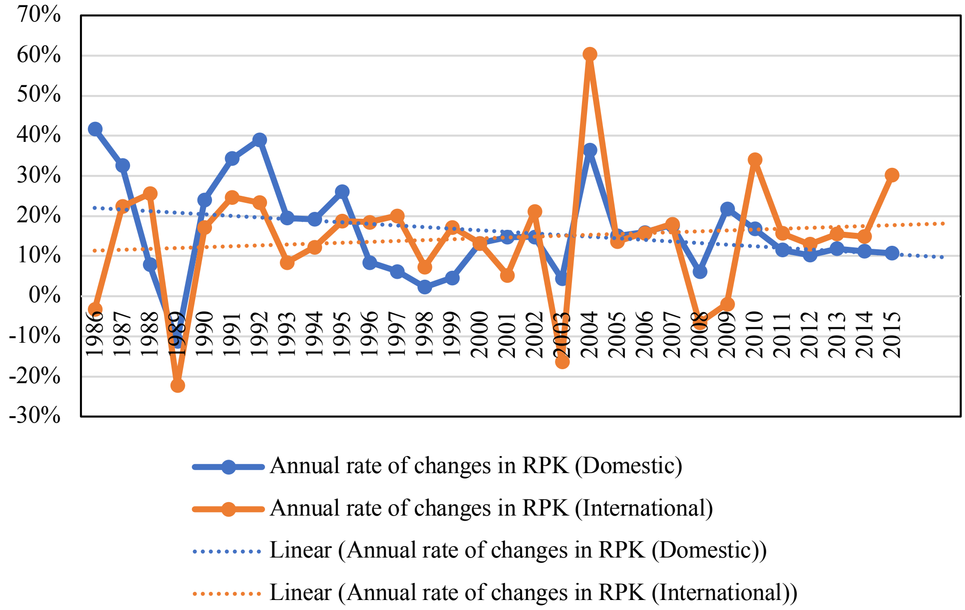


Figure 23 Annual rate of changes of RPK and linear trend line forecast during 1986-2015

(Data source: CAAC 1992, 1998, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016)

5.4.2 Air ticket price and air transport revenue

Figure 24 presents the total transport revenue of both domestic and international passenger flights, as well as the average ticket price during 1986–2015. The linear trend line clearly indicates that the average ticket price will continue to increase during this time period. The graph also presents a directly proportional effect driven by the average ticket price and transport revenue. There are variations in the growth of average ticket prices while the increase in passenger transport revenue does not ascend as the variations always. Although the increased transport revenue is driven by both the increase of average ticket prices and the growth of air transport demand, the transport revenue is likely to rise when demand is adequately high, even if the price may decrease in general.

Nonetheless, the average ticket price affects air transport demand to the degree of price elasticity of demand. By the end of 2015, the revenue of air passenger transport with domestic flights increases to 260,074 million CNY (37,788 million USD[44]) while the average ticket price is 0.468 CNY (0.068 USD) per passenger kilometre in 1978 CNY.[45] The revenue of international passenger air transport increased to 127,859 million CNY (18,577 million USD) while the average ticket price is 0.746 CNY (0.108 USD) per passenger kilometre in 1978 Chinese CNY.

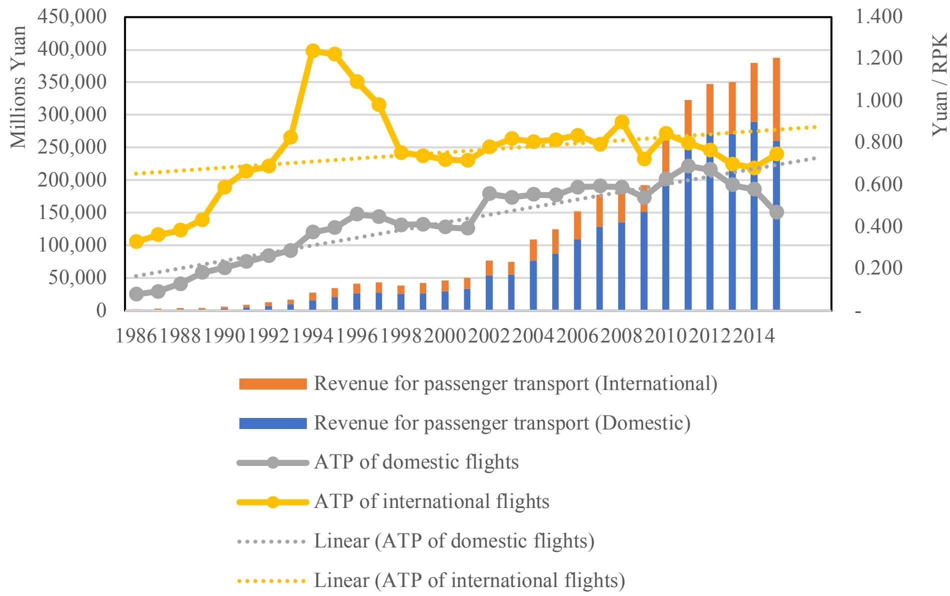


Figure 24 Transport revenue and the average ticket price of both domestic and international flights from 1986 to 2015

(Data source: CAAC 1992, 1998, 2000-2016)

There have been several evolvements for how Chinese airlines price their service. During 1949–1979, when the government centrally controlled the economy, the civil aviation industry was newly established in China and airlines did not have the power to decide their airfares by themselves but only to abide by ticket prices decided by the government. The air ticket price was mainly based on costs of air transport and ticket prices of alternative transport modes (i.e. water transport, railway transport and road transport) on the same route.

However, there had been large variations in the airline ticket price caused by the political environment. For instance, the ticket price for air transport is 0.24 CNY (0.0349 USD) per passenger

44 Currency exchange rate is 1 CNY = 0.1453 USD (XE.COM, 28/03/2016)

45 The average ticket price has deflated with the consumer price index. The price in 1978 is the index.

kilometre for those routes having water transport as an alternative, which equals the average transport cost. For those routes having the railway as an alternative, airline ticket prices were decided at 0.215 CNY (0.0312 USD) per passenger kilometre, which was lower than the average transport cost; for those routes not having alternatives, ticket prices for air transport is 0.31 CNY (0.045 USD) per passenger kilometre, which is higher than the average transport cost (Min, Yang and Liu 2003). When it comes to 1966, the civil aviation industry had been regulated under the Chinese Army, which led to substantial economic loss because the regulation ignored the cost of transportation and economic benefits. The government changed the pricing strategy to discriminate based on the passengers' nationalities, which means Chinese citizens could purchase airline tickets for domestic flights at a lower price than passengers from other countries.

Since 1980, there has been a new age of the Chinese aviation industry, which was a network of the industry had been established, including airlines, airports group, aviation fuel companies, aircraft-related materials companies. Although the aviation industry was still not entirely independent, different sectors within it had begun to transform their business into market discipline instead of fully controlled by the government.

In 1984, published fares were adopted, which meant passengers could purchase airline tickets at the same price; however, certain discounts were offered to Chinese citizens. That means, still, there were two levels of airline ticket prices: one for Chinese citizens and another for passengers from other countries. Prior to 1992, ticket prices of passenger air transport were decided by both Price Bureau and CAAC together under the law of pricing commercial goods. In 1992, the State Department indicated a signal of marketisation through publishing the directive that allows airlines could adjust their airfares with a floatation of 10% up and down. On 1 March 1996, a new pricing strategy was launched based on the law of civil aviation and pricing, which allowed airlines pricing their services under the guidance of the government. In the meantime, the public could purchase airline tickets for personal travel rather than only government officials.

After 1996, the pricing strategy for domestic flights changed frequently and the result on ticket prices and passenger air transport revenue can be seen in Figure 24. First, Chinese passengers and passengers from other countries could purchase airline tickets at the same price, which means they could purchase their tickets with the price of 0.75 CNY (0.1091 USD) per passenger kilometre when they buy it in China or with the price of 0.94 CNY (0.1367 USD) per passenger kilometre whey they bought outside China (Pan and Zhao 2005).

Considering both affordability of passengers and contestability of airlines, CAAC launched a new pricing system in which there is only one ticket price for air transport but there would be multiple degrees of discounts. This was the first step in transforming airline industry pricing from government-controlled to marketisation. However, because the market mechanism was immature, airlines started disordered competition and price wars by launching large sales in airline tickets.

In addition to the effect of the Asian financial crisis, there was a loss of 2,400 million CNY in 1998. To reorganise and standardise the market competition, the NDRC and CAAC issued the document that sales of airline tickets had been prohibited unless it is for travel group (10% off), teachers and students during vacation (10% off) and disabled veterans (20% off). Otherwise, airlines had to abide by the same ticket price issued by the government (Chen 2001). This led to airlines pricing back to the government-controlled temporarily. It is only temporary because the airline industry expanded and developed heavily during that period in which the government-controlled pricing strategy could not meet the passenger demand in personal leisure travel.

In April 2000, major airlines in China formed a pricing alliance to price their services together over 102 air routes. Thereafter, CAAC applied sales strategy on group travel to some pilot air travel routes (i.e. flights to Hainan Province) in May 2000. Then in October 2000, CAAC lost control of the price administration in which airlines could price their services by themselves based on the published fares and could not exceed 10% extra. In March 2001, CAAC called back the prohibition on sales tickets, which allowed part of airline tickets to go on sale. In the following November, domestic flights had raised fuel charges which allowed the ticket price to float up to 15% at the most, 150 CNY (21.8 USD), for a one-way ticket.

In the meantime, a linkage mechanism had been built between fuel prices and air ticket prices, which meant airlines could float their ticket prices with 3% most when fuel prices changed by 10%. Furthermore, CAAC decreased their management scope on group travel discount which airlines could set different level of sales tickets based on travel groups' sizes, purposes of travel, and the time of purchasing tickets. There were many pressures from airlines and passengers because of frequent changes in pricing strategies. This period, however, established a solid foundation for the marketisation of airline industry.

After a chaotic period of pricing strategies in the airline industry, a pricing reform plan was issued by NDRC and CAAC in 2004. The plan specified NDRC and CAAC needed to set the baseline airline ticket price and its flotation scope relying on the social average unit cost, market supply and demand, and publics' affordability. The new reform plan allowed airlines to price their services based on the baseline price set by NDRC and CAAC with the flotation up to 125% and down to 55%. Except for 242 leisure travel routes and 225 routes, run by one company exclusively, there was no boundary for floating downward. Driven by the airline competition, the price war started during the following years. Airline companies did not abide by the flotation ranges made by NDRC and CAAC but instead sold airline tickets at a very low level to possess larger market share.

After years of efforts, the marketisation and competition among airlines grew maturely; therefore, the State Department issued another document to cancel the limitation on flotation downward, which means airlines could price their services within the flotation upward 25% from the baseline price and no downward limitations after October 2013 (State Department 2012). For those routes operated by more two airlines and having alternative transport modes, airlines were encouraged to have competition with each other and other kinds of transport by setting air ticket prices by themselves instead of relying on the published fares from the government. Therefore, airlines obtained more freedom on pricing their services since 2013. Furthermore, more flying routes are included in the scheme of market regulation instead of the government administration. Since November 2016, airlines can price their services by themselves based on the market condition for flights are operated within the distance of 800 km; they also can price flights that operate over 800 km distance if they are competing with high-speed railways (CAAC 2016).

As discussed above, Chinese airlines price their services based on the base fare made by NDRC and CAAC, and they can float it within a range given up by the Chinese government. However, when it comes to international flights, pricing strategies are involved more factors in the process. Typically, the price of airline tickets consists of several items: base fare, taxes and airport fees, fuel surcharge, a service fee to issue, food, seat selection and baggage. Among all those things included in the ticket price, airlines could decide the base fare, service fee to issue, food, seat selection and baggage. Chinese airlines cannot price their flight seats based on only what the government decides but also the international market in which they participate and their competitors or alliances. To be more competitive, the pricing strategy for international flights operated by Chinese airlines is more market regulated than the government administrated.

Yet no matter who prices the air travel ticket, the base fare of both domestic flights and international flights are decided based on operational costs and passengers' affordability (personal income). In terms of operational costs, the cost of jet fuel consists of a significant share of it. This means the fluctuation of average ticket price could be driven by the changes in fuel prices. As presented in Figure 25, the fuel price keeps growing although there are some fluctuations shown in the figure, which are consistent with the average ticket prices shown in Figure 24.

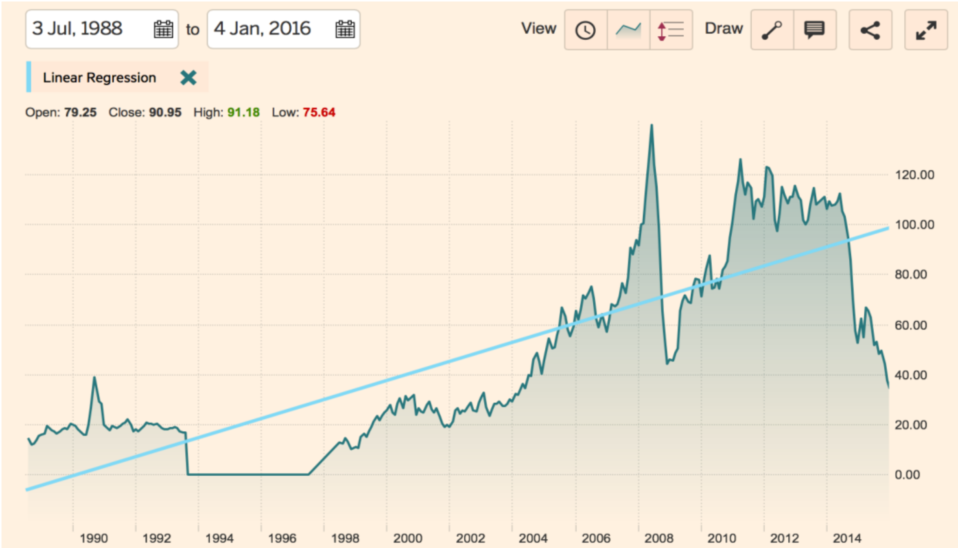


Figure 25 Crude oil prices during 1988-2015

(Source: Financial Times n.d.)

5.4.3 Fuel efficiency

Comparing the level of fuel consumption and CO_2 emissions in 2005, airlines have adopted a voluntary fuel efficiency goal of reducing by at least 25% by 2020, with a 2% growth in fuel efficiency per RTK per year (IATA 2007). Likewise, ICAO (2010) also concluded that it is most likely to meet the goal of annual fuel efficiency goal of 2% by 2020. In terms of the fuel efficiency of Chinese aircraft operators, it shows an increase of efficiency growth in terms of RTK on Chinese airlines. In addition, the average annual fuel efficiency growth during 1986 and 2015 is 1.75%, which is a little lower than IATA's voluntary fuel efficiency goal.

As can be seen from the figure below, there are variations between 1986 and 1998, which mainly caused by aircraft replacement. During that period, most aircraft were rented from aircraft manufacturers, and only a small share of aircraft was purchased, which means some aircraft were not newly manufactured when Chinese airlines rented them. Therefore, airlines could rent old aircraft with high fuel consumption, which could lead to the fuel efficiency variations during that period since airlines rented or purchased more aircraft every year. In addition, the variations in fuel efficiency could result from aircraft operations.

Since 1999, the fuel efficiency remains to descend which appears relatively stable than that in the previous stage. As can be seen from Figure 27 airlines keep replacing aircraft with low fuel efficiency by those with high fuel efficiency. Figure 28 shows airlines prefer A320 and Boeing 737-800 more than other types of aircraft, and these two kinds of aircraft have an average annual improvement rate at 2% in fuel efficiency. Although aircraft of Boeing 757 has the lowest unit fuel consumption as presented in Figure 28, they only account for a small share of Chinese passenger airlines fleet because Boeing had stopped production of this model. Aircraft like Dornier 320 or from Bombardier have been replaced in later years because their fuel efficiency not only cannot be improved but also is less efficient as a result of age.

In addition, as can be seen from figures below, more fuel-efficient aircraft were developed in recent years for other three distance ranges (i.e. Boeing 777, Boeing 787, and A330), and the fuel efficiency of Chinese airline industry has improved by renting or purchasing these aircraft instead of using old models. Notably, Chinese airlines have stopped using aircraft purchased from McDonnell Douglas (MD) for passenger travel as showed in Figure 27. This is not only because MD was taken over by Boeing and they stopped producing similar aircraft but also similar aircraft from MD are less fuel-efficient than those from other manufacturers.

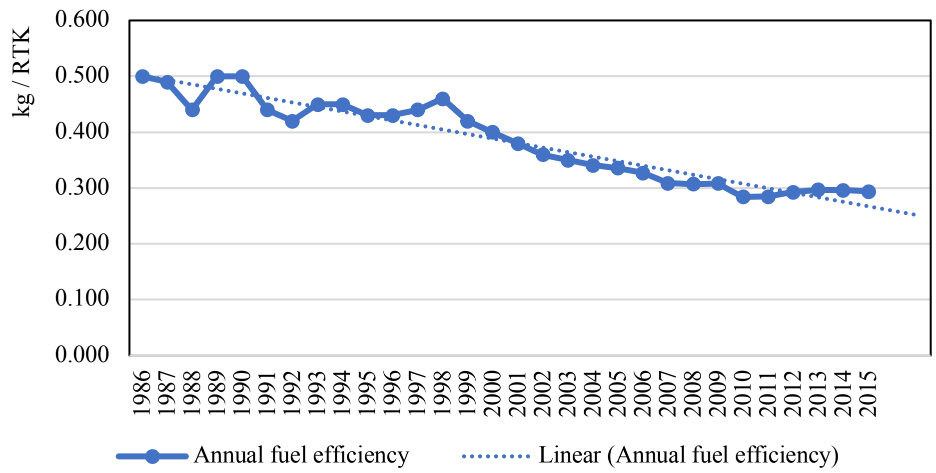


Figure 26 Annual fuel efficiency changes from 1986 to 2015

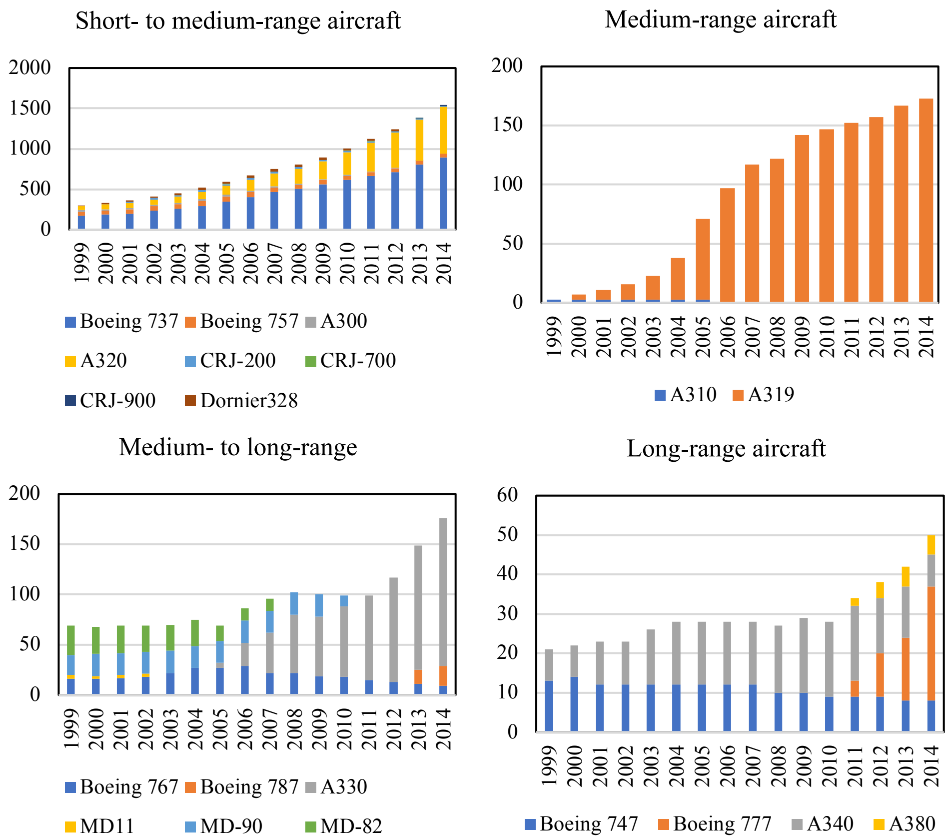


Figure 27 Aircraft operated by Chinese airlines during 1999-2014 (Data source: CAAC 2000-2015)

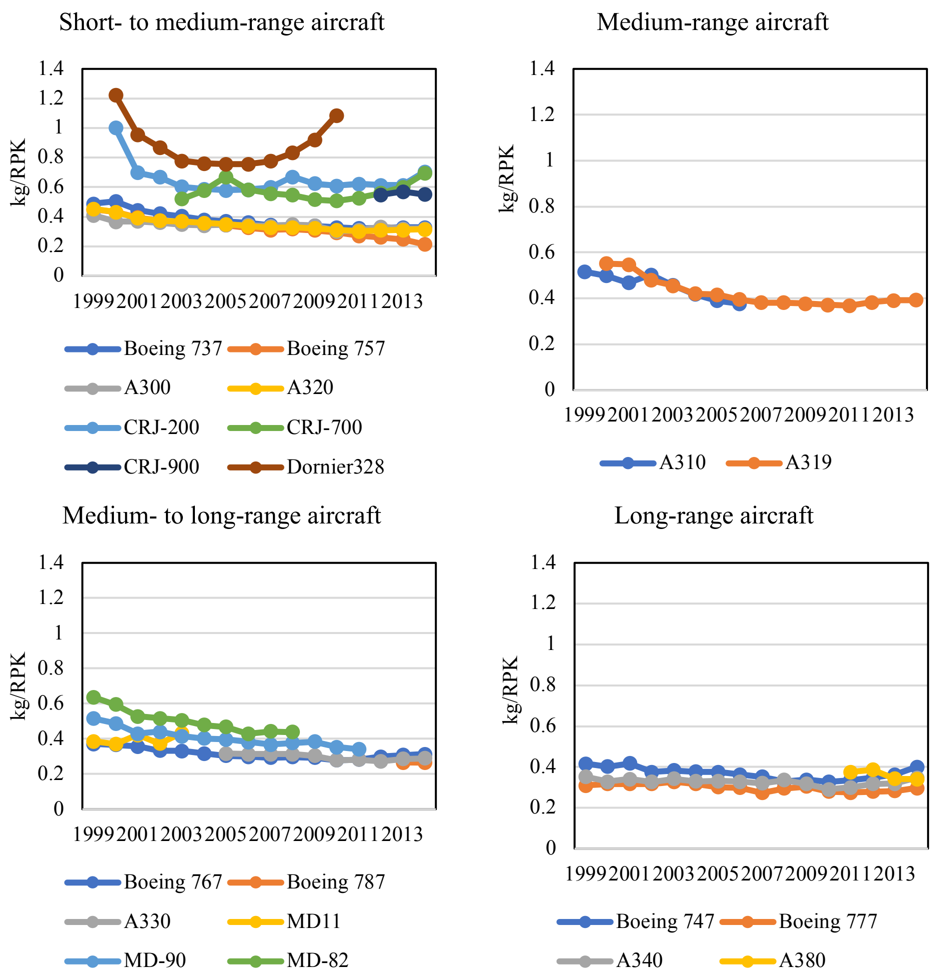


Figure 28 Fuel efficiency of aircraft owned by Chinese airlines during 1999-2014

(Data source: CAAC 2000-2015)

5.4.4 Fuel consumption and CO_2 emissions

As can be learned from the previous section, fuel efficiency improved during 1986–2015. However, the fuel consumption for both domestic flights and international flights increased heavily with an average annual growth rate of 14.76% and 12.8%, respectively. This is due to tremendous increase in air travel demand each year; however, the ascendant of fuel consumption still shows the effect of fuel efficiency improvements since the growth rate is smaller than that of air travel demand. By the end of 2015, total fuel burned for passenger air transport was 18.9 million ton, which 14.45 million ton was burned in domestic flights and 4.45 million ton was burned in international flights. Furthermore, as the airline industry has high energy intensity and aircraft emissions, mainly coming from jet fuel burn, we can learn about how many CO_2 emitted from aircraft based on how many fuels airlines burned between 1986 and 2015.

There is no detailed and publicly available statistics regarding CO_2 emissions, so the two-tiered methodology in the ‘Greenhouse Gas Inventory Reference Manual’ (IPCC 1997) is used to calculate CO_2 emitted from aircraft operated by Chinese airlines. Therefore, the CO_2 emissions have been growing alongside the growth of fuel consumption from 1986–2015, as shown in Figure 29. The graph indicates a large increase in CO_2 emissions (from 1.57 million tonnes in 1986 to 59.6 million tonnes in 2015), which will continue to increase significantly if there is no mitigation instrument or huge progress in technology in the future. All these emissions are calculated based on both domestic and international flights carried by Chinese airlines only, which means CO_2 emissions from other international flights departing from and arriving at Chinese airport have been excluded. The current amount of CO_2 emissions consists of 2% of the total passenger transport CO_2 emissions[46] in China.

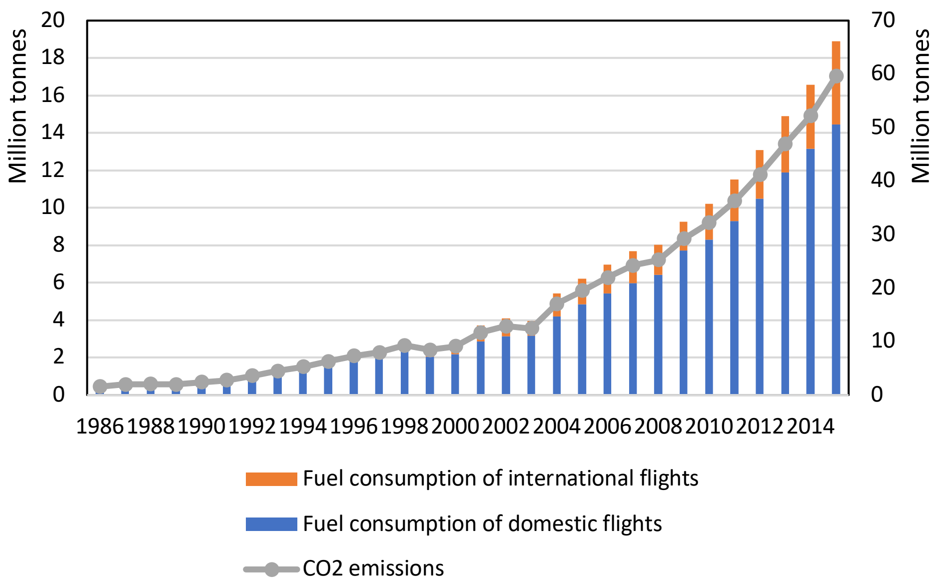


Figure 29 Fuel consumption and CO_2 emissions during 1986–2015

[46] Total transport CO_2 emissions are calculated based on CO_2 per capita China (data source: World Bank Data) and total passenger transported by all modes (data source: NBSC).

5.5 Modelling results

5.5.1 Ordinary least square model

As can be seen from section 2.2.2, variables that can influence passenger air transport demand most include airfare and GDP. The population is not included based on the results from unit root test below and the limited variability in the variable (as can be seen from the limited range in Figure 30). Therefore, this chapter constructs the air transport demand model based on these three variables firstly. To be more specific, domestic air travel demand model and international air travel demand model can be expressed with the ordinary least square (OLS) model which are listed below.

$$\boldsymbol{LGRPK\_D = \alpha + \beta_1 LGATP\_D + \beta_2 LGGDP} \qquad (3)$$

$$\boldsymbol{LGRPK\_I = \alpha + \beta_1 LGATP\_I + \beta_2 LGGDP} \qquad (4)$$

where, LGRPK_D and LGRPK_I mean the logarithm form of domestic and international air passenger transport demand individually, LGATP_D and LGATP_I indicate the logarithm form of the average ticket price of domestic and international flights carried by Chinese airlines, and LGGDP denotes the logarithm form of Chinese national GDP.

Before modelling the model, we need to test each variable individually because most time series are trended and therefore in most cases are non-stationary. The problem with non-stationary or trended data is that the standard OLS regression procedures can easily lead to incorrect conclusions. This tends to happen in presence of very high value of R^2. Both Table 9 and Table 10 indicate this kind of possibility that there is spurious regression existing in results (i.e., R-squared values are over 0.99,). One can notice that the domestic demand model shows a wrong sign of the price elasticity. Therefore, it is critical to test for unit root for each variable in the model.

Table 9 OLS estimates of domestic air passenger transport demand

Dependent Variable: LGRPK_D
Method: Least Squares
Sample: 1985 2015
Included observations: 31

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-14.50	1.310013	-11.07	0.00
LGATP_D	0.27	0.055492	4.79	0.00
LGGDP	1.31	0.04134	31.61	0.00

R-squared	0.99	Mean dependent var	25.08
Adjusted R-squared	0.99	S.D. dependent var	1.27
S.E. of regression	0.10	Akaike info criterion	-1.71
Sum squared resid	0.27	Schwarz criterion	-1.57
Log likelihood	29.44	Hannan-Quinn criter.	-1.66
F-statistic	2494.27	Durbin-Watson stat	1.24
Prob(F-statistic)	0.00		

Table 10 OLS estimates of international air passenger transport demand

Dependent Variable: LGRPK_I
Method: Least Squares
Sample: 1985 2015
Included observations: 31

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-17.81	0.843572	-21.11	0.00
LGATP_I	-0.06	0.063125	-0.95	0.35
LGGDP	1.36	0.02727	50.03	0.00

R-squared	0.99	Mean dependent var	23.82
Adjusted R-squared	0.99	S.D. dependent var	1.16
S.E. of regression	0.11	Akaike info criterion	-1.48
Sum squared resid	0.34	Schwarz criterion	-1.34
Log likelihood	25.94	Hannan-Quinn criter.	-1.43
F-statistic	1657.48	Durbin-Watson stat	1.48
Prob(F-statistic)	0.00		

5.5.2 Unit root test

The simplest, purely statistical time series model is the autoregressive of order one model, or AR(1) model, which is given below:

$$\boldsymbol{Y_t = \emptyset Y_{t-1} + u_t} \tag{5}$$

where, for simplicity, the equation does not include a constant and $|\emptyset| < 1$ and u_t is a Gaussian (white noise) error term. In general, there will be three possible cases: a) $|\emptyset| < 1$ and therefore the series is stationary; b) $|\emptyset| > 1$where in this case the series explodes; and, c) $\emptyset = 1$ where in this case the series contains a unit root and is non-stationary. As presented in Figure 30, all times series involved in both passenger air travel demand model typically have an underlying rate of growth. Such time series are not stationary as the mean is continually rising even we already took the logarithm form of each variable. Therefore, it is necessary to test unit root before we perform the regression analysis.

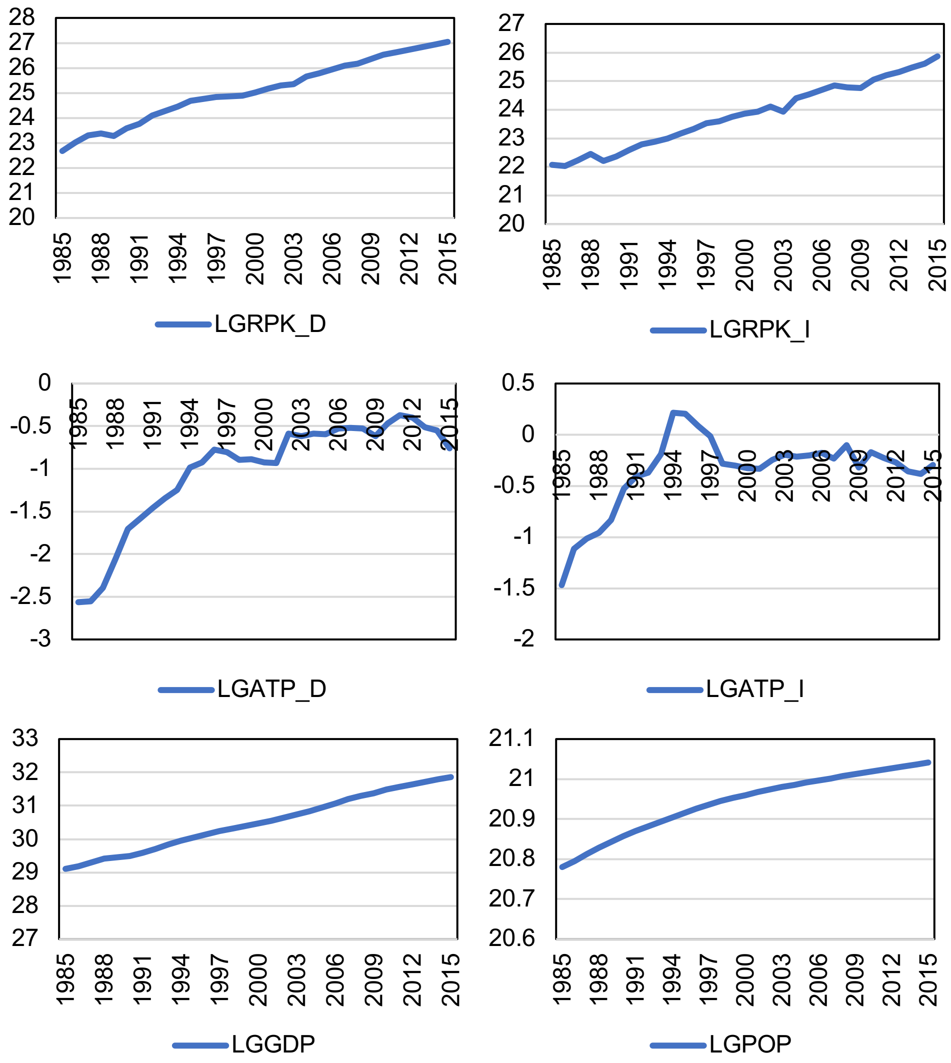


Figure 30 Plot of all variables in air passenger travel demand

To test the unit root of each variable, the study chooses Dickey-Fuller Generalised Least Squares (DF-GLS) as the method. It proposed by Elliott, Rothenberg, and Stock (1996) that performs the modified Dickey-Fuller t-test. Essentially, this is similar to the augmented Dickey-Fuller (ADF) test, except that the time series is transformed via a generalised least squares regression before performing the test. Elliott, Rothenberg and Stock and later studies have indicated that the DF-GLS test has significantly greater power than the previous versions of the ADF test.

As can be seen from Table 11, all variables at least have a unit root under the level order no matter whether the equation includes constant only or both constant and trend term, except for LGGDP. We can learn from the table below, test result showed the variable, LGGDP, is stationary at the level order if the test equation includes both constant and trend term. However, in most cases, GDP has been considered non-stationary at the level order (Christiano and Eichenbaum 1989; Fleissig and Strauss 1999; Li 2000; Smyth and Inder 2004). In our case, the stationarity of the real GDP in the levels may result from the size of the sample is a little bit small.

However, the population is surprisingly not stationary at first difference and also have no stochasticity as we can see from the graph above. Because all variables in the same equation have to be integrated into one order; and, that is why we need to discard the population from the model in order to perform a proper regression analysis.

Table 11 Unit-root test results

Variable	**Level order**			**First difference order**		
	Model	DF-GLS Value	5% t-Statistic	Model	DF-GLS Value	5% t-Statistic
LGRPK_D	constant	0.75	-1.95	constant	-2.569798	-1.95
	constant and trend	-1.80	-3.19	constant and trend	-3.553653	-3.19
LGRPK_I	constant	-0.09	-1.95	constant	-6.639058	-1.95
	constant and trend	-4.40	-3.19	constant and trend	-7.106202	-3.19
LGATP_D	constant	-1.05	-1.95	constant	-3.139749	-1.95
	constant and trend	-0.84	-3.19	constant and trend	-4.767643	-3.19
LGATP_I	constant	-1.38	-1.95	constant	-1.868278	-1.95
	constant and trend	-1.76	-3.19	constant and trend	-4.552265	-3.19
LGGDP	constant	-0.43	-1.95	constant	-3.840378	-1.95
	constant and trend	-3.62	-3.19	constant and trend	-3.868593	-3.19
LGPOP	constant	1.17	-1.95	constant	-0.919104	-1.95
	constant and trend	-0.95	-3.19	constant and trend	-1.966083	-3.19

5.5.3 Cointegration test

In order to test the cointegration, the Johansen approach has been chosen here and the test results are presented in tables below. Prior to performing the Johansen cointegration test, we need to ensure all variables in the regression analysis should integrate in the same order, which we have done in the previous section (5.5.1.1) that all variables are integrated with first differences.

Also, it is very important to find the appropriate (optimal) lag length because we want to have Gaussian error terms (i.e., standard normal error terms that do not suffer from non-normality, autocorrelation, heteroskedasticity etc.). The most common procedure to determine the optimal lag length is to estimate Vector Autoregressive (VAR)[47] model (Asterious and Hall 2007).

As can be seen from Table 12, we test the VAR model with different lag structures from the largest available option for the model which are five lags included. The SC test suggests a model with one lag but another popular selection criterion—AIC select five lags; however, this is way too large considering the number of observations available. Therefore, we chose lag one as the optimal lag length to test the cointegration of variables included in the domestic demand model.

Table 12 VAR lag order selection criteria for domestic demand model

Endogenous variables: LGRPK_D LGATP_D LGGDP

Exogenous variables: C

Sample: 1985 2015

Included observations: 26

Lag	LogL	LR	FPE	AIC	SC	HQ
0	15.15	NA	7.88E-05	-0.93	-0.78	-0.89
1	132.37	198.36	1.93E-08	-9.25	-8.67*	-9.09
2	141.97	14.03	1.90E-08	-9.30	-8.28	-9.01
3	158.13	19.88*	1.19E-08	-9.85	-8.40	-9.43
4	170.15	12.02	1.12E-08	-10.08	-8.20	-9.54
5	184.44	10.99	1.02e-08*	-10.49*	-8.17	-9.82*

[47] VAR model is a stochastic process model used to capture the linear interdependencies among multiple time series (Sims 1996).

Note: * indicates lag order selected by the criterion; LR[48]: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error[49]; AIC: Akai information criterion[50]; SC: Schwarz information criterion[51]; HQ: Hannan-Quinn information criterion.

Similarly, Table 13 also indicates that SC criterion suggests one as the optimal lag length for international demand model, which is not surprise because SC criterion is the most conservative method in choosing lag orders. However, it is quite different from Table 12 that, except for SC, all other criteria would recommend different lag orders when we test different lag structures in the VAR model of domestic demand. In contrast, as we can see from the table below, all criteria suggest two as the optimal lag length including the AIC, another powerful tool to select the lag order. Hence, for international demand model, we choose two as the optimal lag length by involving more dynamics to the model.

Table 13 VAR lag order selection criteria for international demand model

Endogenous variables: LGRPK_I LGATP_I LGGDP						
Exogenous variables: C						
Sample: 1985 2015						
Included observations: 26						
Lag	LogL	LR	FPE	AIC	SC	HQ
0	2.93	NA	0.00	0.00	0.14	0.046
1	111.39	183.54	9.66e-08	-7.64	-7.06*	-7.47
2	123.75	18.06*	7.72e-08*	-7.90*	-6.88	-7.61*
3	132.68	10.98	8.44e-08	-7.89	-6.44	-7.48
4	134.62	1.93	1.72e-07	-7.35	-5.46	-6.81
5	146.08	8.81	1.96e-07	-7.54	-5.22	-6.87

Note: * indicates lag order selected by the criterion; LR: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akai information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.

We test for cointegration in a model with constant only, and a model with a constant and trend. Firstly, we illustrate cointegration test

[48] Likelihood ratio

[49] FPE criterion was first of two tools proposed by Akaike for the purpose of model order selection. It was derived for time-invariant system/signals operated under stationary conditions (Niedźwiecki and Ciołek 2017).

[50] The AIC is an estimator of the relative quality of statistical models for a given set of data developed by Akaike (1974). Given a collection of models for the data, AIC estimates the quality of each model, relative to each of the other models. Thus, AIC provides a means for model selection.

[51] SC is a criterion for model selection among a finite set of models. It is based, in part, on the likelihood function and it closely related to AIC.

result for domestic demand model in Table 14 and Table 15. As we can see from both tables, only the mode including constant only shows there is cointegration among all variables in the domestic model. Therefore, we would choose model 3 to test the cointegration for the domestic model.

Table 14 Cointegration test result for domestic demand model (constant only)

Sample (adjusted): 1987 2015
Included observations: 29 after adjustments
Trend assumption: Linear deterministic trend
Series: LGRPK_D LGATP_D LGGDP
Lags interval (in first differences): 1 to 1
Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.1 Critical Value	Prob.**
None *	0.416596	28.51200	27.06695	0.0698
At most 1	0.281305	12.88462	13.42878	0.1191
At most 2 *	0.107724	3.305401	2.705545	0.0690

Note: Trace test indicates 1 cointegrating eqn(s) at the 0.1 level; * denotes rejection of the hypothesis at the 0.1 level; **MacKinnon-Haug-Michelis (1999) p-values

Table 15 Cointegration test result for domestic demand model (constant and trend)

Sample (adjusted): 1987 2015
Included observations: 29 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: LGRPK_D LGATP_D LGGDP
Lags interval (in first differences): 1 to 1
Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.1 Critical Value	Prob.**
None *	0.437191	34.49082	39.75526	0.2666
At most 1 *	0.338244	17.82118	23.34234	0.3560
At most 2 *	0.182632	5.848301	10.66637	0.4798

Note: Trace test indicates no cointegrating eqn(s) at the 0.1 level; * denotes rejection of the hypothesis at the 0.1 level; **MacKinnon-Haug-Michelis (1999) p-values

In the case of international air travel demand is less strong, as the Johansen cointegration test results show both models indicate that there is one cointegration equation at 0.15 level according to trace statistics[52]. Max-Eigenvalue test, however, 3 indicates there is cointegration among all variables only in the case of the model with an intercept only. Therefore, we report results from this model in the following.

Table 16 Cointegration test result for international demand model (constant only)

Sample (adjusted): 1988 2015

Included observations: 28 after adjustment

Trend assumption: Linear deterministic trend (restricted)

Series: LGRPK_I LGATP_I LGGDP

Lags interval (in first differences): 1 to 2

Unrestricted Cointegration Rank Test (Maximum Eigenvalue

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.15 Critical Value	Prob.**
None *	0.510614	20.00892	17.49272	0.0712
At most 1	0.193222	6.011793	11.08502	0.6117
At most 2	0.002937	0.082361	2.072251	0.7741

Note: Max Eigenvalue test indicates 1 cointegrating eqn(s) at the 0.15 level; * denotes rejection of the hypothesis at the 0.15 level; **MacKinnon-Haug-Michelis (1999) p-values

Table 17 Cointegration test result for international demand model (constant and trend)

Sample (adjusted): 1988 2015

Included observations: 28 after adjustments

Trend assumption: Linear deterministic trend

Series: LGRPK_I LGATP_I LGGDP

Lags interval (in first differences): 1 to 2

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.15 Critical Value	Prob.**
None	0.528839	21.07155	21.94281	0.1875
At most 1	0.424983	15.49395	15.88976	0.1683
At most 2	0.191692	5.958749	9.532765	0.4656

Note: Max Eigenvalue test indicates no cointegrating eqn(s) at the 0.15 level; * denotes rejection of the hypothesis at the 0.15 level; **MacKinnon-Haug-Michelis (1999) p-values

5.5.4 Vector error correction model

The Johansen cointegration indicates there is a long run relationship between air passenger travel demand and airfare and

[52] Full Johansen cointegration tests for variables included in international air travel demand model are illustrated in the Appendix A.3.

GDP. In order to understand the adjustment speed and direction of the error correction process as well as short run relationships among these three variables—RPK, ATP and GDP—we build a VEC model that can be expressed as:

$$\mathbf{ECM} = \boldsymbol{LGRPK_{t-1}} + \boldsymbol{\beta_1 LGATP_{t-1}} + \boldsymbol{\beta_2 LGGDP_{t-1}} + \boldsymbol{\alpha} \quad (6)$$

$$\boldsymbol{\Delta LGRPK_t} = \boldsymbol{\alpha} + \boldsymbol{b_1 \Delta LGATP_t} + \boldsymbol{b_2 \Delta LGGDP_t} - \boldsymbol{\pi \widehat{ECM}_{t-1}} + \boldsymbol{LGRPK_t} \quad (7)$$

which will have the advantage of including both long-run and short-run information. In Eq. (6), the ECM means the error correction term. If there is a long-run relationship between the dependent variable and independent variables, the ECM should equal to zero in the long-run equation. In this Eq. (7), b_1 and b_2 are the short-run effects that measures the immediate impact that a change in $LGATP_t$ and $LGGDP_t$ will have on a change in $LGRPK_t$.

As discussed in the previous section, we choose the model with constant only to correct the error term for both domestic and international demand model. In terms of the optimal lag length, for domestic demand model, we choose one as the optimal lag length because this has been confirmed by multiple tests. However, for international demand model, we test the VEC model with two lags.

5.5.4.1 Estimations for domestic air passenger travel demand

Table 18 reports result from the estimation including restrictions which are accepted by usual LR tests. Dummy variables are inserted into the short-term component of the model based to ensure that 'specific events' are taken into account – see dum88, dum89, dum92 and dum04. Figure 31 shows several extreme years, 1989, 1992 and 2004; and, all these due to some special event that we have discussed in the section on 5.4.1. After we eliminate all these immediate shocks, we check the residuals for the VEC again and the year-1988 appears to be another extreme point and that is why we include it into the VEC model as well. As illustrated in Table 18, after we include the dummy variable, dum88, the R-squared value has been increased to 0.81. The interpretation of the elasticities of demand is presented in section 5.5.4.3.

Table 18 Vector error correction model for domestic air passenger travel demand

Sample (adjusted): 1987 2015
Included observations: 29 after adjustments

Standard errors in ( ) & t-statistics in [ ]

Cointegration Restrictions:

B(1,1)=1,A(3,1)=0

Convergence achieved after 5 iterations.
Restrictions identify all cointegrating vectors

LR test for binding restrictions (rank = 1):

Chi-square(1)	0.001778		
Probability	0.966363		
Cointegrating Eq:	CointEq1[53]		
LGRPK_D(-1)	1.000000		
LGATP_D(-1)	0.406711		
	(0.17002)		
	[2.39210]		
LGGDP(-1)	-1.538211		
	(0.10825)		
	[-14.2093]		
C	22.21439		
Error Correction:	D(LGRPK_D)	D(LGATP_D)	D(LGGDP)
CointEq1	-0.26292	-0.127931	0.000000
	(0.05232)	(0.11798)	(0.00000)
	[-5.02561]	[-1.08432]	[NA]
D(LGRPK_D(-1))	0.021441	0.385116	0.097691
	(0.10257)	(0.25118)	(0.02924)
	[0.20905]	[1.53325]	[3.34075]
D(LGATP_D(-1))	0.127755	0.171972	-0.001986
	(0.08338)	(0.20418)	(0.02377)
	[1.53225]	[0.84225]	[-0.08356]
D(LGGDP(-1))	0.675752	0.067160	0.474612
	(0.50815)	(1.24441)	(0.14488)
	[1.32982]	[0.05397]	[3.27600]
C	0.075982	-0.028257	0.033806
	(0.04274)	(0.10466)	(0.01218)
	[1.77782]	[-0.26998]	[2.77440]
DUM88	-0.238638	0.165358	-0.00678

[53] Because in the VEC model, both dependent variable and independent variable are in the same side of the equation, the sign of the coefficients listed here is exactly opposite with the sign of the coefficients from the normal OLS estimations.

	(0.06042)	(0.14797)	(0.01723)
	[-3.94934]	[1.11748]	[-0.39359]
DUM89	-0.437635	0.211975	-0.049531
	(0.06283)	(0.15385)	(0.01791)
	[-6.96584]	[1.37777]	[-2.76526]
DUM92	0.146255	0.025471	0.038175
	(0.05067)	(0.12407)	(0.01444)
	[2.88667]	[0.20529]	[2.64282]
DUM04	0.176290	0.039000	0.014491
	(0.05240)	(0.12833)	(0.01494)
	[3.36422]	[0.30391]	[0.96995]
R-squared	0.818971	0.466061	0.753636
Adj. R-squared	0.746560	0.252485	0.655091
Sum sq. resids	0.047746	0.286338	0.003881
S.E. equation	0.048860	0.119653	0.013930
F-statistic	11.30996	2.182179	7.647598
Log likelihood	51.78347	25.81001	88.17580
Akaike AIC	-2.950584	-1.159311	-5.4604
Schwarz SC	-2.526251	-0.734978	-5.036067
Mean dependent	0.138505	0.061775	0.091934
S.D. dependent	0.097055	0.138393	0.023719
Determinant resid covariance	1.67E-09		
Log likelihood	169.5674		
Akaike information criterion	-9.625341		
Schwarz criterion	-8.210897		

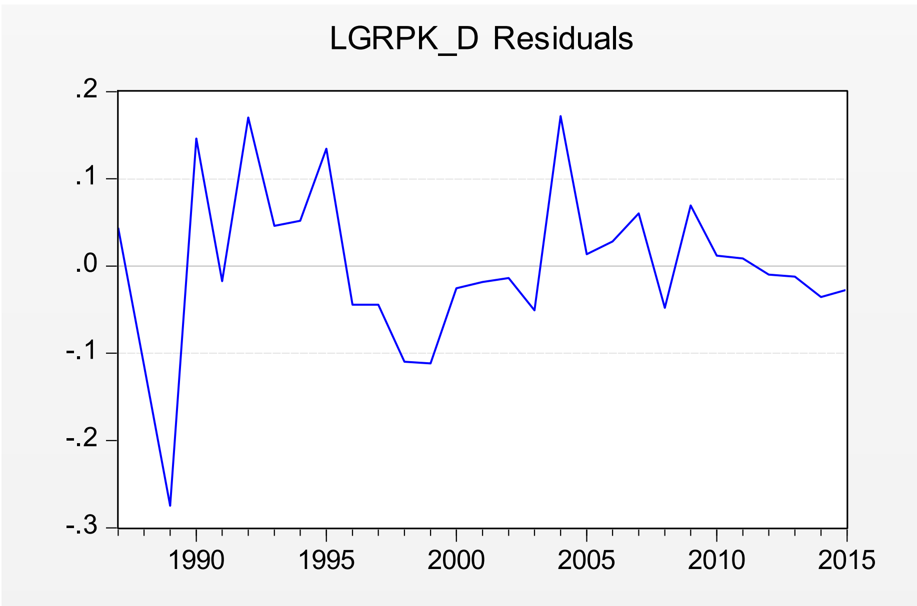


Figure 31 Residuals of domestic air passenger travel demand in the VEC model

5.5.4.2 Estimations for international air passenger travel demand

When it comes to international air passenger travel demand, Table 19 illustrates the VEC model estimation results for international air transport demand. As we can see from the table below, the coefficients' signs are correct. Also, by involving dummy variables into the VEC model, we can see that the goodness of fit has improved, with an R-squared equal to 0.88. In order to define the special event, we draw the graph of the residuals of the dependent variable of international air travel demand—LGRPK_I. As can be learned from Figure 32, several years stands out of the ordinary, 1989, 2003, 2004 and 2008. The reason why these years have unusual increase or decrease has been discussed in both Chapter 2 and previous section in Chapter 5 (Section 5.4.1).

Table 19 Vector correction model for international air passenger travel demand

Sample (adjusted): 1988 2015 Included observations: 28 after adjustments			
Standard errors in ( ) & t-statistics in [ ]			
Cointegration Restrictions:			
B(1,1)=1, A(3,1)=0			
Convergence achieved after 44 iterations. Restrictions identify all cointegrating vectors			
LR test for binding restrictions (rank = 1):			
Chi-square(1)	0.252230		
Probability	0.615509		
Cointegrating Eq:	CointEq1		
LGRPK_I(-1)	1.000000		
LGATP_I(-1)	0.717902		
	(0.25829)		
	[2.77949]		
LGGDP(-1)	-1.211536		
	(0.08478)		
	[-14.2906]		
C	13.34500		
Error Correction:	D(LGRPK_I)	D(LGATP_I)	D(LGGDP)
CointEq1	0.042174	-0.392488	0.000000
	(0.07547)	(0.15922)	(0.00000)
	[0.55882]	[-2.46504]	[NA]
D(LGRPK_I(-1))	-0.257712	-0.086437	-0.019578

	(0.18791)	(0.41687)	(0.05034)
	[-1.37150]	[-0.20735]	[-0.38895]
D(LGRPK_I(-2))	-0.194837	0.062312	-0.004484
	(0.11625)	(0.25791)	(0.03114)
	[-1.67595]	[0.24160]	[-0.14398]
D(LGATP_I(-1))	-0.094098	0.068698	-0.005452
	(0.09572)	(0.21236)	(0.02564)
	[-0.98303]	[0.32350]	[-0.21262]
D(LGATP_I(-2))	0.174003	-0.094496	0.044291
	(0.09211)	(0.20434)	(0.02467)
	[1.88914]	[-0.46245]	[1.79507]
D(LGGDP(-1))	0.704652	1.531692	0.881770
	(0.89048)	(1.97551)	(0.23854)
	[0.79132]	[0.77534]	[3.69650]
D(LGGDP(-2))	-1.71023	-0.093896	-0.450403
	(0.85469)	(1.89611)	(0.22895)
	[-2.00100]	[-0.04952]	[-1.96721]
C	0.298238	-0.101789	0.055619
	(0.07634)	(0.16936)	(0.02045)
	[3.90667]	[-0.60102]	[2.71972]
DUM89	-0.328807	-0.107104	-0.053045
	(0.08712)	(0.19327)	(0.02334)
	[-3.77434]	[-0.55418]	[-2.27300]
DUM03	-0.345923	0.085308	0.001882
	(0.06461)	(0.14334)	(0.01731)
	[-5.35387]	[0.59514]	[0.10873]
DUM04	0.245553	-0.120568	-0.007774
	(0.08346)	(0.18516)	(0.02236)
	[2.94214]	[-0.65117]	[-0.34770]
DUM08	-0.197115	0.124096	-0.023316
	(0.06988)	(0.15504)	(0.01872)
	[-2.82063]	[0.80044]	[-1.24547]
R-squared	0.884074	0.444865	0.722606
Adj. R-squared	0.804375	0.063210	0.531897
Sum sq. resids	0.059593	0.293297	0.004276
S.E. equation	0.061029	0.135392	0.016349
F-statistic	11.09266	1.165619	3.789058
Log likelihood	46.40364	24.09256	83.28559
Akaike AIC	-2.457403	-0.863755	-5.091828
Schwarz SC	-1.886458	-0.29281	-4.520883
Mean dependent	0.129859	0.025872	0.091290
S.D. dependent	0.137983	0.139885	0.023895
Determinant resid covariance (dof adj.)		1.30E-08	

Determinant resid covariance	2.43E-09
Log likelihood	158.4000
Akaike information criterion	-8.528574
Schwarz criterion	6.673003

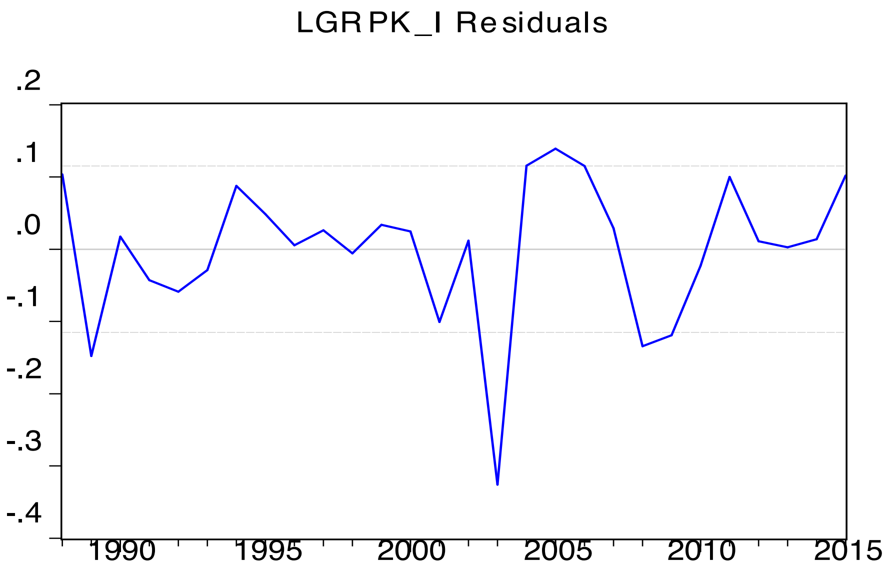


Figure 32 Residuals of international air travel demand in the VEC model

5.5.4.3 Price elasticity of demand

A variety of research, as we discuss below, has been developed regarding the price elasticity of demand (PED, Ed) in transport studies, i.e. PED in the aviation industry that measures the quantitative response of passenger demand to a change in price. According to the concept, PED can be calculated in Eq. (8) (Samuelson and Nordhaus 2010).

$$\text{PED} = \frac{\%\ Changes\ in\ quantity\ demanded}{\%\ Changes\ in\ price} \tag{8}$$

where PED is usually negative because the price is inversely proportional to quantity demanded (Gillespie 2007). The results of PED are interpreted in Table 20 (Parkin, Matthews and Powell 2005). Linear regression analysis in logarithm form is another common method to compute PED.

Table 20 Elasticity of demand interpretation

Value	Descriptive Term
Ed = 0	Perfectly inelastic demand
-1 < Ed < 0	Inelastic or relatively inelastic demand
Ed = -1	Unit elastic, unit elasticity, unitary elasticity or unitarily elastic demand
-∞ < Ed < -1	Elastic or relatively elastic demand
Ed = -∞	Perfectly elastic demand

Firstly, we divide the percentage change in RPK by the percentage change in airfares for both domestic flights and international flights. As presented in Figure 33, there is a slight decrease in the ratio between the annual percentage changes RPK and the annual percentage changes in the average ticket price for domestic flights from 1986–2015. However, there are several years stands out due to 'special events', which we discussed in section 5.4.1. In order to capture the value of the PED, we take those years out of the analysis to find out a long-run relationship between the annual changes in RPK and annual changes in airfare. The average PED is -0.43 for domestic flights and the linear forecast trend line indicates the ratio is going to decrease further. Similarly, in Figure 33, there is also a gradual drop in the ratio between the annual percentage changes of RPK and the annual percentage changes in the average ticket price for international flights during 1986–2015; however, the decrease is not significant, which indicates that PED will remain at a similar level in following years. Therefore, the average PED of the international air transport demand, -0.78, should be a convincing value.

the PED of domestic flights is not consistent with most literature that the air transportation for short-haul flights (domestic flights) is price elastic; however, the air transportation for long-haul flights (international flights) is price inelastic, which is consistent with the result we calculated based on Eq. (8). The inconsistency of the price elasticity for domestic air passenger travel demand may result from the unicity of the Eq. (8) because it does not consider any other factors that could influence the air travel demand and airfare.

The price elasticity of demand is calculated based on a simple theory above; however, it should involve a more complicated process or more factors. To be specific, not only the travel distance (short-haul or long-haul) is significant to the PED but also the travellers' purposes (business travellers and leisure travellers) are important because business travellers are less price sensitive than leisure travellers. However, there is lack of data of travellers' type, therefore, we could not include it into the calculation. Furthermore, for domestic air passenger transport, the expansion of the high-speed rail network is a critical impact factor, but unfortunately, we could not get the detailed data. To capture the elasticity, another variable was introduced in this study, namely the personal income (GDP) that significantly influences the demand for both domestic and international air travel.

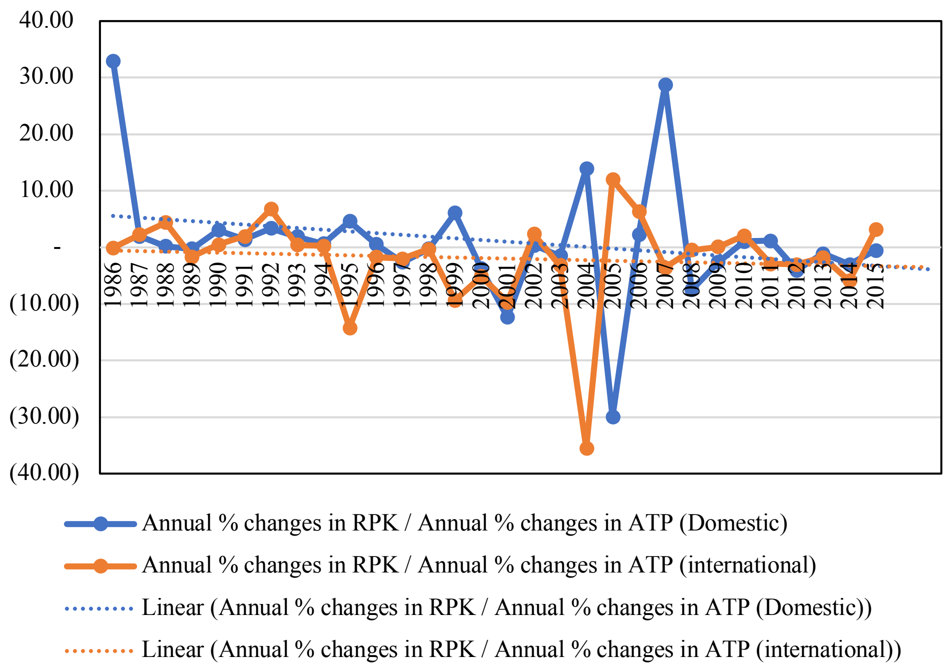


Figure 33 Annual price elasticity of demand from 1986 to 2015

Based on the previous discussion, we introduced airfare and GDP as explanatory variables into the demand model. By building the VEC model, we include both long-run and short-run relationship between the RPK and independent variables (ATP and GDP) in one mechanism, which gave us both price elasticity and income elasticity of air travel demand.

Both results of PED from two methods are presented in Table 21. It can be seen that both methods for computing PED show similar results if we take out the influence of 'special events'. However, it is still worth to run a sensitivity analysis on PED when we consider it as an input variable for the simulation model described in the following chapter because the result is not quite consistent with previous literature that we discussed below; also, some missing factors from the demand model due to the data availability may result in the limitation of the estimation of PED.

Table 21 Result of the PED during 1986–2015

	Price Elasticity		Income Elasticity	
	Domestic	International	Domestic	International
Equation	$PED = \frac{RPK_{t+1} - RPK_t}{RPK_t} \Big/ \frac{ATP_{t+1} - ATP_t}{ATP_t}$			
Result	-0.43	-0.78		
Interpretation	Inelastic	Inelastic		
Equation	$ECM = LGRPK_{t-1} + \beta_1 LGATP_{t-1} + \beta_2 LGGDP_{t-1} + \alpha$			
Result	-0.41	-0.72	1.54	1.21
Interpretation	Inelastic	Inelastic	Elastic	Elastic

The summary of a working paper from the World Bank (Oum, Waters and Yong 1990) summarised 14 studies prior to 1990 on passenger air transportation. It indicates that the PED for air passenger transport (both vocational and non-vocational) most likely ranges between -0.7 and -2.1. Another study indicates that the own-PED of international leisure air passenger transport ranges between -1.7 and -0.56, while the international business air transport ranges from -0.5 to -0.198, based on the summary of 21 studies (Gillen, Morrison and Stewart 2003). The study of Castelli et al. (2003) and Granados et al. (2012) show similar results: the PED for international leisure transport is -1.058 and the overall PED ranges from -0.45 to ~ -0.71. One of the discussion papers from the Tinbergen Institute concludes that the overall mean price elasticity, based on their set of 204 observations, is below unity at -1.146 (ranges from -3.20 to -0.21); their meta-analysis also suggests the long-run price elasticity fits in this range (Brons, et al. 2002). Also, IATA elasticity report reviewed 23 papers over the last 25 years and indicated price elasticity is a significant demand response to changes in airfare (InterVISTAS 2007). In particular, the price elasticity at the route or market level ranges from -1.2 to -1.5 and the PED will be around -0.8 if there is no route substitution term. In terms of long-haul flights, especially transcontinental routes, passenger transport is less sensitive to air ticket prices' changes, which should be around -0.6.

Although there have been various researches on the PED for passenger travel in the international aviation industry, there is no single study that explores the PED for the Chinese aviation industry only, especially for international flights. Hence, this section explores the PED for both domestic and international flights undertaken by Chinese airlines during 1986–2015. As can be seen from Table 21, PED from both equation indicate air travel demand in China is price inelastic no matter for domestic or international flights.

Regardless of the methodology, travellers for domestic flights seem to be less sensitive to price changes than travellers for international flights. This may be caused by several factors. Firstly, it may result from the lack of inclusion of the existence of alternative transportation in domestic travel. To be more specific, there are various alternatives for domestic air transport (i.e. auto travel, coach, railway, ferry). Passengers can choose from all those transportation types based on their affordability and other factors, which means they can always choose any other transportation mode if the airfare exceeds their budgets. Another reason may be the territory of China is too large and most travellers cannot travel by other transportation modes in a similar time range. For example, if a person would like to travel from Beijing to Guangzhou, it would take five hours approximately including time of arriving and leaving both airports; however, it would take around eleven hours for high-speed rail, which doubles the travel time, and it could be more if we consider the traffic impact on travel to/from the train station of each city. On the other hand, there is almost no such option to substitute international flights, especially for long-haul flights. People can choose not to travel abroad when the airfare exceeds their budgets. This is an overall result for both business travellers and leisure travellers, which means the result may differ according to different types of passengers.

5.5.3 Development of Baseline Future Scenario

We estimate the baseline activity for both domestic and international flights carried out by Chinese airlines based on the results from a historical analysis. This section explores the RPK, CO_2 emissions and revenue of the airlines. The estimation assumes that the RPK will be increased with the growth of average ticket price and national GDP.

RPK during the projected period can be derived from Eq. (6) and constructed as follow

$$\boldsymbol{RPK_t = exp\{ECM_{t+1} - \alpha - \beta_1 log(ATP_t) - \beta_2 log(GDP_t)\}} \quad (9)$$

where RPK is revenue passenger kilometre, ECM is error correction term but in the long-run equilibrium it equals to 0, ATP is average ticket price (revenue per passenger kilometre), GDP is national gross domestic products in China. The average ticket price is predicted according to historical annual growth rate. Because we use GDP as the income factor, the future GDP of China is projected based on Five Year Plan made by the State Department. However, the projection of GDP growth is actually complicated, we need to adopt a sensitivity analysis to see how different scenarios could influence future air passenger transport in China. The sensitivity analysis is discussed in Chapter 6.

The estimation results indicate that the increase in CO_2 emissions is almost as fast as the air transport demand (RPK). In particular, the RPK for both domestic and international flights in 2015 was 727,060 (555,640 for domestic and 171,420 for international flights) million passenger kilometres, which will grow to 1,027,780 (811,676 for domestic flights and 216,103 for international flights) in 2020. By the end of 2025, the RPK will reach 1,458,129 (811,676 for domestic flights and 216,103 for international flights) million passenger kilometres and keep increasing to 2,075,507 (1,732,056 for domestic flights and 343,451 for international flights) million passenger kilometres in 2030. When it meets the baseline CO_2 emissions, the emissions grow along with the increase of the RPK over the period of 2016–2030.

In 2015, aircraft operated by Chinese airlines had emitted 59.6 (45.56 for domestic flights and 14.04 for international flights) million ton of CO_2. With the annual ascendant of RPK, the CO_2 emissions will also increase dramatically. The CO_2 emissions in 2020 will be 80.06 (60.11 for domestic flights and 16 for international flights) million ton, which will rise to 108.02 (79.37 for domestic flights and 18.24 for international flights) and 146.22 (104.8 for domestic flights and 20.79 for international flights) million ton by the end of 2025 and 2030, respectively.

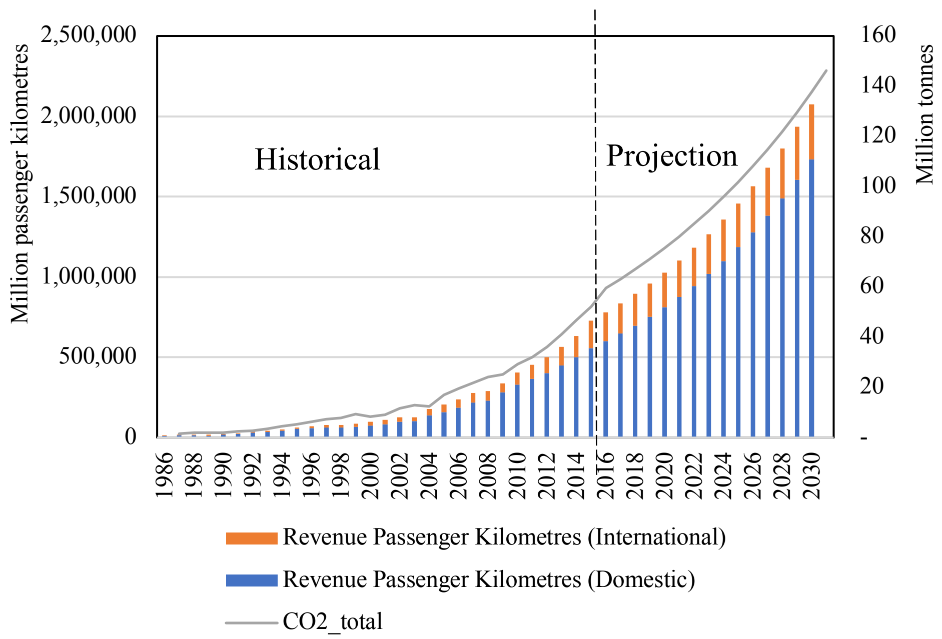


Figure 34 Baseline air passenger transport demand and CO_2 emissions

Although the total of CO_2 emissions from Chinese airlines increases along with the growth of RPK, it does not mean there is no improvement under the baseline scenario. As discussed in the methodology section, the fuel efficiency has been assumed to be improved by 1% per annum under the BAU scenario; and, this has been reflected in Figure 35. We can learn from the graph below that unit CO_2 emissions would decrease in the future if aircraft operators in China could truly make the improvement that we assumed in fuel efficiency.

Figure 34 shows that the growth under the baseline scenario is significant for both the RPK and CO_2 emissions although the unit CO_2 emissions would be improved. In this study, research attention is focussed on this increase, especially taking into account the severe issue of climate change. This explains the necessity of China to employ a mitigation instrument in its aviation industry. However, the projection of future demand and CO_2 emissions could have different scenarios due to different economic policies in China. Moreover, the assumption of the fuel efficiency improvement is a little bit conservative; therefore, the projection of future unit CO_2 emissions may differ if the passenger airline industry in China adopts other new technologies (e.g. ultra-high capacity aircraft).

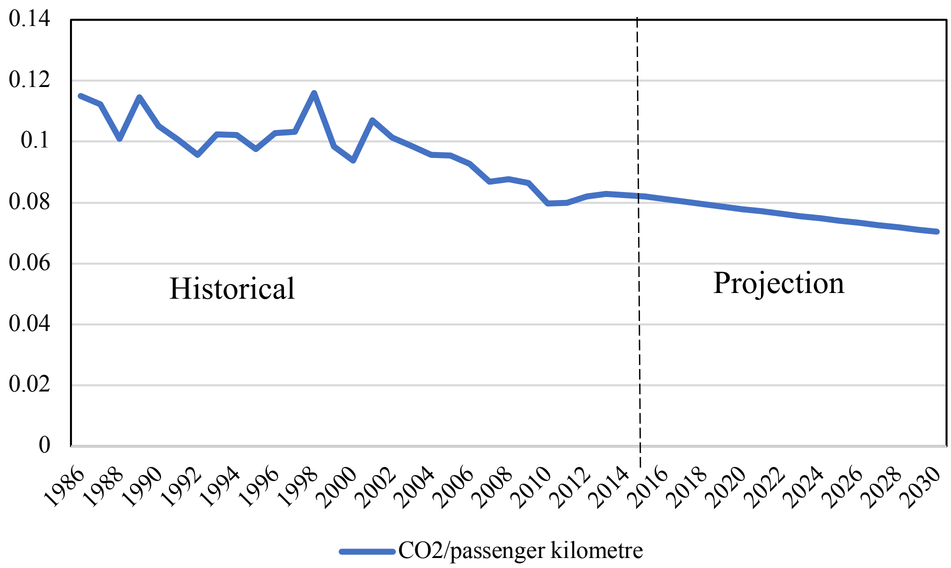


Figure 35 CO_2 emissions per passenger kilometre during 1986-2030

In comparing with other research, we can see from Figure 36 that our estimate for Chinese domestic air passenger travel demand is a little bit aggressive than others except for the ICAO's forecast. However, the reason for the high growth rate, 8.8%, in ICAO's report is there is no exact annual increase for Chinese domestic market only; thus, this section took the annual growth rate for Central South West Asia[54] into the comparison. Therefore, if we could take out the effect for flights among countries in this area and their domestic air passenger travel, the estimate from ICAO would be different.

[54] ICAO defines the Central and South-West Asia as including Afghanistan, Bangladesh, Bhutan, China, India, Kazakhstan, Kyrgyzstan, Mongolia, Myanmar, Nepal, Pakistan, Sri Lanka, Tajikistan, Turkmenistan and Uzbekistan.

Moreover, the most significant reason that could lead to the current situation is the estimation for the GDP growth in China, 7% per year, is a little bit optimistic in comparing with other research. Again, it proves we need to perform sensitivity analysis to see how different GDP growth would lead to different scenarios of CO_2 emissions growth in Chinese domestic air passenger travel.

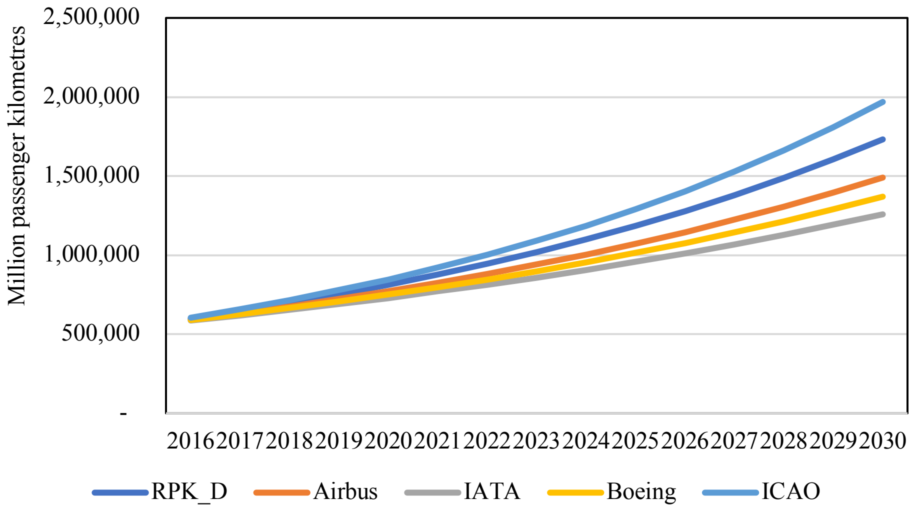


Figure 36 Domestic air passenger travel forecasts in China during 2016-2030

(Data source: Airbus 2016; IATA 2014; Boeing 2016; ICAO 2016)

Furthermore, by looking at the graph below (Figure 37), the forecast in this chapter seems a little bit conservative but it may not be true because our projection is only based on international flights carried by Chinese airlines; which means if we include foreign airlines into our analysis, the growth rate may become higher than what we have now. However, it still quite close to forecasts from other reports that the annual growth rate from/to China would increase 5-6% per annum, which indicates the estimation of our analysis should be accurate. Even though other research can confirm the result, the sensitivity analysis is still needed to test the model.

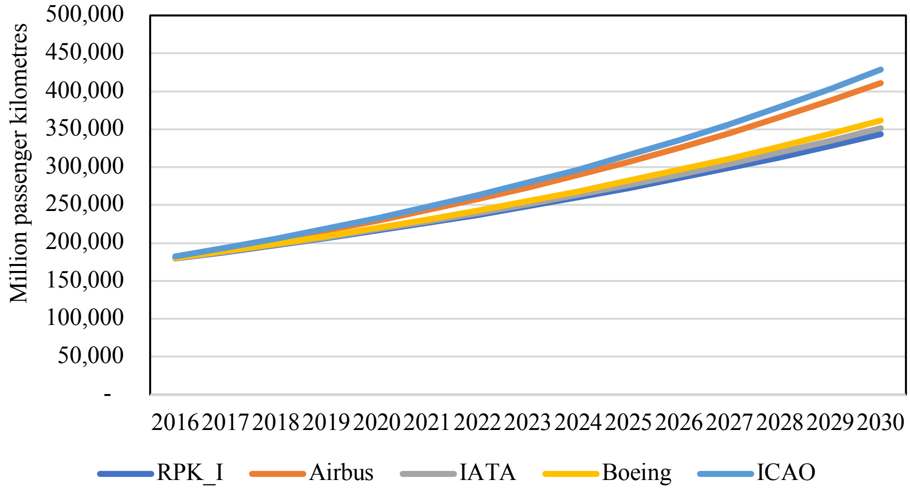


Figure 37 International air passenger travel forecasts from/to China during 2016-2030

(Data source: Airbus 2016; IATA 2014; Boeing 2016; ICAO 2016)

In summary, the market growth of the demand for both domestic and international air travel in China was stable during 1986–2015, with a slight increase of the average ticket price as well as a stable growth in GDP. An inverse relationship is found between the average ticket price and RPK, which indicates that more people would like to travel by air with lower ticket prices. The fuel efficiency analysis carried out in this study shows that the gradual growth might be caused by the developments in technology. The increase of CO_2 emissions from aircraft carried by Chinese airlines was significant during past 30 years. Without conducting effective improvements in technologies, the CO_2 emissions of the aviation industry will grow severely due to the rapid increase of demands in China.

5.6 Conclusion

This chapter has sufficiently explored several variables to investigate the historical developments of the Chinese aviation industry in both domestic and international markets. A baseline-based BAU scenario has been built in this study to predict the possible development of Chinese aviation industry in the future. According to the historical developments of Chinese airlines in both domestic and international passenger transport markets, it is learned that a steady but heavy growth has been conducted in Chinese airlines operations. Consequently, the Chinese aviation industry has caused a severe amount of CO_2 emissions in relation to both domestic and international aviation industries. Based on the baseline BAU scenario, it is also concluded that the CO_2 emitted by Chinese airlines would see strong growth if no effective mitigation instruments are launched in the near future. As discussed in Section 5.4.3, the demand module that is driven by average ticket price and national GDP shows that the growth in demand is mainly driven by the GDP, which refers to the fact that the demand for air passenger travel on Chinese airlines has highly likely been increased if economic growth in China remains rapid.

Due to limited data, this analysis is only based on the national GDP in China and average ticket prices charged by Chinese airlines and, therefore, the analysing results may vary if more variables or data are included to run a city pair analysis. In the analysis of price elasticity, the value of -0.41 (domestic flights) and -0.72 (international flights) are used as the true value for a baseline scenario projection based on a previous literature review. However, different true values are also found in the previous literature because some researches have concluded that domestic air travel is price elastic. Hence, no extra cost is attributable to an emissions abatement instrument, which will significantly impact the air travel demand. Examining the effect of price elasticity is of necessity in future research because it would affect whether emissions mitigation measures influence air passenger travel. In addition, the emissions calculations in this study are based on Tier 2 methodology; however different aircraft sizes or different aircraft engines have not been taken into account in this study due to data availability.

According to the historical analysis, price elasticity was examined using two different approaches. However, both methods show similar results, which could confirm that our analysis should be accurate under the current assumption. Moreover, the fuel consumption of aircraft engaged in air travel carried by Chinese airlines was tremendous, as shown in the historical analysis.

Consequently, CO_2 emission from Chinese airlines was also remarkable.

The baseline scenario in this chapter demonstrated that aircraft emission is likely to continue to grow strongly without any effective mitigation action. It was concluded that the aviation industry may not be able to achieve long-term sustainable growth based only on progress in technology, operations and infrastructures. Therefore, further research was suggested, focus on the future development of the Chinese aviation industry in the international market, especially under scenarios of other mitigation measures.

Chapter 6 The Impact on Chinese Airlines of Emissions Mitigation up to 2030

This chapter models cost impacts of the Chinese aviation industry by applying different mitigation options to domestic flights and international flights based on the historical analysis in Chapter 5. For domestic flights, three instruments have been considered in this chapter: emissions trading, carbon taxation and voluntary carbon offset. In terms of international flights, this chapter models the impact on it by assuming China will join CORSIA, a market-based mitigation scheme launched by ICAO. By investigating the cost impacts from different schemes, this chapter projects different scenarios about the future development of the Chinese aviation industry, which presents possible political solutions for emissions reductions in China.

6.1 Introduction

As discussed in the previous chapter, China needs more aggressive mitigation policies besides technology and operation improvements to achieve long-term sustainable growth. Carbon tax and carbon emission trading have frequently been adopted as cost-effective economic approaches to mitigate CO_2 emissions (Zhang et al. 2009). A carbon tax is a tax levied on the carbon content of fuels (Hoeller and Walline, Energy Prices, Taxes and Carbon Dioxide Emissions 1991). It will cause emitters to reduce their emissions through abatement to the extent that their marginal abatement cost is below the tax rate; thus, CO_2 emissions relies on the opportunities for and costs of reduction (Andersen and Ekins 2009).

Emission trading is a market-based approach used to control the pollution by providing economic incentives for achieving reductions in emissions of pollutants (Stavins 2011). Instead of charging all emissions, emissions trading adopts the principle called ‘cap-and-trade’, which means the regulatory authority will set a cap of total emissions that can be emitted by participants; and, allowances can be auctioned or allocated free to participating parties and can subsequently be traded (Teeter and Sandberg 2016). As discussed in Ekins and Barker (2001), there is broad equivalence between levying a carbon tax and an emission trading scheme under a precise set of restrictive assumption (Pezzey 1992, Farrow 1995). Moreover, carbon offsets, as a voluntary scheme, is a primary choice for the airline industry, and a number of carriers has implemented this approach. Carbon offsetting means passengers can voluntarily purchase CERs from CDM projects or foresting programmes to offset their own carbon footprint.

As indicated above, carbon taxation, emissions trading and carbon offsetting could have different impacts on different industries (Zhang et al. 2009), including how they are designed and implemented; therefore, caution is needed before emissions reduction policy adopted for aviation activity. In this chapter, we estimate the cost effect of different mechanisms—carbon taxation, emissions trading and carbon offsetting—in China by modelling their price impact on demand for domestic flights by Chinese airlines and the subsequent impact of this on emissions up to 2030. In addition, because any application to international flights must go through ICAO, the scenario of emissions reduction in the international aviation of China is assumed to be part of the voluntary mitigation scheme—CORSIA—which will be led by ICAO.

In this chapter, the impacts of integrating domestic flights into taxation, an emissions trading scheme and carbon offsetting on Chinese airlines are estimated by looking at different levels for the carbon tax rate, emission allowances prices and CERs prices, as well as their impacts on costs and CO_2 emissions. The impact of joining CORSIA on CO_2 emissions from international flights operated by Chinese airlines is estimated as well. Firstly, a literature review has been undertaken on the design options of different mitigation mechanisms could be applied to the Chinese aviation industry. Secondly, various models for impact assessment have been discussed to build an appropriate one for analysis in this chapter. Thirdly, scenarios are built according to different instruments and different design options for aircraft emissions abatement in China.

Moreover, we illustrate how different instruments under different design options would affect CO_2 emissions and the extra costs by running scenarios from 2016–2030. We also investigate the impacts on the demand of both domestic and international flights, RPK, the average ticket price and airlines' revenue.

6.2 Literature Review

6.2.1 Mechanism designing

6.2.1.1 Carbon taxation

As has been discussed in Chapter Four, the government places a carbon tax on CO_2 emissions, which could internalise some costs of eliminating environmental impacts caused by GHG emissions. However, there are several aspects that should be considered in designing a carbon tax, including: tax base, which sector to tax, where to set the tax rate, how to use tax revenues, how to assess the impact on consumers and how to ensure that the tax achieve emissions abatement objectives (Sumner, Bird and Dobos 2011). When it comes to which sector to tax, there is no need to discuss here because we obviously want to tax the aviation industry to reduce its GHG emissions. However, there is still the question of whether to tax the upstream or downstream of the supply chain within the industry. Barthold (1994) indicated that we should first identify which activities may be discouraged if there is a carbon tax and that provides the answer of whom to tax.

In the airline industry, the upstream may refer to aviation fuel refiners, and the downstream refers to the aircraft carriers. If the upstream means airlines, the downstream then means consumers. Mansur (2011) discusses how cost-effectiveness, transaction costs, leakage and offsets relate to the issue of regulatory vertical segment selection. The author concludes that upstream regulation could substantially reduce transaction costs. However, in the aviation industry, it is much easier to tax the airlines or consumers by looking at their consumption of fossil fuels. In the following subsections, there are discussions about tax base and tax rates, which are two factors that will be used to build future scenarios.

(1) Tax base

Firstly, in designing a carbon tax to mitigate aircraft emissions, the government needs to decide whether to tax the energy of use or to tax its corresponding emissions. According to the concept of the carbon taxation, CO_2 should be taxed directly; however, it requires accurate monitoring technologies and highly precision equipment to measure CO_2 emissions. In particular, both the technology and monitoring equipment in China cannot meet the requirement; therefore, the most possible way to implement carbon taxes in China is to tax CO_2 emissions by linking the fossil fuels that are consumed by industries (Feng 2013). This kind of tax base is easy to compute and operate as well as have lower administration costs. However, to tax CO_2 through its proportion to fossil fuels will depress the use of such energy but will not stimulate technology innovations and the use of alternative energies.

(2) Tax rate

Economists have researched the tax rate in environmental taxes to mitigate climate change. As described in Chapter Four, the principle of setting correct tax rate was established by Pigou, which is the tax rate should cover the social costs of mitigating GHG emissions. However, for various purposes, the tax rate can be set at higher levels to stimulate industries' development in environmental sustainability and raise funds for emissions reduction programmes. In addition, OECD (2010) concludes that the tax rate should cover the social cost of environmental damage.

In the context of carbon taxes and CO_2 emissions abatement, a number of recent studies have attempted to calculate the level of taxes necessary to abate emissions. By considering levels and applications across 41 OECD and G20 countries, OECD (2016) addressed that the marginal cost of climate change is very uncertain and most emissions in investigated countries are not priced or the price is meager. According to its analysis, CO_2 emissions should be priced at least at 30 EUR per tonne to be effective; however, only 10% of emissions from investigated countries are priced at or above this level. OECD (2016) also points out that it is difficult to decide the correct rates of carbon taxes, and its analysis can only provide guidelines on how to set the rate.

Metcalf and Weisbach (2009) also addressed in their analysis that the computation of the optimal tax rates is quite tricky because it involves too many uncertain factors, such as predictions of local effects of climate change, projections of future economic and technological developments. In the survey of IPCC (IPCC 2007), an average optimal tax rate at \$12 per tonne of CO_2 is summarised based on 100 different studies; however, the tax rate ranges from \$3–\$95 per tCO_2. Wisseman and Dellink (2007) prove that carbon taxes will lead to greater emissions abatement than uniform energy taxes in the case of Irish; and the carbon tax of 10–15 EUR (13.16-19.73 USD) per tonne of CO_2 emissions could achieve a reduction at 25.8% in comparing with the level of 1998. Sumner, Bird and Dobos (2011) conclude several carbon tax rates that have been set in different regions with various purposes, which clearly indicates the tax rate varies among different regions with a range of 0.045 USD–105 USD per metric tonne of CO_2.

In terms of setting the tax rate in China, some scholars addressed that it is difficult to 'copy' the tax rate that has been set for European countries since the economy in China and industries cannot afford such high extra costs. For this reason, a tax rate at 10–20 CNY (1.45-2.9 USD) per tonne is considered to be reasonable (Zheng and Fan 1999; Wang et al. 2012).

6.2.1.2 Allowances allocation for emissions trading

In carbon emissions trading schemes, there is a close relationship between the allocation of allowances and trading units, which means it could determine the cost of emission trading (Han et al. 2016). A number of researchers have debated how to allocate tradable permits for different industries, which includes grandfathering (allocating permits based historical emissions), benchmarking (giving companies allowances-based industries' benchmark) and auctioning. It is always a question of how allowances should be allocated to participants within the emissions trading scheme. Egenhofer (2007) addressed how the allocation method of allowances does not have significant impacts on the market efficiency; it is controversial is because different methods would benefit different subjects. However, an empirical assessment for Germany found that the grandfathering allocation method from the first phase (2005–2007) of the EU ETS does not have dynamic effects on the operational efficiency and employment of German companies (Anger and Oberndorfer 2008).

In a comparative analysis of the auction and grandfathering, Cramton and Kerr (2002) indicate the auction of permits is preferred over the grandfathering because it would reduce distortionary taxes, provide more flexibility of costs distribution and offer more significant incentives for innovation. Sijm, Neuhoff and Chen (2006) analysed the application of the grandfathering in the power industry that indicates the marginal profits of the power production would increase with the growth of carbon prices. This means the power industry could gain windfall profits under the emissions trading and there would be a positive relationship between their profits and EUAs prices.

In terms of the aviation industry, CE Delft (2005) compared all three allocation methods—grandfathering, benchmark and auctioning—in its analysis for the EC, which indicates there is no definite conclusion about which method is the best due to it involves various aspects when evaluating these allocation methods. However, their report presented that auctioning is preferable because it is the most efficient from an economic perspective. There is an equal treatment of new entrants and existing participants, which is considered a distinct advantage. Morrell (2007) examined how three different allocation methods would influence different types of airlines (network carrier, low-cost carrier (LCC) and leisure/charter airlines). From the impact analysis, all three allocation methods would have significant influences on low-cost carriers; especially, the grandfathering approach tends to penalise the faster-growing LCC and favour the network carrier. Auctioning is the costliest option for all airlines despite their business models. Morrell (2007) split the benchmark into LTO and cruise phases that avoid the length of distances of different flights and does not penalise low emissions smaller aircraft.

When it comes to emissions trading in China, there have been seven pilot schemes in different major cities and then the Chinese government starts to launch a nationwide emissions trading scheme by late 2017, for which the allowances are granted for all entrants based on benchmarking that is similar to the practice in the EU ETS (Zhang 2015). Cong and Wei (2010) analysed the influences of carbon emissions trading on the Chinese power sector based on two different allocation methods. They conclude, in comparing with the emissions-based allocation, that the output-based allocation is more conductive in reducing emissions from China’s power industry. Tang et al. (2015) built a multi-agent-based model to analyse the impacts on several industries by including them in the emissions trading scheme. Their model adopted two different allocation methods: grandfathering and benchmarking. By comparing these two different allocation approaches, they presented that both rules would result in a negative impact on the national GDP and carbon emissions; however, benchmarking is more aggressive, leading to larger damage on the economy and further abatement in the carbon emissions.

On the other hand, Liu et al. (2015) pointed out the accuracy should be questioned if allowances are allocated to participating companies based on their historical emissions since most Chinese firms do not keep record about how much they emitted in previous years; therefore, allowances should be granted based on enterprises’ operation and the economic growth in China. Similarly, Jotzo (2013) also concluded that free permits should be determined with the GDP in China. However, the analysis put forward that the emissions cap can be set at a flexible level, which means the Chinese government could define the cap as an absolute number of permits based on expected future GDP, and making adjustments with the real GDP of each year. Moreover, Han et al. (2017) build three different scenarios—baseline, energy saving and low carbon—for China’s road transport sector to analyse the impact of the emission trading scheme on both carbon emissions and trading costs. In their analysis, they constructed a scientific framework to allocate allowances based on carbon emissions potential, the direction of future vehicle possession, the positioning of carbon trading market, etc.

6.2.1.3 Carbon offset

Carbon offset as a voluntary approach is quite popular for the airline industry to compensate their footprints, which facilitates a series of researches. Smith and Rodger (2009) introduced five possible domestic carbon offset schemes to offset CO_2 emissions from international flights to and from New Zealand. They have been unable to identify any offsetting option that is physically or politically realistic. On the other hand, the analysis indicates carbon offset for international flights cannot only be implemented in one country but also be applied in the pair country (origin–destination).

Another solution is for passengers and companies to purchase CERs from CDM programmes in developing countries. However, over 70% of CDM projects are hosted by a few countries, such as India, Brazil, Mexico and especially China (UNFCCC 2017); therefore, their contribution is limited on local livelihood that does not improve the country of participating companies. In particular, voluntary carbon offsetting schemes becomes more and more popular with aircraft carriers to compensate their footprints. However, as addressed in section 4.2.3, there is a number of carbon offsetting schemes supplying VERs and NVERs from non-CDM projects to individuals and companies to offset corresponding carbon emissions, which gives rise to the issue of whether the efficiency and creditability are authentic (Gössling et al. 2007).

Furthermore, in the aviation sector, the efficiency of a carbon offsetting scheme is largely determined by passengers' willingness to pay (WTP). Chang, Shon and Lin (2010) conducted a questionnaire to study the WTP of passengers from two airports flying to different destinations all over the world. They concluded only 1.4% of travellers have the experience of purchasing airline carbon offset. Even if the price of carbon offsetting dropped to an unreasonable low level, less than 10% would like to pay for emissions induced by themselves. Certainly, several trip characteristics (i.e. purposes of travel, cabin classes, frequencies of travelling abroad) will dominate passengers' WTP. The knowledge about the carbon offset scheme and the trust of the airlines are essential to determine the WTP (Lu and Shon 2012).

Hooper et al. (2008) explored the WTP of passengers in two different ways: responding to the percentage of travel cost or responding to the actual amount of offset costs. From their study, 17.7% of passengers would like to pay for carbon offset when the cost showed in the percentage of total travel costs. In contrast, only 3.1% of travellers were willing to compensate their climate impacts from air travel when the cost shown in an actual amount.

As can be seen from a case study in Australia, there is a significant mean WTP for carbon reduction at 21 Australian USD per person per tonne of CO_2 reduced in the form of voluntary carbon offsets (Choi and Ritchie 2014). However, Choi (2015) also presented there is a substantial reduction in the WTP of air travellers and the payment amount of carbon offsetting when there is already a mandatory price applied. Therefore, to test the efficiency and creditability of the carbon offset scheme, both the projects adopted by airlines and the WTP of passengers are significant to consider in this chapter.

6.2.2 Methodology review

6.2.2.1 Integrated system of interacting models

The integrated system of interacting models presents a quantitative description of the air transport system and an assessment of aircraft emissions under different mitigation measures (i.e. technology innovation, operational measures and economic mechanisms) (Brok and Lépinay 2012). Several models would interact with each other in the integrated system, such as aircraft technology, air transport demand, aviation operating cost, flights and emission, airport management, local air quality and noise, and economic impact. On the other hand, this is also a system that involves several players who respond to each other's reactions under different mitigation measures. This involves policymakers, aircraft manufacturers, airlines, airport controllers and, of course, consumers. Three very famous integrated models are listed below: The Aviation Emissions and Evaluation of Reduction Options Modelling System (AERO-MS), Aviation Integrated Modelling (AIM) and Global Airline Industry Dynamics (GAID).

(1) AERO-MS

The impact of putting aviation into the current system can be estimated through different models, such as the AERO model, which was specifically designed to model the impact of policy measures on aviation emissions (European Aviation Safety Agency 2009). The Dutch government initiated the development of AERO-MS in the early 1990s. A consortium of consultants (e.g. National Aerospace Laboratory [NLR], MVA Limited [UK Transportation consultants] and TASK [Netherland]) developed AERO-MS over several phases in the period 1992 to 2001. As an integrated system of interacting models, AERO-MS involves several models: aircraft technology (ATEC) model, air transport demand model (ADEM), aviation operating cost (ACOS) model, flights and emission model (FLEM), and direct economic impacts (DECI) model (NLR, TAKS, MVA 2013).

The AERO-MS Unified Database includes the EUROCONTROL WISDOM Operations Database, which contains a detailed record of aviation movements in the Base Year. Policy measures can affect the supply side costs of the industry, which may lead to airlines increasing prices to customers. The AERO-MS forecasts the extent to which demand for air travel is reduced due to higher prices, and the changes in the structure of the global fleet with respect to fuel-efficient technology. The effects of policy options are computed relative to a future scenario, whereby a scenario reflects an expectation of autonomous developments with respect to air transport and flight activities without emission reduction options being imposed. All AERO-MS computations begin with a baseline situation representing the air transport system for the Base Year. Since 1995, the AERO-MS has formed a key part of over 20 international studies in which the results have provided a quantified basis for policy judgement related to environmental protection, such as the impact assessment of inclusion of aviation in the EU GHG emissions trading scheme (EC 2006).

As described previously, the ATEC model built up here can generate inputs for ADEM, ACOS model and FLEM. ADEM and ACOS model interact closely and then lead to the result of the DECI model. Accordingly, all economic benefits could feedback to the technology development, which would influence the simulation in the ATEC model. Clearly, each model included in the AERO-MS interacts with each other and projects future scenarios for the aviation industry under different aircraft emissions abatement measures. However, as such a complicated interacting model, the AERO-MS is hard to apply in general research due to the difficulty of obtaining so many kinds of data.

(2) AIM

AIM is an ambitious project with the goal of developing a policy assessment tool for aviation, environment and economic interactions at local and global levels, now and into the future. The architecture contains a set of integrated modules of key elements, such as aircraft technology and cost, air transport demand, airport activity, global climate and regional economic impact (Reynolds 2009). The Aircraft Technology and Cost Module simulates aircraft fuel use, emissions production and ownership/operating costs for various airframe/engine technology evolution scenarios. Air Transport Demand Module predicts passenger and freight flows into the future between origin–destination city pairs within the global air transportation network. The Airport Activity Module investigates operations within the vicinity of the airport and calculates delays and future airline response to them (e.g. via re-routing or rescheduling). Aircraft Movement Module simulates airborne trajectories between city–pairs and accounts for inefficiencies and delays for given air traffic control scenarios.

Global Climate Module investigates global environmental impacts of the aircraft movements in terms of multiple emissions species and contrails. The Local Air Quality and Noise Module investigates local environmental impacts from a dispersion of critical air quality species and noise from take-off and landing operations. Regional Economics Module investigates positive and negative economic impacts of aviation in various parts of the world.

These modules are under development within AIM (currently using a 2015 base year) and build upon existing, proven capabilities within the Institute of Aviation and Environment. The architecture of interacting modules is designed to capture major interdependencies and for different trade-offs to be examined, for example between competing for environmental and economic metrics (Reynolds et al. 2007). Policy assessment can be conducted by imposing policy effect on the upstream modules and following impacts through the downstream modules to the output metrics, which can then be compared to a baseline case. Similar to the AERO-MS, it is also hard to be applied in general research due to data availability. It is difficult to say whether the built-in baseline year of data can meet most researchers' demand. If it does not suit the users' needs, the revision of the model and the renewal of the base year data are difficult for some researchers.

(3) Aviation Dynamics Model

The GAID model is derived from system dynamics, also called industrial dynamics, which is a methodology and mathematical modelling technique for framing, understanding, and discuss complex issues and problems (Radzicki and Taylor 2008). It was originally developed at the Massachusetts Institute of Technology (MIT) to help analyse complex problems in business and management (Forrester 1961). The system dynamics model is also well suited for modelling transportation systems (Abbas and Bell 1994). In an OECD (1974) report, the system dynamics was first applied to the transport modelling; the urban dynamic development model was structured basing on Forrester model.

The dynamics that describe the global air transportation system are governed by feedback and time dependencies, stakeholder interactions and decision processes, and non-linearity that make it hard for simple extrapolation models to capture and test future dynamics of the system (Sgouridis, Bonnefoy and Hansman 2011). Significant research interest in the aviation system complexity was generated by the dynamic density, which would be used to define situations that were so complex that centralized control was required (RTCA 1995). Windermere Inc. proposed a measure related to the cognitive workload of the controller without knowledge of the intents of the aircraft for perceived complexity air traffic control (Windermere Inc. 1996). Laudeman et al. (1998) from NASA have developed a metric called 'Dynamic Density' which is more quantitative than the previous one and is based on the flow characteristics of airspace. Efforts to define 'Dynamic Density' have identified the importance of a wide range of potential complexity factors, including structural considerations (Sridhar, Seth and Grabbe 2001). The significance of including structural consideration has been explicitly identified in recent work at EUROCONTROL.

The GAID model extends the system dynamics structures used in the aviation system modelling, as presented by Weil (1996), Lyneis (2000) and Liehr et al. (2001). It is extensively described in Sogouridis (2007). The model represents the dynamic interactions between the primary aviation industry stakeholders, including aircraft manufacturers, airlines and passengers. The GAID model is intended to emulate the key dynamics of the industry while also allowing for experimentation with alternatives that would cause structural changes to the system. It was intended for high-level policy analysis rather than detailed forecasting. This approach is based on a portfolio of mitigating measures and policies spanning across technology and operational improvements, use of biofuels, demand shift and carbon pricing requirements to transition the air transportation industry close to an operating point of environmental and mobility sustainability (Sgouridis, Bonnefoy and Hansman 2011).

In comparing AERO-MS and AIM, the GAID model is an integrated system on a smaller scale because it only includes interactions within the aviation industry, which will not include local authorities and national governments. Therefore, unlike the AERO-MS and AIM, most researchers can adopt it. Moreover, it is easier to revise an interaction model in a small range (i.e. GAID) according to different users' needs than the other two models.

6.2.2.2 Route-based analysis model

Modelling the EU ETS requires an estimation of both CO_2 emissions based on European fuel consumption and the corresponding transport performance in passenger-kilometres/tonne-kilometres. This is a difficult mission because there are no detailed and publicly available statistics regarding CO_2 emissions in the European aviation sector so far. Most studies estimate the CO_2 emissions from aircraft relying on the flights' schedules and aircraft performance from Official Airline Guides (OAG), which is also called a route-based analysis.

For the simulation model based on flight schedules to estimate CO_2 emissions, their methodologies are similar. First, they combine worldwide flight schedules from the OAG with aircraft performance software (Schaefer, et al. 2010). Second, they simulate cost and demand implications for selected airlines on some certain routes (Albers, Bühne and Peters 2009). Third, they estimate current and future CO_2 emissions, the costs of acquiring allowances and the demand-side effects of different airline strategies to shift the cost burden onto passengers (Scheelhaase and Grimme 2007).

The analysis of Scheelhaase and Grimme (2007) focussed on the short-term impacts on different types of carriers within the EU, including full-service, low cost, holiday and regional airlines. Three options are developed under the model to estimate the effects by varying allowances prices, initial allocation methods and growth rates. Furthermore, a route-based analysis is conducted to estimate the impacts of the EU ETS on selected European airlines by exploring hub effects for certain routes (Albers, Bühne and Peters 2009). Individual routes are selected based on two criteria: the typical flight patterns through, to and from Europe and the extent variance in ETS-effects on different routings between similar origin and destination pairs should be reflected. By comparing the policy-induced effects on airlines in some certain routes having direct flights, indirect flights through the EU hub, and indirect flights through the non-EU hub, the model is enabled to simulate whether the hub effects within the EU ETS would cause airline network reconfigurations.

Schaefer et al. (2010) describe a simulation model for the economic impact of the EU ETS based on flight schedules for passenger and cargo air traffic coupled to an aircraft performance module via software called VarMission. The application of VarMission software indicates the study here considers the emissions from aircraft are different in different flying phases, including taxiing on the ground, take-off, climb, curies and descent flight phases. The simulation model here focussed on the assessment of cost impacts. It excluded the demand effect which is obviously could be induced by the price increase and the price elasticity of demand. Moreover, this forecasting model increases frequencies on existing routes but does not take into account potential impacts of the EU ETS on airline strategies concerning aircraft size, frequencies or the discontinuation of existing routes.

6.2.2.3 Elasticity-based model

From previous research, there is also much work to estimate the demand impacts causing by the inclusion of aviation into the EU ETS. The principal source for passenger demand forecasting parameters is the Passenger Demand Forecasting Handbook, which provides guidance on the preparation of passenger demand forecasts and gives the best estimates of demand effects that can be made at the moment (Department for Transport, UK 2010). To analyse the impact on airlines of bringing intra-EU flights within an emissions trading regime, an elasticity-based spreadsheet-modelling framework was adopted (BAA External Emissions Trading Steering Group 2003). In this analysis, it is assumed that flights between uncongested airports prices at marginal cost, while flights to and from congested airports adopt a demand clearance pricing strategy. The framework building here also takes into account the various effects that such a scheme would have and compares the outcome with a system of charge for emissions, which could offer a quantified result to present which scheme is more appropriate for the aviation emissions abatement.

Vespermann and Wald (2011) built a simulation model to study how the EU ETS would influence the air transport demand and its correspondent CO_2 emissions. The projection of future air passenger travel demand in this model is totally based on the price effect, which is to study the function of the price elasticity of demand. However, the future demand growth cannot be estimated just based on the PED and a general assumption of the market growth. The previously mentioned air transport demand in the AERO-MS also includes macroeconomic and demographic development in the future demand forecast (Brok and Lépinay 2012). Furthermore, the air transportation demand module in the AIM involves more factors to simulate future air passenger demand based on route-based analysis, which not only involves the national GDP and population of the city pair but also involves whether each city is a special city or there is alternative transport mode between each city pair (Dray, et al. 2010). Even though each demand model in air passenger traffic includes different independent variables to explain how future demand will increase, all of them are elasticity-based models and all include airfare. Therefore, the elasticity-based model is a quite common way to predict future air travel demand associating with extra costs from economic instruments.

6.2.2.4 Computable general equilibrium (CGE) model

CGE models are a class of economic models that use actual economic data to estimate how an economy might react to changes in policy, technology or other external factors (Dixon and Jorgenson 2012). The model is a standard tool of empirical analysis, and it is widely used to analyse the aggregate welfare and distributional impacts of policies whose effects may be transmitted through multiple markets, or contain menus of different tax, subsidy, quota or transfer instruments (Wing 2004). The modelling was used earlier in the area in environmental regulation may be able to be found in studies from Weyant (1999), Bovenberg and Goulder (1996), and Goulder (2002).

In general, the CGE model is commonly used for estimating the economic reactions for the environmental taxation application.

However, Winchester et al. (2011) employ version 4 of the Emissions Prediction and Policy Analysis (EPPA) model (Paltsev, et al. 2005) to analyse of the policy by summing that the cap-and-trade programme applies to all sectors. EPPA is a recursive dynamic, CGE model of the global economy that links GHG emissions to economic activity. Following Winchester et al. (2011), there is a study assesses the impact of the EU ETS on aviation by linking an economy-wide CGE model with a partial equilibrium model that focuses on the aviation industry (Malina, et al. 2012).

By using a CGE model, the analysis explored the impact of the EU ETS on fuel prices and GDP and simulated the impact of changes in these variables in a partial equilibrium model of the aviation industry. To investigate the impact of the EU ETS on US aviation, there is a comparison analysis under three scenarios with a reference case (BAU). The CGE model can figure out the interaction between each industry under economic mitigation instruments, which other previously mentioned models could not achieve.

In summary, even most models mentioned above could assess various impacts of including the aviation industry in aircraft mitigation schemes, it does not give the purpose of my thesis. The research here places focus on cost impact only, which means air travel cost and extra cost from aircraft mitigation schemes are the most important factor that could influence aircraft emissions. Also, as the industry is dynamic, if there is one factor changes that would definitely lead to other factors within the industry to change. Therefore, a cost elasticity based dynamic model should be the most appropriate model to assess the cost impact on Chinese passenger airlines of their inclusion in aircraft mitigation schemes.

6.3 Methodology

6.3.1 Simulation model

This chapter models both domestic flights and international flights carried by Chinese airlines in a carbon constraints age. In particular, this chapter examines the impacts of applying a carbon tax and, alternatively, joining a carbon emission trading scheme or voluntary carbon offsetting scheme on baseline emissions from domestic flights. We model the effect of carbon taxation or the additional cost of purchasing emissions permits or CERs by modelling the price impact on the travel behaviour of domestic flights and the influence of this on future emissions. Although CERs will not exist anymore after 2020 due to the expiration of Kyoto Protocol by then, we just use it as an instrument to evaluate cost impacts of the carbon offsetting. Airlines could purchase credit to offset their carbon footprints from any carbon markets.

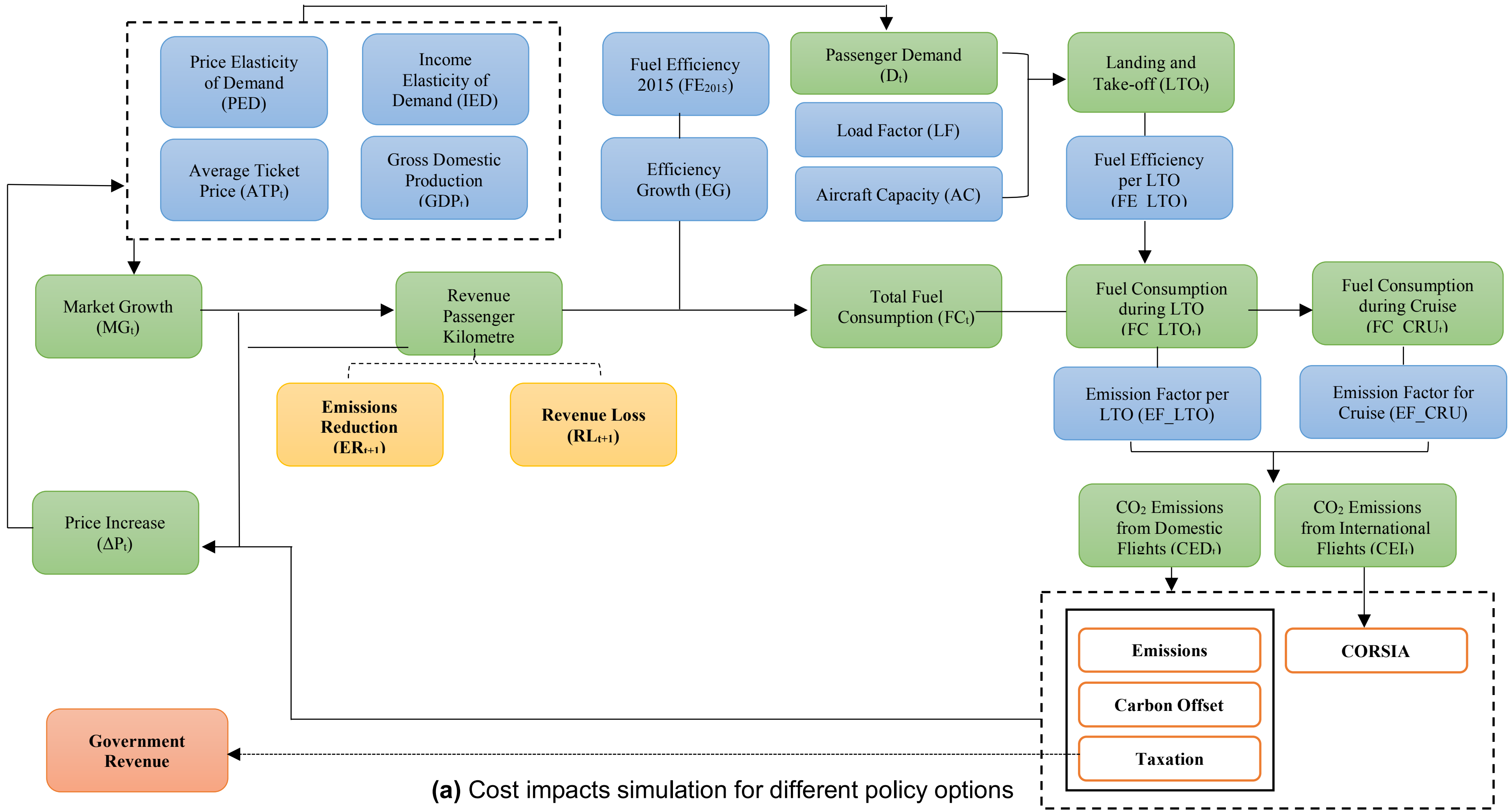
For cost impact calculation, all studies in this chapter assume that the cost of paying a carbon tax and purchasing CO_2 allowances or CER is fully passed on to consumers, causing an increase in airfares and reduce in demand. When it comes to international flights, this chapter models the impact of joining the international aviation mitigation scheme led by ICAO—CORSIA on its future emissions, which means this chapter examines the effectiveness of CORSIA in CO_2 emissions offsets from international flights operated by Chinese airlines. We perform sensitivity analysis on a number of factors that could influence the effectiveness of each mechanism, including price elasticity of demand, market growth (GDP growth and population growth), fuel efficiency improvement and WTP for carbon offset. Applying these three instruments during the period of 2016—2030, RPK of each would be affected by previous year; therefore, both revenues and emissions project to be influenced in some way.

Previously, there have studies to investigate the impacts on input and output by applying carbon tax and the impact on cost, profit, demand and supply by applying carbon emission trading scheme. Most were using simulations as the major estimation method, which we do in this chapter. The simulation model built in this chapter includes carbon offsetting. Referring to the past literature, air travel demand can be projected based on several factors, such as the national GDP, population, personal income, airfare, travel time, etc.; therefore, the model presented in Figure 38 includes average ticket price and GDP to be the independent variables to project future air travel demand due to the availability of data. As addressed in Chapter Five, CO_2 emissions are calculated based on two flying phases—LTO and cruise—which requires the simulation model to involve computation of the LTO numbers. As an industry dynamics model, although the model presented below does not include specific future aircraft technologies and the use of alternative fuels, it assumes that the fuel efficiency of the Chinese airline sector will be improved by 1% annually. There are sixteen input variables (blue box) and eighteen calculate variables (green, yellow and red boxes) in total from both Figure 38 (a) and (b) which are performed in Matlab. The subscript t stands for the period over 2016–2030. As CORSIA will start to work in 2021, the study then assumes that no economic measures will be applied to international flights operated by Chinese airlines from 2016–2020.

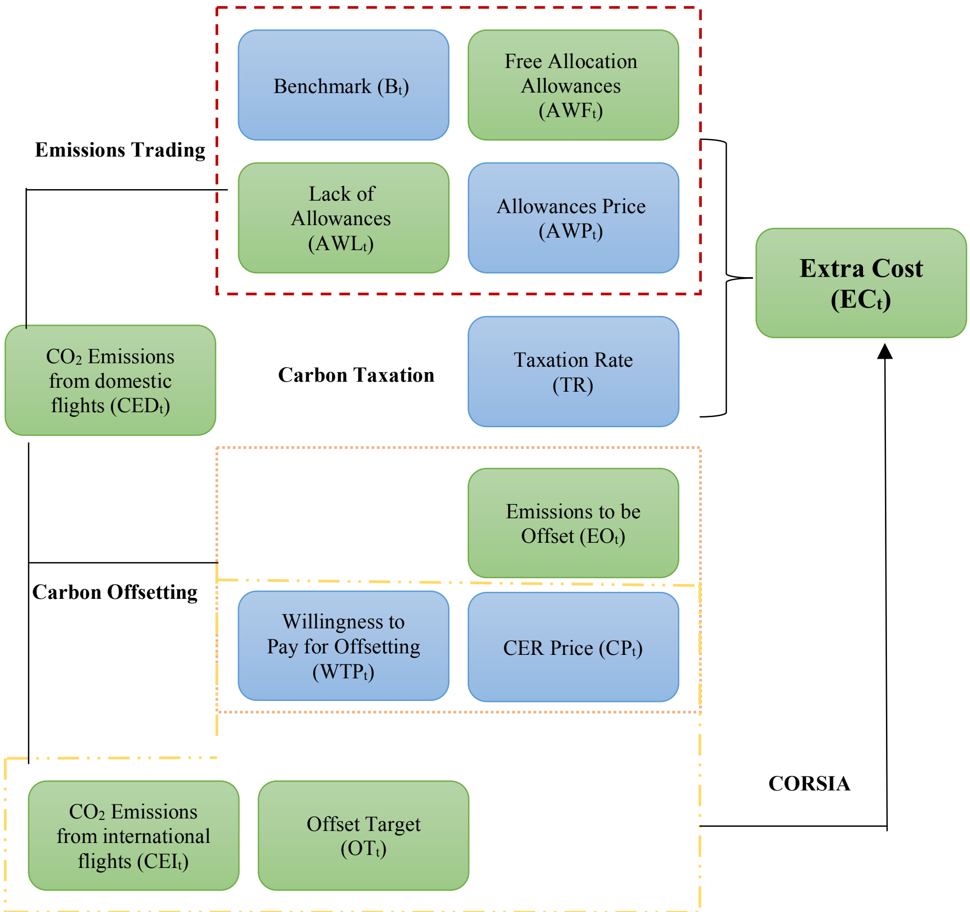
As we can see from the model, there are a number of variables, from which we can gain the input variables in blue boxes from historical analysis or public database and then we can calculate the others in green, yellow and red boxes. Firstly, we can get the future market growth by imposing it to the demand model that involves average ticket price, personal income, population and their corresponding elasticities of demand. Then, we could project future passenger numbers and RPK based the market growth and the level of both in 2015. By multiply the RPK and projected fuel efficiency, we can get the total fuel consumption of Chinese airlines. Also, future passenger numbers can be divided by the load factor, which would give the result of total available seats up to 2030; and, divided the total available seat numbers with the average aircraft capacity, we can get the total number of LTO. In addition, we can learn how much CO_2 that Chinese airlines emitted in the given year based on total fuel consumption, number of LTO, and corresponding emissions factor for LTO and cruising phases for domestic and international flights. By modelling cost impacts of different mechanisms, we can finally get the result of emissions reductions and airline revenue losses.

To be more specific, we list the result of the input variables in the following table and additionally, the calculation and data source of each input variable expresses in Table 22. In addition, the table shows the elasticities of demand for the RPK demand and the passenger demand separately, which, because average ticket price and GDP would influence the RPK and passenger numbers in different levels.

For the cost estimation model shown in Figure 38(b), the simulation model assumes airlines will pass all extra costs from paying carbon taxation or purchasing emission permits onto consumers, which could affect the demand in the next year. In contrast, carbon offsetting, as a voluntary approach, will not affect the air travel demand for air passengers because the cost of offsetting CO_2 emissions is fully depending on travellers' WTP. This means that for people who would like to pay, the cost will not affect their decision on whether to travel by air in this aspect. In addition, the model will show the result of emission reduction and revenue loss because of the decrease of demand due to the ETS and carbon taxation; and, the model will present emission reductions under different scenarios about how many passengers would like to pay. The calculation equations are presented in Table 23.



(a) Cost impacts simulation for different policy options



(b) Cost estimation for specific policy options

Figure 38 Simulation model of cost impacts from carbon tax, emissions trading, and carbon offsetting

Table 22 Values of input variables

Variables	Name	Value Domestic	International	Data source
PED	Price Elasticity of Demand (RPK)	-0.41	-0.72	Chapter Five
	Price Elasticity of Demand (passenger number)	-0.47	-0.27	
ATP[55]	Average Ticket Price	ATP_{2015} = 0.468 CNY/RPK (0.07 USD/RPK)	ATP_{2015} = 0.746 CNY/RPK (0.11 USD/RPK)	Chapter Five
IED	Income Elasticity of Demand (RPK)	1.54	1.21	Chapter Five
	Income Elasticity of Demand	1.51	1.27	

[55] ATP is not the actual ticket price sold on the market because the data is unavailable. This is the average revenue per passenger kilometre.

	(passenger numbers)			
GDP	Gross Domestic Production	GDP_{2015} = 1648.97 CNY (239.59 USD)		National Bureau of Statistics of China
FE_{2015}	Fuel Efficiency of 2015	0.026/RPK		CAAC Statistics
EG	Efficiency Growth	1%		ICAO
LF	Load Factor	75.59%	65.59%	CAAC Statistics
AC	Aircraft Capacity	250	300	IPCC
FE_LTO	Fuel Efficiency per LTO	850kg/LTO	2500kg/LTO	IPCC
EF_LTO	Emissions Factor per LTO	2680kg/LTO	7900kg/LTO	IPCC
EF_CRU	Emissions Factor during Cruise	3150kg/ton		IPCC
B_t	Benchmark	To be set in Section 6.3.2		
AWP_t	Allowances Price	To be set in Section 6.3.2		
TR	Taxation Rate	To be set in Section 6.3.2		
WTP_t	Willingness to Pay	To be set in Section 6.3.2		
CP_t	CERs Price	To be set in Section 6.3.2		

Table 23 Calculation equations

Variable	Descriptive Term	Equation
D_{t+1}	Demand Changes in %	$D_{t+1} = \Delta P_{t+1}/ATP_t \times PED$
$RPK\_baseline_t$	RPK under the Baseline Scenario	$RPK_{baseline_t} = \exp\{e + \log\beta_1 ATP_t + \log\beta_2 INC_t\}$
MG	Market Growth	$MG = \frac{\sum(RPK_{baseline_{t+1}} - RPK_{baseline_t})}{RPK_{baseline_t}} \times \frac{1}{n}$ [56]
RPK_{t+1}	Revenue Passenger Kilometres	$RPK_{t+1} = RPK_t \times (1 + MG + D_{t+1})$
FC_t	Fuel Consumption	$FC_t = RPK_t \times FE_{2015} \times (1 - EG)^{t-2015}$

[56] In this equation, the subscript t denotes the given year, t+1 means the year following. And the divisor n is the total number of years of the future time period (2016-2030).

$PD\_baseline_t$	Passenger Numbers under the Baseline Scenario	$\mathrm{PD\_baseline_t = exp\,\{e + log\beta_1 ATP_t + log\beta_2\}}$
PD_{t+1}	Passengers Numbers	$\mathrm{PD_{t+1} = PD_t \times (1 + \frac{\sum(PD\_baseline_{t+1} - PD\_baseline_t)}{n} + D_{t+1})}$
LTO_t	Landing and Take-off	$\mathrm{LTO_t = PD_t/LF\ /AC}$
CED_t	CO_2 Emissions from Domestic Flights	$\mathrm{CED_t = LTO_t \times EF_{LTO} + \frac{FC_t -\ LTO_t \times FE_{LTO}}{1000} *\ EF_{CRU}}$
CEI_t	CO_2 Emissions from International Flights	$\mathrm{CEI_t = LTO_t \times EF_{LTO} + \frac{FC_t -\ LTO_t \times FE_{LTO}}{1000} *\ EF_{CRU}}$
AWF_t	Allowances Free	$\mathrm{AWF_t = RPK_{2015} \times B_t}$
AWL_t	Lack of Allowances	$\mathrm{AWL_t = CED_t - AWF_t}$
EO_t	Emissions to be Offset	$\mathrm{EO_t = CED_t \times WTP_t}$
OT_t	Offset Target	$\mathrm{OT_t = \%100 \times (CED_t \times sector\ growth\ in\ year\ t)) + 0\% \times (CED_t \times airline\ growth\ in\ year\ t)}$ $\mathrm{OT_{2030} = \%100 \times (CED_{2030} \times sector\ growth\ in\ 2030)) + 20\% \times (CED_{2030} \times airline\ growth\ in\ 2030)}$
EC_t	Extra Cost	Emissions Trading: $\mathrm{EC_t = AWL_t \times AWP_t}$ Carbon Taxation: $\mathrm{EC_t = CED_t \times TR}$ Carbon Offsetting: there is no extra costs for airlines CORSIA: $\mathrm{EC_t = (OT_t - CEI_t \times WTP_t) \times CP_t}$
ΔP_t	Price Increase	$\mathrm{\Delta P_{t+1} = \frac{EC_t}{RPK_t}}$
ATP_{t+1}	Average Ticket Price	$\mathrm{ATP_{t+1} =\ ATP_t +\ \Delta P_{t+1}}$

ER_{n+1}	Emission Reduction	Carbon Taxation & ETS: $ER_{t+1} = CE\_baseline_{t+1} - CED_{t+1}$[57] Carbon Offsetting: $ER_{t+1} = EO_{t+1}$ CORSIA: $ER_{t+1} = OT_{t+1}$
RL_{t+1}	Revenue Loss	Carbon Taxation: $RL_{t+1} = Revenue\_baseline_{t+1} - RPK_{t+1} \times ATP_{t+1} - EC_t$[58] Emissions Trading: $RL_{t+1} = Revenue\_baseline_{t+1} - RPK_{t+1} \times ATP_{t+1}$ Carbon Offsetting: there is no revenue loss because there are no extra costs for airlines

6.3.2 Future scenarios

According to 'The Thirteenth Five Year Plan' for the Chinese aviation industry, the reduction target for aviation emissions in 2016–2020 is 4% lower than the average unit emissions (CO_2 emissions per tonne kilometre) from 2011–2015, which can be achieved by the improvement of fuel efficiency solely. This means there is no need for any other mitigation policies besides what has been applied to the industry already. However, China needs more ambitious reduction targets for the following decade to achieve its commitment in Paris Agreement. Reaching the emissions peak at 2030 means other mitigation options, aside from improvements in technologies and operations, are needed. Moreover, there are three scenarios from the model above: one is applying a carbon tax, referring to S_{CT}; the second is applying an emission trading scheme, referring to S_{ETS}; and the final option is voluntary carbon offsetting, referring to S_{off}. Numerous studies have been processed to discuss the impacts of reducing CO_2 emissions by applying a carbon tax. These analyses indicate that a carbon tax has been introduced in different countries with varying degrees of success (Di Cosmo and Hyland 2013).

The case study in European countries provides that only in Finland did the carbon tax cause a significant abatement of CO_2

57 $CED\_baseline_{t+1}$ means CO_2 emissions from domestic flights in a given year under the baseline scenario has been projected in Chapter 5.

58 $Revenue\_baseline_{t+1}$ represents airline revenues in a given year under the baseline scenario has been projected in Chapter.

emissions (Lin and Li 2009). In 1990, Finland was the first country in Europe to introduce a CO_2 tax (Andersen and Ekins 2009), where transport fuels were already subject to energy taxes (Nordic Council of Ministers 1994). To be more specific, the CO_2 tax rate was set at approximately 1.2 EUR (1.58 USD[59]) per tonne CO_2. It has been gradually increased thereafter, reaching approximately 18 EUR (23.68 USD) per tonne CO_2 in 2003 and 20 EUR (26.31 USD) per tonne CO_2 in 2008 (Andersen and Ekins 2009). The OECD (2011) pointed out that the simple average effective tax rates on CO_2 from aviation fuels cross OECD countries is 23 EUR (30.23 USD per tonne CO_2 through their analysis. However, in their latest release—Taxing Energy Use 2015 (OECD 2015)—the weighted effective tax rate on CO_2 from aviation fuels cross all OECD countries and its partner economies is only 5.64 EUR (7.42 USD) per tonne CO_2. This is due to the large range among all investigated countries, in which the average tax rate on transport CO_2 in Brazil is zero and the tax rate is 263 EUR (345.99 USD) in the UK. They predict the effective tax rates for China should be 19.94 EUR (26.19 USD) per tonne of CO_2 from the non-road transport sector. Consequently, carbon tax rate in this chapter has been set at three different levels 90, 180 and 270 CNY (13.07, 26.15 and 39.23 USD) per tonne CO_2 emissions during 2016–2030 to make the carbon tax mechanism to be effective in reducing CO_2 emissions.

Furthermore, as mentioned above in the introduction, this chapter selects the mechanism of EU ETS as the reference to design the emission trading mechanism, which means benchmarking rather than grandfathering has been applied to decide the free allocation allowances. There are three trading phases from 2016–2030 in this study: phase I is from 2016–2020, phase II is from 2021–2025 and phase III is from 2026–2030. According to the EC and EEA Joint Committee decisions (EC 2011), the benchmark should be calculated by dividing the total annual amount of free allowances available by the sum of tonne-kilometre data, which is RPK in here. The annual average of CO_2 emissions for air transport travel in the period from

[59] The average exchange rate of EUR/USD in 2011 is 1 EUR = 1.31555 USD.

2011–2015 establishes the baseline for historical domestic aviation emission in this chapter, which has been calculated at 37.33 million tonnes. As a result, the cap on total allowances for phases I, II and III could be set at 35.46, 33.59 and 31.73 million tonnes per year, respectively, which equates to 95%, 90% and 85% of historical emissions, respectively.

For the basis of the benchmark, this chapter grants 82% of the allowances for free to aircraft operators and 15% are auctioned. The balance of 3% is held in a special reserve for later distribution to fast-growing aircraft operators and new entrants in the market (No 87/2011) for the first trading period. Then, during the second trading period (2026–2030), 77% of the allowances are granted for free to aircraft operators and 20% are auctioned. The balance of 3% is held in a special reserve for later distribution to fast-growing aircraft operators and new entrants in the market. Similarly, 3% of the allowances are still held for fast-growing carriers and new market entrants, and 72% are granted for free to airlines. Therefore, each airline could receive 0.0523, 0.0466 and 0.0411 allowances, respectively, per 1,000 passenger kilometres flown on domestic flights in three different trading phases, independently.

Furthermore, a random series of numbers have been generated for allowances prices, which complies with normal distribution at $\sim N(49, 30.38)$, $\sim N(213, 30.38)$, and $\sim N(377{,}30.38)$ in CNY ($\sim N(7.13, 0.64)$, $\sim N(14.53, 0.64)$, and $\sim N(29.06, 0.64)$ in USD) per tonne CO_2 emissions to optimise the effectiveness of ETS in emissions abatement. The baseline price, $\sim N(49, 30.38)$, is set upon the average dealing price for BEA (Beijing Emissions Allowances) at China Beijing Environment Exchange (CBEE) during 2014–2017. The involvement of the normal distribution is to test whether the fluctuations of allowances' price would affect the modelling result. As we can see from Figure 39, if the future allowance price would change at the historical trend, the fluctuation would not be obvious in the future. However, if the future allowance price would change more rapidly due to the new entrants to the carbon market, the modelling result would change accordingly.

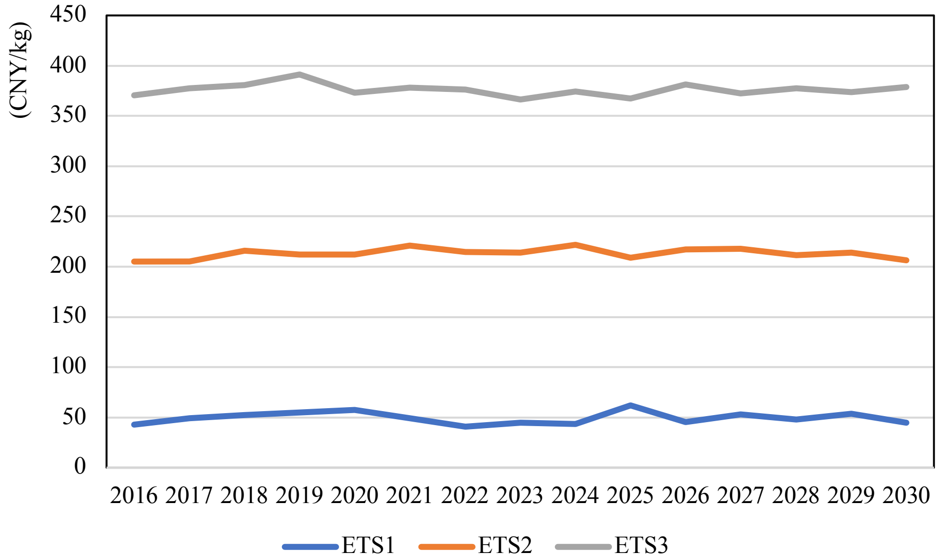


Figure 39 Future carbon allowance price under three different assumptions

In terms of the voluntary carbon offsetting scheme, there are several studies about applying it to different industries. However, there is lack of reference for implementing offsetting on the aviation industry, which has been discussed in Chapter Four. As there is lack of data about CER prices in the CBEE, this chapter assumes Chinese airlines will purchase CERs from International Exchange (ICE) to offset their footprints. The reason why we choose the CERs over VERs and NVERs is CERs produced from CDM projects are more reliable, which will not lead to debates about whether the offset scheme is credible.

As can be seen in Figure 40, the price of CERs decreased dramatically since 2011 and reached at the bottom in 2013. After that, the CER price keeps at a very low level, which complies with $\sim N(3.08, 1.18)$ in Chinese CNY ($\sim N(0.45, 0.02)$ in USD). Therefore, in scenario for carbon offsetting, the CER price has been set into three different levels $\sim N(3.08,1.18)$, $\sim N(35.62,0.66)$, and $\sim N(94.55, 1.84)$ in CNY ($\sim N(0.45,0.02)$, $\sim N(5.17, 1)$, and $\sim N(13.74, 0.04)$ in USD). When it comes to international flights operated by Chinese airlines, this chapter assumes China will join CORSIA voluntarily at the beginning of 2021. To simplify the calculation process, we assume Chinese airlines will purchase CERs generated from CDM projects in International Exchange to offset their footprints for international flights. Therefore, CER prices have been set for domestic flights and can be applied to here directly. As we have addressed in Section 6.1, although the CER will be expired after 2020, we just use it as an instrument for modelling; and, aircraft carriers can purchase credits from any carbon market, i.e. EU ETS.

WTP is another factor that should be considered in scenario analysis of carbon offsetting scheme. Several pieces of research have been conducted to investigate passengers' WTP on domestic and international flights and they have been discussed in the literature review. Based on past studies, the WTP of offsetting carbon footprints for passenger flights is less than 10%; even travellers realised the aviation industry contributed to a certain proportion of global GHG emissions and the offset price is quite low. WTP varies due to different levels of public education and personal income; therefore, WTP can be expected to grow during the projection period due to comprehensive public education and increasing personal income.

This chapter assumes WTP from 2016–2030 will be 0%–20% under the first price scenario, 0%–15% under the second price scenario, and 0%–10% under the third price scenario. Furthermore, there is a difference between the carbon offset applied to domestic flights and international flights. For the domestic flights' passengers, this chapter assumes they will purchase CERs to offset their own footprint voluntarily, which means there is no extra cost for airlines to pass to travellers by way of increasing the airfare in the following year. Therefore, passenger demand for domestic flights will not decline because passengers, who would like to pay to offset carbon footprints, will not 'back off' due to extra costs from the offsetting scheme. Furthermore, because only a small share of travellers would like to pay to offset their flight emissions, airlines need to accept the rest responsibility of carbon offset that required by CORSIA under ICAO. As a result, this chapter assumes carriers will pass through all costs from CORSIA to international flight passengers, which means this may lead to a decrease in its travel demand due to price impacts.

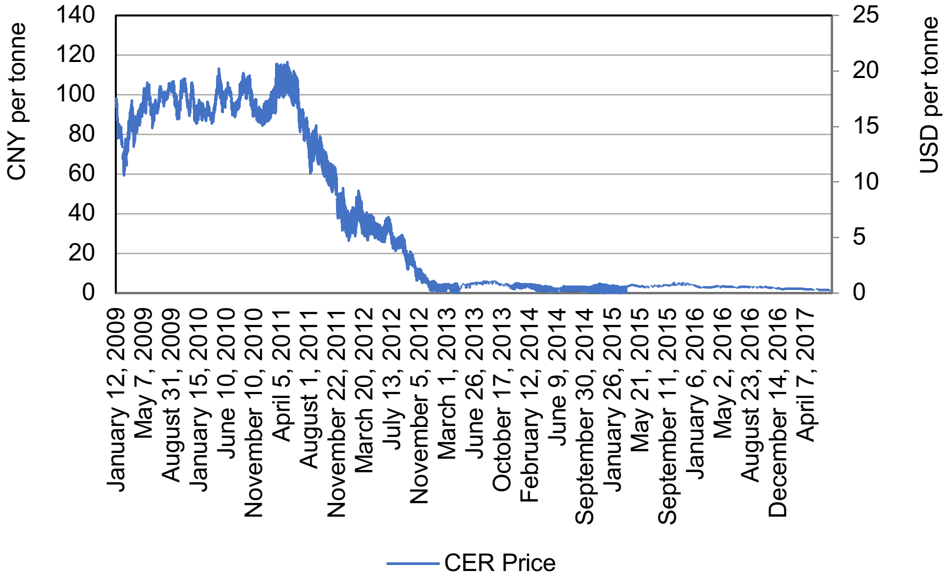


Figure 40 CER future daily prices traded in ICE during 2009-2017

(Data source: ICE Historical Market Data)

6.4 Scenario Analysis Based on Simulation Model

There are three scenarios of domestic flights carried by Chinese airlines: the first is to evaluate the cost impacts of the carbon tax; the second is to estimate the cost impacts of the emission trading scheme on, and the third is to assess impacts to the aircraft emissions by applying voluntary carbon offsetting scheme. In terms of international flights carried by Chinese airlines, there is only one scenario, which is to study how carbon offset would influence aircraft emissions because China has made the commitment to join the CORSIA. According to the OECD (2011) report on environmental taxation, the OECD projected the carbon price in the ICE will increase to 126 EUR (165.76 USD) per tonne CO_2 by 2050, which means it could be increased to 72 EUR (94.72 USD) by the end of 2030. On the other hand, the highest, average and lowest historical transaction price in the CBEE is 69, 49 and 32 CNY per tonne of CO_2 in its trading period. Correspondingly, this study, in order to optimise the emission trading scheme for the domestic flight in China, composes the historical price of BEA and OECD estimations to form three different price levels for emission trading, which are 49, 213 and 377 CNY (7.12, 30.95 and 94.72 USD) per tonne CO_2

allowances. Table 24 presents all scenarios that have been set up for the analysis in this chapter.

Table 24 Design options for different scenarios during 2016—2030

Scenario	Variation	Unit	Tax rate / Allowances price /CER price		
S_{CT}	Tax Rate	(CNY/tonne CO_2)	90	180	270
		(USD/tonne CO_2)	13	26	39
S_{ETS}	Allowances Price	(CNY/tonne CO_2)	~N(49,30.38)	~N(213,30.38)	~N(377, 30.38)
		(USD/tonne CO_2)	~N(7.12,0.32)	~N(30.95,0.32)	~N(94.72,0.32)
S_{OFF}	CER Price	(CNY/tonne CO_2)	~N(3.08,1.18)	~N(35.62,0.66)	~N(94.55, 1.84)
		(USD/tonne CO_2)	~N(0.45,0.02)	~N(5.17, 1)	~N(13.74, 0.04)
	WTP	%	0–20	0–15	0–10
			2016–2020	2021–2025	2026–2030
S_{ETS}	Benchmark	(per 1,000 RPK)	0.0523	0.0466	0.0411

Note: All tax rates, allowances prices and CER prices remain steady during 2016–2030 at three different levels.

6.4.1 Average ticket price and demand

Because the airlines would pass all costs to consumers, extra costs under different mechanisms would also cause different changes in the average ticket price. Thus, the demand for both domestic and international flights carried by Chinese airlines is also affected by different level.

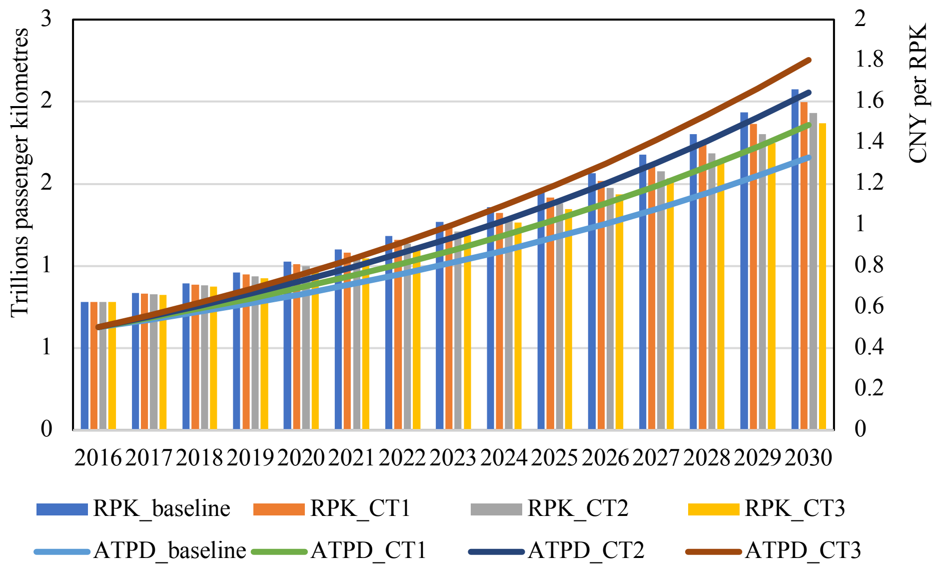
Figure 41 shows the average ticket price under different tax rates, allowances prices, and CERs price as well as the corresponding demand over the period of 2016–2030. Although the increasing rates of the average ticket price under S_{CT}, S_{ETS} and S_{OFF} are different, it still can be seen from the graph that the pattern of all of them are growing steadily. By comparing S_{CT} and S_{ETS} with each other, the graph clearly shows that CT3 and ETS3 have the lowest demand for all flights carried by Chinese airlines in each graph (Figure 41 (a) and (b)), which also have the highest average ticket price; this is due to the inverse effect between prices and the quantity of demand.

As the thesis indicated in the historical analysis section (Chapter 5), both domestic and international air transports operating by Chinese airlines are price inelastic but still price elasticity of demand is an important response to demand in changes of airfare. Evidently, S_{CT} has a higher cost than S_{ETS}, as displayed in Figure 41.

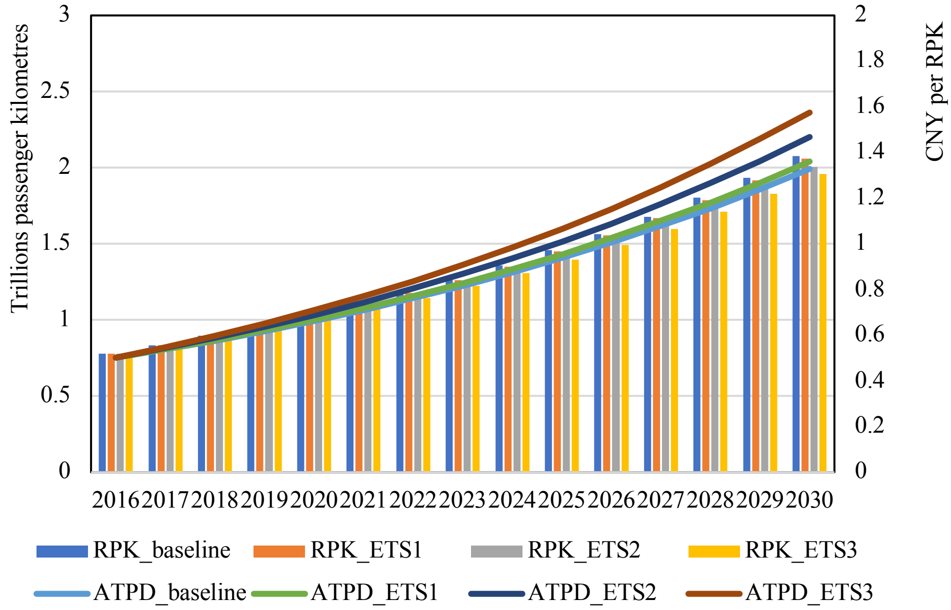
By comparing both scenarios, it is clear that the carbon taxation has a more direct impact on passenger transport demand and its consequent aircraft emissions. Unlike mitigating CO_2 emissions from both domestic and international flights, the carbon offset scheme offers a voluntary approach for passengers to pay to neutralise their own carbon footprints through purchasing CERs from CDM or forestry programmes. There are basically no changes in the growth of air passenger transport demand, which can be seen in Figure 41 (c). In this case, there are no extra costs for airlines because travellers are willing to pay for offsetting their own emissions by themselves; thus, several aircraft carriers have already adopted this kind of instrument to achieve their environmental sustainability. However, as discussed in Chapter Four, there is always a doubt about the creditability of carbon offsets in neutralising CO_2 emissions. Although the carbon offset scheme will not bring extra burdens to airlines and will not influence the increase of future business, its effectiveness has always been questioned due to the creditability of CDM programmes that each airline chooses.

For scenario CT, the ATP of domestic flights ascends to 1.48, 1.64 and 1.8 CNY (0.22, 0.24 and 0.26 USD) per passenger kilometre, respectively, by the end of 2030 under three different tax rates. The average annual growth of the ticket price is 8%, 9% and 10% for CT1, 2 and 3, independently. This is higher than the baseline ATP with 1%, 2% and 3%. Then, under the emissions trading, the ATP of domestic flights increases to 1.36, 1.46 and 1.57 CNY (0.2, 0.21 and 0.23 USD) per passenger kilometre in 2030, which approximately rises by 7.3%, 8% and 8.5% per year. Figure 41 (c) indicates there is no much changes in average ticket price on international flights because the amount of extra costs from Chinese passenger airlines is quite small. Also, there is no further changes of average ticket price on domestic flights because there are no extra costs that will be passed on to consumers and that is why we did not present the domestic airfare in Figure 41(c).

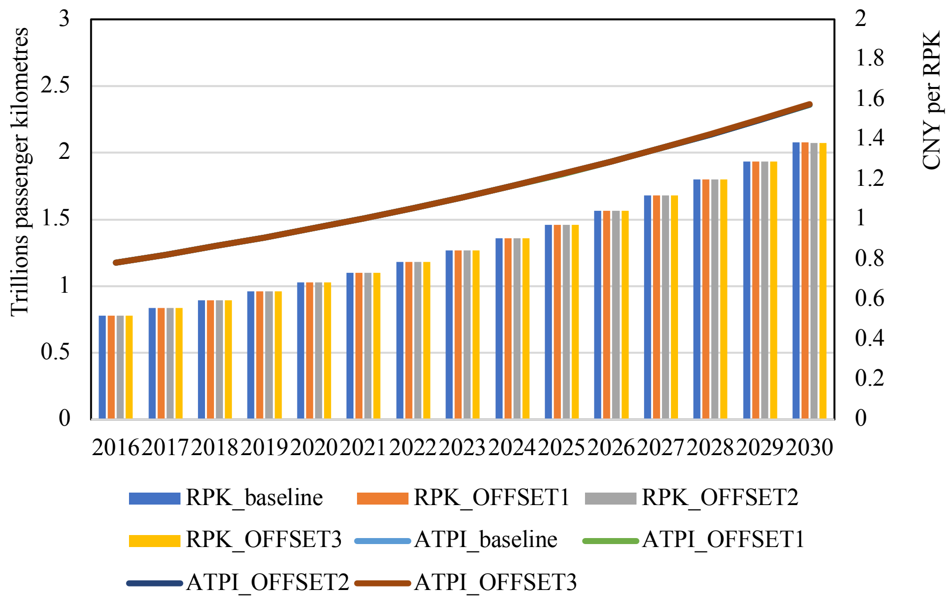
In terms of international flights carried by Chinese airlines, the annual increase of the airfare is 5% for all three scenarios, which is similar to the rise of average ticket price under the baseline scenario. This is due to this chapter only assuming one future scenario for international flights, which is to join ICAO-led CORSIA. For instance, if a passenger flew from Shanghai to London through Beijing in 2030 under the scenario that there is no single instrument is applied to reduce aircraft emissions in China, the average ticket price will be 10,840 CNY (1,575 USD) per person. However, the airfare per passenger for the same journey in 2030 will rise to: a) 12,144, 13,366 and 14,670 CNY (1,765, 1,942 and 2,132 USD) under the S_{CT}; b) 11,084, 11,981 and 12,796 CNY (1,610, 1,741 and 1,859 USD) under the S_{ETS}; and c) 12,820, 12,828 and 12,844 CNY (1,863, 1,864 and 1,866 USD) under the S_{OFFSET}. As can be seen from the estimation under the different scenarios, domestic airfare changes are different in comparison to the baseline price. To be more specific, under the lowest carbon price scenario of S_{ETS}, the increase of domestic air ticket price would be 2% only but it could be improved by 36% under the highest carbon taxation scenario. Therefore, most passengers probably do not care about the increased amount of the ticket price if the carbon price is low, especially business travellers; however, the passenger would highly possible to choose other transport modes under the highest carbon taxation scenario.



(a) Average ticket price and air travel demand for both domestic and international flights under the BAU and S_{CT}



(b) Average ticket price and passenger travel demand for both domestic and international flights under the BAU and S_{ETS}



(c) Average ticket price and passenger travel demand for both domestic and international flights under the BAU and S_{OFF}

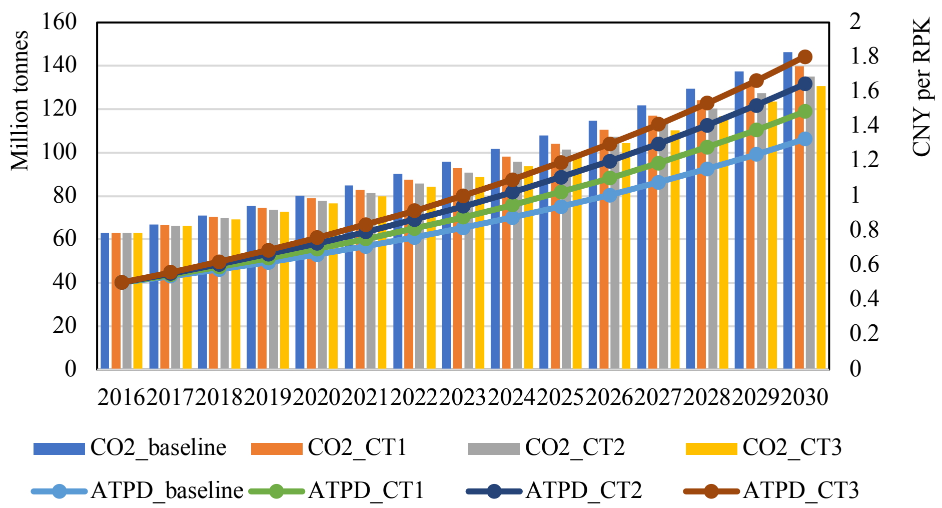
Figure 41 Average ticket price and passenger air travel demand under different scenarios from 2016 to 2030

6.4.2 All emission results

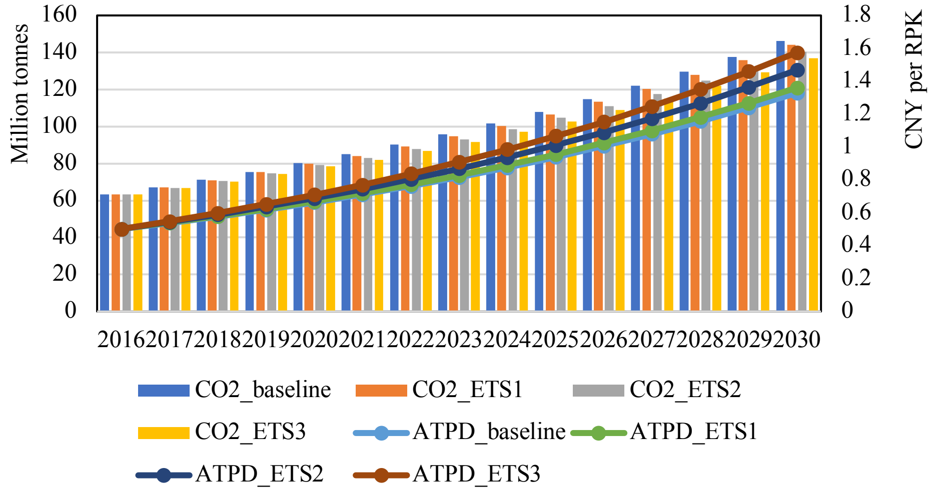
Under the carbon taxation mechanism, the model projects the emission reduction of CO_2 at three different tax rates, 90/180/270 CNY (13/26/39 USD) per tonne CO_2. These tax rates remain the same during the whole estimation period and the results are presented in Figure 42(a). The graph shows the annual CO_2 emissions reduction over the period of 2016–2030 and it clearly indicates there is a gradual increase of emissions reductions under all three different tax rates. In 2020, the CO_2 emission is 78, 77 and 76 million tonnes under different tax rates, respectively. This presents a decline of 1.49%, 2.92% and 4.29% in comparing with the BAU scenario illustrated in Chapter Five. By the end of 2025, CO_2 emissions will decrease by 3.54%, 6.12% and 8.47%, respectively, under the impact of both carbon taxation for domestic flights and CORSIA for international flights. Finally, CO_2 emissions drop to 139, 135 and 130 million tonnes by the end of 2030, accounting for 95%, 92% and 89% of CO_2 emissions under the BAU scenario, respectively.

In terms of the emission trading scheme, the allowances price is varied at different design options for ETS scenario, which the allowances price are assumed to be three different normal distribution series, which are ~N(49,30.38), ~N(213,30.38) and ~N(377,30.38) CNY per tonne CO_2. As can be seen from Figure 42(b), there is also a general increase of the direct CO_2 emissions abatement over the period of 2016–2030. The CO_2 emissions are projected to decrease by 0.27%, 1.2% and 2.15% under scenarios ETS1, ETS2 and ETS3 in 2020, independently. This means 1.19, 2.33, and 3.43 million tonnes of CO_2 could be reduced respectively under different prices. Following that, in 2025, there is a saving of the CO_2 emissions at 3.82, 6.6 and 9.14 million tonnes based on different allowances prices for domestic flights and CERs price for international flights, which shows a decrease of 1.28%, 3.16%, and 4.92%, respectively. By the end of 2030, the mitigation of CO_2 emissions grows up to 6.3, 11.12 and 15.4 million tonnes for scenarios ETS and CORSIA for both domestic and international flights, accounting for 1.39%, 3.94% and 6.28% of baseline CO_2 emissions.

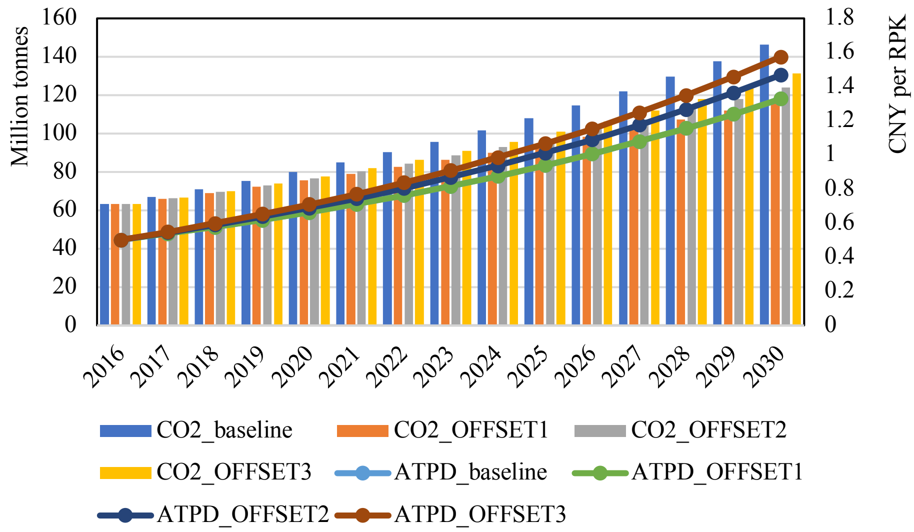
In addition, Figure 42(c) shows the emissions reduction result under different scenarios of carbon offsetting for both domestic and international flights. By the end of 2020, in comparing with the baseline scenario, there will be a decline of 5.7%, 4.28% and 2.9% under different CERs prices and the WTP. CO_2 emissions will reduce 13, 10, and 7 million tonnes in 2025, respectively, which accounts for 12.9%, 9.79% and 6.57% of CO_2 emissions from both domestic and international flights under the baseline scenario. As shown in the same figure, CO_2 emissions under the BAU scenario will increase to 146 million tonnes in total; however, by implementing the carbon offset and CORSIA to domestic and international flights separately, CO_2 emissions will only ascend to 116, 123 and 131 million tonnes. Moreover, unlike the reduction illustrated in Figure 42 (a) and (b), the amount of CO_2 emissions abatement presented in Figure 42 (c) is not according to the price increase but mainly relying on the level of passengers' WTP. Unlike carbon taxation and the ETS, emissions reductions achieved under carbon offsetting are mainly from other sectors instead of the aviation sector itself. As we described in the simulation model, both carbon taxation and ETS would lead to extra costs on consumers that could result in a demand drop and emissions reductions. However, under the carbon offsetting, the air travel demand would not be influenced because passengers are offsetting their carbon footprints voluntarily by purchasing CERs from the market. Therefore, in this case, passengers would contribute to emissions reductions in other industries.



(a) CO_2 emissions and average ticket price under carbon taxation



(b) CO_2 emissions and average ticket price under emissions trading



(c) CO_2 emissions under carbon offset

Figure 42 Annual CO_2 emissions and average ticket price from different scenarios during 2016-2030

6.4.3 Extra costs

As mentioned previously, this paper assumes that airlines would fully pass their extra costs from each mechanism onto consumers. The changes in the amount of extra costs depend on tax rates and allowances prices only under carbon taxation and the ETS. However, the extra cost from the carbon offset is only from CORSIA, which means there is no extra cost for domestic flights carbon offset. Therefore, we cannot see the data on carbon offset costs due to its small amounts. Figure 43 indicates that the extra cost for paying the carbon tax under different tax rates has obvious differences from each other. Furthermore, a steady growth of extra costs has been shown in all three scenarios over the period of 2016–2030 on the basis of different tax rates. To be more precise, the result from the simulation model about the extra costs in 2020 under different tax rates that there is 5.58 billion CNY (0.81 billion USD), 10.95 billion CNY (1.59 billion USD) and 16.14 billion CNY (2.34 billion USD) additional costs resulting from the environmental taxation. By the end of 2025, the extra cost grows up to 7.63 billion CNY (1.1 billion USD), 14.79 billion CNY (2.15 billion USD) and 21.55 billion CNY (3.13 billion USD) under scenario CT1, 2 & 3, independently. Up to 2030, there would be an extra cost from carbon taxation in 10.49 billion CNY (1.52 billion USD), 20.16 billion CNY (2.92 billion USD) and 29.14 billion CNY (4.23 billion USD) for all three taxation rates individually. In addition, Figure 43 indicates that the cost of purchasing CO_2 emission allowances in sustained growth from 2016–2030.

Moreover, the results presented in Table 25 indicate that the increase in the cost is growing along with the increase in the amount of lack of allowances. In 2020, the amount of lack of free allocation allowances for ETS 1, 2 and 3 are 20.71, 20.46 and 20.21 million tonnes, respectively. The lack of free allocation allowances increases to 32.37, 31.63 and 48.83 million tonnes under ETS 1, 2 and 3 in 2025, respectively. Then, they continually rise to 50.36, 48.83 and 47.44 million tonnes in 2030, respectively. Because there is no extra cost of carbon offsetting for domestic flights to be passed onto travellers, the extra costs under S_{OFF} only include those assumed commitments to ICAO that passengers are not willing to pay for. Thus, the small amount of extra costs under S_{OFF} is not shown in Figure 43.

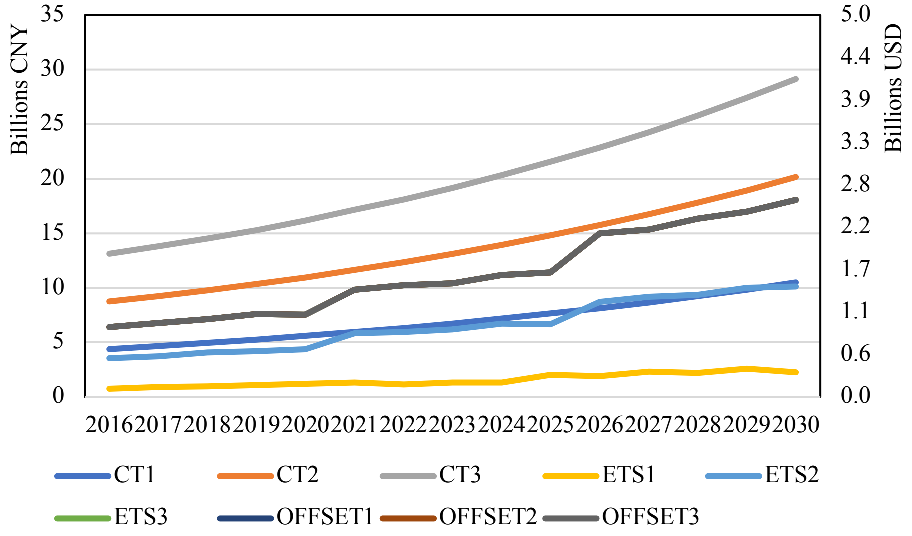


Figure 43 Extra cost under different scenarios from 2016 to 2030

Table 25 Lack of allowances and extra cost under S_{ETS} and CORSIA

Scenario		2020	2025	2030
ETS1& CORSIA1	Lack of allowances for domestic flights (million tonnes)	20.71	32.37	50.36
	Offset target of international flights (million tonnes)	N/A	0.79	0.87
	Extra cost (billions CNY)	1.19	2	2.25
	(billions USD)	0.17	0.29	0.32
ETS2& CORSIA2	Lack of allowances for domestic flights (million tonnes)	20.46	31.63	48.83
	Offset target of international flights (million tonnes)	N/A	0.81	0.92
	Extra cost (billions CNY)	4.33	6.62	10.12
	(billions USD)	0.63	0.96	1.47
ETS3& CORSIA3	Lack of allowances for domestic flights (million tonnes)	20.21	30.94	47.44
	Offset target of international flights (million tonnes)	N/A	0.84	0.97
	Extra cost (billions CNY)	7.54	11.43	18.05
	(billions USD)	1.09	1.66	2.62

6.4.4 Airlines' revenue

By adopting mitigation policies, airlines need to face extra costs for paying a carbon tax or purchasing emission allowances, which supposedly may lead to the revenue loss. However, Figure 44 presents Chinese passenger airlines would only receive fewer revenues than baseline revenues under S_{CT}; this is because we assumed travellers would respond to the extra cost of a new tax that binding with the airfare. Therefore, a demand drop could be caused by the extra taxation and in the meantime, the tax revenue will go to the government instead of airline companies; that is why aircraft operators would have fewer revenues under the scenario of applying carbon taxation.

In terms of the S_{ETS}, there is a slight increase in airline revenues from domestic air travel under different allowances prices as can be seen from Figure 44 and Table 26. Because there is nearly no change in international airfare as illustrated in section 6.4.1, the increase of total air transport revenue all comes from domestic passenger air traffic. By the end of 2030, carriers will receive 2.73, 2.64 and 2.56 trillion CNY (0.39, 0.38 and 0.37 trillion USD) from domestic air travel under different tax rates of the carbon taxation scenario, respectively. In comparison, there will be 0.11, 0.2 and 0.28 trillion fewer revenues in CNY, respectively, than the domestic transport revenue under the BAU scenario. On the other hand, there is a small ascendant of airline revenue from domestic passenger flights under the emissions trading scheme, which is 0.03, 0.11 and 0.24 trillion CNY (0.004, 0.01 and 0.03 trillion USD) higher than that of the BAU scenario. This is because only a small proportion (around 1%) of air travel demand will be influenced by emissions trading, whereas the growth of airfare on domestic flights is higher than that.

Furthermore, both the figure and the table indicate there is almost no transport revenue change under the carbon offset scheme. The most significant reason is there is nearly no change in air travel demand and average ticket price because airlines do not have any extra costs from the carbon offset, and the neutralising of carbon footprints depends on the WTP of travellers solely. Therefore, from the perspective of airline revenue, the emissions trading scheme seems to be more attractive to Chinese aircraft carriers since they will have more revenues even though there is a slight decrease in air travel demand.

Like carbon taxation, emissions trading not only will raise government revenues but also will raise airlines' revenues; thus, it seems more appealing to airline companies. The government can use this extra revenue to invest in related infrastructure development or related research programmes that can contribute to improve operational and fuel efficiency. Also, emissions permit auctioning revenue also may reduce distortionary taxes and lead to tax reform. On the other hand, airlines could place the extra revenue from the emissions trading into aircraft replacements or other measures that could improve their operational management which ultimately reduce their direct CO_2 emissions.

However, all these conclusions are made without considering increased operating costs and extra administration charges. Especially, if airline companies cannot pass on 100% of the extra costs from the emissions trading scheme, they have to absorb those costs themselves, which would lead to a profit loss. Although there is an increased revenue for the ETS scenario as showed in Figure 44, it does not mean airline companies would have more profits. When airline companies pass all extra costs from emissions trading on their passengers, it would lead to a demand drop; which may result in a lower load factor for each aircraft. Then, the unit cost (cost per RPK) may increase to some extent; thus, it may cause a lower operating profit or even a loss for some itineraries.

Nonetheless, from the revenue perspective, the ETS should be a more appealing choice to reduce aircraft emissions; however, to have a more accurate estimation, we need to have a more detailed cost analysis in the future. Due to the data availability, it will not be discussed in this research. On the other hand, even if the airlines' revenue could not cover the increased costs, it would encourage airline companies to apply other methods to reduce aircraft emissions to save costs and increase their profitability.

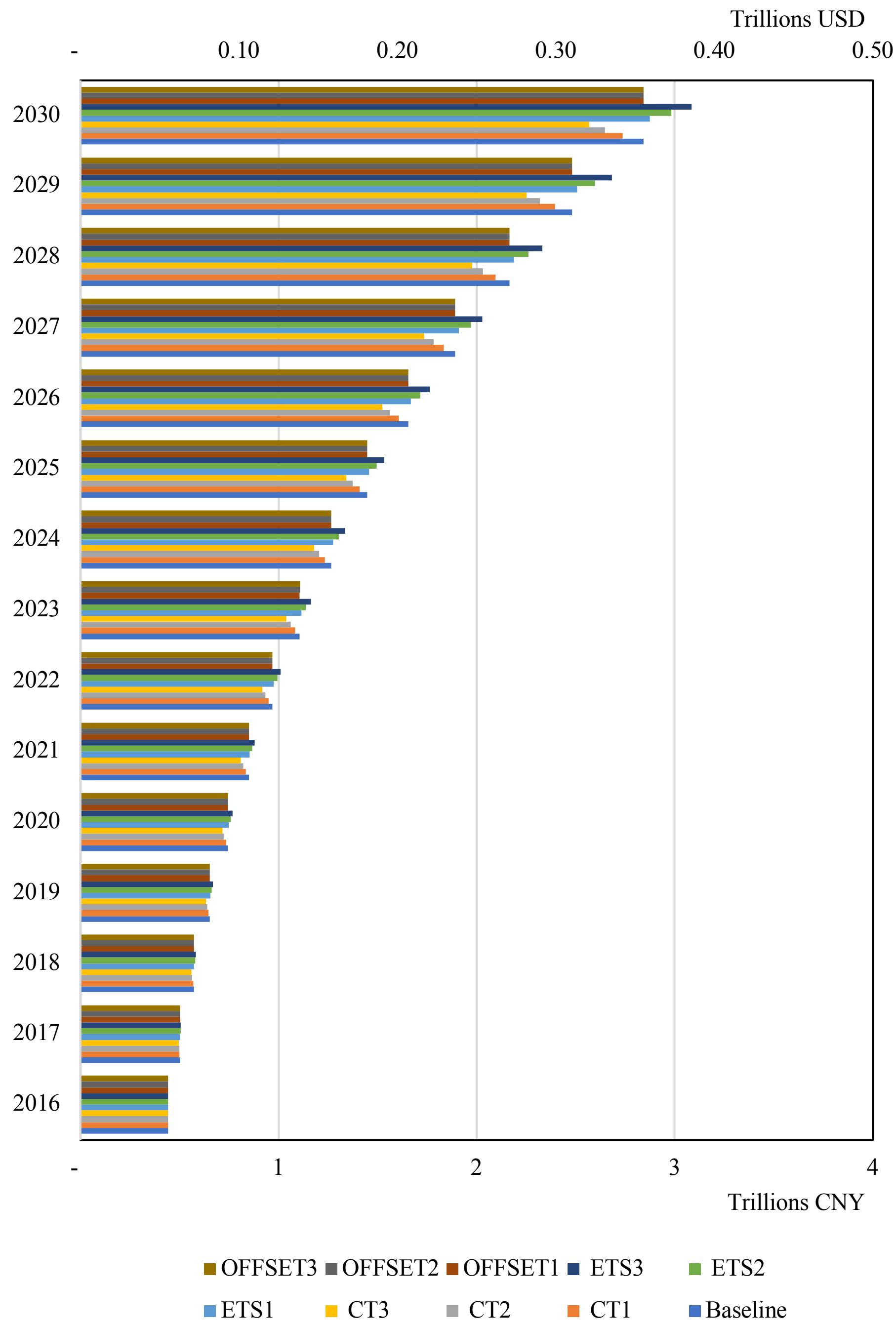


Figure 44 Airline revenue under different scenarios from 2016 to 2030

Table 26 Passenger transport revenue of Chinese airlines under different scenarios in 2030

Scenario	Unit	Airline revenue in 2030			
		Domestic	% changes	International	% changes
Baseline	Trillions of CNY Trillion USD	2.3 0.33	0	0.54 0.07	0
CT1	Trillions of CNY Trillion USD	2.19 0.31	-4.78	0.54 0.07	0
CT2	Trillions of CNY Trillion USD	2.1 0.3	-9	0.54 0.07	0
CT3	Trillions of CNY Trillion USD	2.02 0.29	13.3	0.54 0.07	0
ETS1	Trillions of CNY Trillion USD	2.33 0.33	0.28	0.54 0.07	0
ETS2	Trillions of CNY	2.44	0.92	0.54	0

	Trillion USD	0.35		0.07	
ETS3	Trillions of CNY Trillion USD	2.54 0.36	1.48	0.54 0.07	0
OFFSET1	Trillions of CNY Trillion USD	2.3 0.33	0	0.54 0.07	0
OFFSET2	Trillions of CNY Trillion USD	2.3 0.33	0	0.54 0.07	0
OFFSET3	Trillions of CNY Trillion USD	2.3 0.33	0	0.54 0.07	0

6.4.5 Sensitivity analysis

The sensitivity analysis is the study of analysing and estimating how the uncertainty of the outputs in the model can be apportioned to varied sources of the uncertainty of the inputs (Saltelli et al. 2008). In this chapter, the sensitivity analysis aims to evaluate that how the uncertainty of a series of inputs variables can affect the output of the model, including price elasticity of demand, market growth, and fuel efficiency improvement. Specifically, each of the input variables carried in the analysis has been set at three different levels to test the sensitivity, including the base value used in the model to see differences. This chapter only performs the analysis by selecting a simple and common approach, changing-one-factor-at-a-time, to see what effect this procedure can apply to modelling results (Satelli, Tarantola and Chan 1999).

6.4.5.1 Price elasticity of demand

As we discussed in Chapter 5, both methods conclude similar results for the PED of domestic and international passenger air travel demand. However, there are other variables that could be involved in the demand model as we addressed before in both Chapter 2 and Chapter 5, which could possibly lead to a different result of the PED. Therefore, by reviewing previous literature mentioned in Chapter 5, this section would adopt different value to test how different level of the PED could lead to changes in aircraft CO_2 emissions abatement under different scenarios.

First, we change the price elasticity of demand to another two levels in comparing with the original input value when other inputs remain the same. As shown in Figure 45, there are three values of PED for both domestic and international flights and there are different

PED values for passenger numbers and RPKs. Specifically, for domestic passenger numbers, the PED is -0.47, -1.2 and -1.6, respectively. For international passenger numbers, the PED is -0.27, -0.5, and -1.058, respectively. In terms of RPKs, there are three levels of the PED for domestic flights, which is -0.4, -1.06 and -1.5, respectively. There are three levels of the PED for international flights, which is -0.71, -0.8 and -1.7, respectively. The low values were discussed in the historical analysis in Chapter Five, while the other two levels have been set based on past literature. In the standard assumption, all air passenger travel demand is price inelastic. Therefore, in the sensitivity analysis, we assume only domestic air passenger transport is price elastic and both domestic and international air travel are price elastic.

As can be seen from the figure below, the PED value is quite critical in forecasting future direct CO_2 emissions because it directly links to the air travel demand. Especially, if we take a look at the result based on all demand are price elastic, we can see that the baseline direct CO_2 emissions will drop along with the airfare increase without any emissions reduction policy employed. However, this kind of situation may not be realistic because the forecast of future airfare is uncertain here because it is all based on the historical trend. The reality in Chinese passenger airlines is the airfare is not only driven by the fuel price in China but also partially controlled by the government. In particular, the fuel price in China is not driven by the market itself but controlled by the government as well. Therefore, if there is a new policy that would be applied to the airline industry or aviation fuels, the forecast of airfare in the passenger airlines industry in China may be quite different.

The first column showed in Figure 45 contains simulation results that we had in section 6.4.2, which is the result we got based on historical analysis that all air travel demand is price inelastic. However, according to previous literature that we discussed in Chapter 5, most research indicate domestic air travel is price elastic due to there are several alternative transportation modes and international air travel demand is a different case, especially for business travellers; that is why we set the sensitivity analysis as domestic air travel demand is price elastic and international air travel demand is price inelastic for one of the testing scenarios. Furthermore, those studies also indicate international leisure travellers also tend to be price elastic because they could choose not to go abroad or go somewhere with lower fares if the airfare exceeds their budgets.

Figure 45 indicates there are more emissions reductions when the PED is higher under the carbon taxation. Specifically, CO_2 emissions will only be reduced by 11.78% at most (under the highest taxation rate) in 2030 when all travel demand are price inelastic. However, if we set the PED for domestic demand is price elastic, the result can be quite different; there could be 10.56%, 19.93% and 29.03% reductions of direct CO_2 emissions, respectively, under the carbon taxation scenario with different tax rates at the same year. On the other hand, CO_2 emissions can be reduced by 15.88%, 31.13% and 46.43% at the end of 2030, respectively, under CT1, CT2, and CT3 if all passenger air traffic are price elastic.

Similarly, the effect of the emissions trading on CO_2 emissions abatement in the Chinese passenger airline industry will be affected by different PED values. In comparing with the standard assumption, CO_2 emissions will be reduced by 15.99% and 24.59 under the highest allowances price in 2030, which exceeds the emissions abatement under the original PED values (all demand are price inelastic) by 9.29% and 17.89%. Conversely, there is nearly no further reduction under the carbon offset because there are no extra costs transferred to consumers. The aircraft emissions mitigation is mainly relying on the passengers' WTP. Therefore, we can learn that the price effect on emissions reductions, according to PED changes have been influenced immediately, which means the simulation model requires an approximately accurate estimation about the PED or it would affect the efficiency of the model.

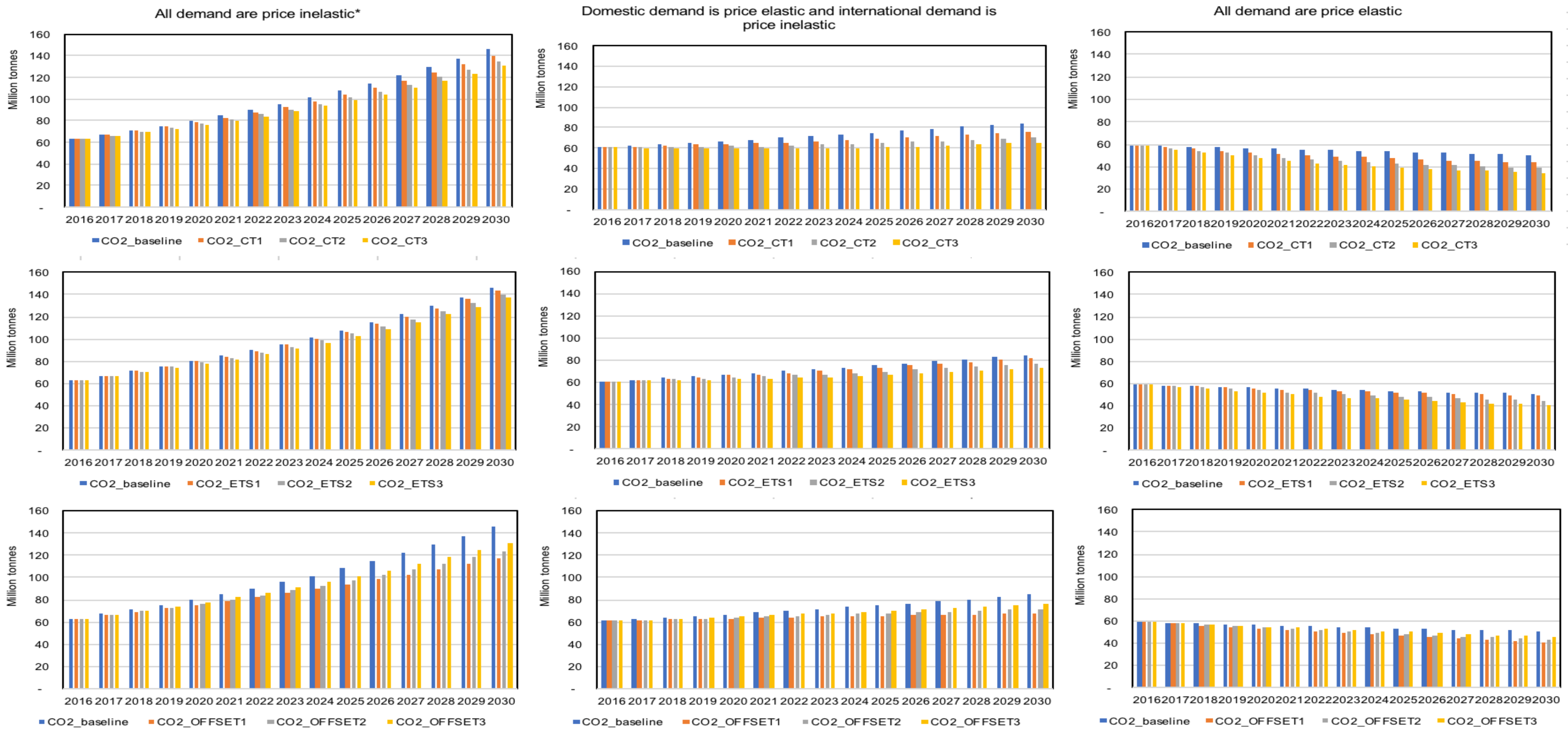


Figure 45 All CO_2 emissions results under different price elasticity of demand

6.4.5.2 Market growth

Then, we test the sensitivity of different market growth rates. As we discussed in the historical analysis, it is a reasonable assumption that the air travel demand will increase with the growth of the national GDP. Thus, we project the future market growth for the Chinese airline industry based on different growth rates in the national GDP. Figure 46 presents CO_2 emissions under different GDP growth rates, which is 7%, 6% and 5.6%, respectively. The high value is the average historical growth of the national GDP that has been adopted in the BAU scenario and the Chinese government sets the medium value—6%—in its 13th Five-Year Plan (2016–2020). However, in the research from Airbus (2016), Boeing (2017) and IATA (2016), they all think the annual national GDP growth rate for China should be around 5.6%; and, that is why we set the lower value at 5.6%.

As shown in Figure 46, the current settings of different mitigation schemes are effective in mitigating direct aircraft CO_2 emissions; however, there are basically no less or further reductions under different GDP growth rates. Nonetheless, different GDP growth rates will influence the amount of baseline CO_2 emissions. In the standard assumption, the GDP growth rate is 7%, CO_2 emissions from air passenger travel operated by Chinese airlines will be 146 million tonnes by the end of 2030, while the amount of baseline CO_2 emissions will be 118 and 109 million tonnes under two different GDP growth rates—6% and 5.6%. Therefore, we can conclude that different market growth rate based on the GDP increase will not affect the cost impact simulation model built in Chapter 6.

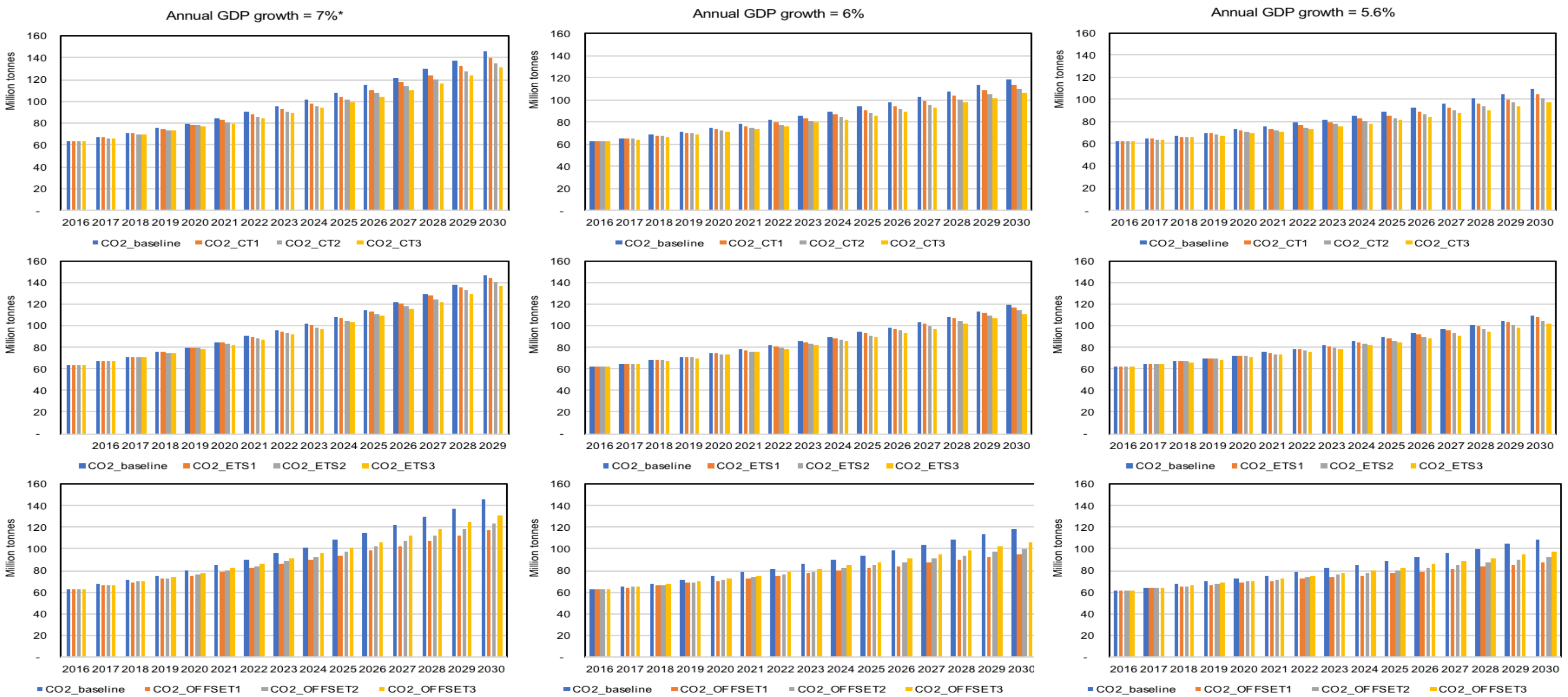


Figure 46 All emissions results under different GDP growth rates

6.4.5.3 Fuel efficiency growth

When it comes to the fuel efficiency growth, results presented in Figure 47 are quite similar to results from sensitivity analysis on the national GDP growth but it also shows its own characteristics. It indicates there will be more CO_2 abatement under the standard assumption that the fuel efficiency improves by 1% per annum under both the carbon taxation and emissions trading scenarios. With the increase of fuel efficiency improvement during the same period, we can see from the graph below that the amount of direct CO_2 emissions abatement from Chinese passenger airlines become smaller but there is no significant difference. Although the reduction of CO_2 emissions under the high-efficiency growth assumption (2% per year) is less than that of the other two assumptions, the overall volume of CO_2 emissions is definitely fewer than emissions under other two assumptions. On the other hand, in 2030, CO_2 emissions will reduce by the same rate—25.16%, 18% and 11.4% under OFFSET1, OFFSET2 and OFFSET3, respectively, with assumptions of 1%, 1.5% and 2% in fuel efficiency growth. In comparing the baseline CO_2 emissions under the 1% fuel efficiency growth, the amount of baseline CO_2 emissions will decrease by 7% and 16% by the end of 2030 under 1.5% and 2% fuel efficiency growth. Therefore, the result proves that the fuel efficiency improvement is really significant in emissions mitigation because it can reduce further aircraft emissions, even though no economic instruments are applied to the Chinese airline industry.

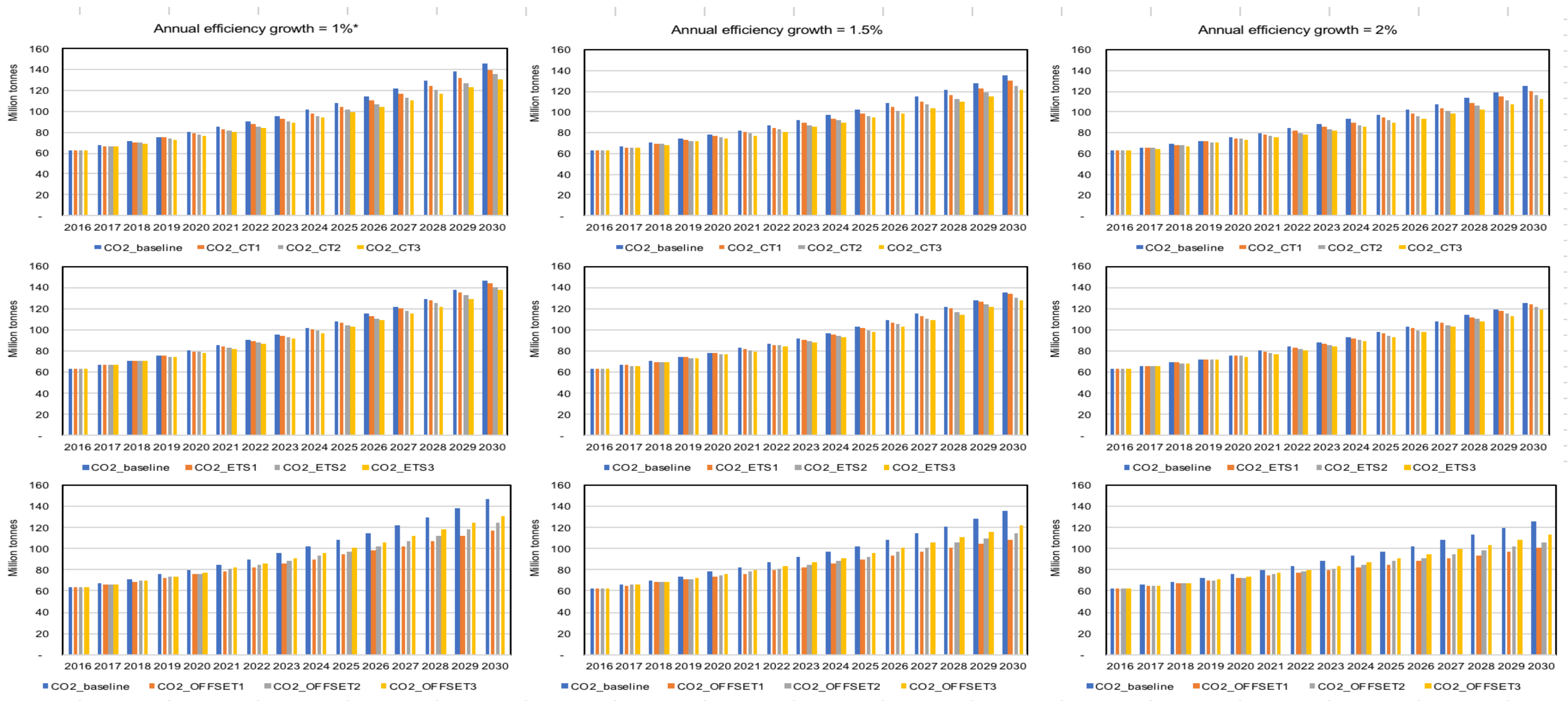


Figure 47 All emissions results under different fuel efficiency growth

In summary, the price elasticity of demand is the most important variable that could influence the efficiency of the simulation model because the model presented in this chapter simulates the cost impacts of different mitigation mechanisms. In terms of national GDP growth and fuel efficiency improvement, these will influence the baseline CO_2 emissions to different extents and, therefore, affect the CO_2 emissions reductions, but will not influence the effectiveness of the simulation model. This is because they do not have any impact on the price effect. However, their influences on the overall CO_2 emissions may affect the tax rate that made by the Chinese government or the carbon price and CERs price in the exchange market

6.5 Conclusion

As a major CO_2 emitting country and a significant player of international negotiation, China has an obligation and a responsibility to contribute to aircraft emissions abatement in the global landscape. This chapter conducts an empirical analysis to show why Chinese aviation needs emissions reduction and how economic instruments could contribute to it. It also shows how carbon taxation, emissions trading and carbon offsets could influence air travel demand, CO_2 emissions and airline revenue.

A number of simplifications are necessary when modelling the future. In particular, the price elasticity of demand may be even lower than we have assumed, and the passenger behaviour does not necessarily perfectly reflect actual price changes because of the uncertainty of the elasticity of the whole passenger airline industry. Moreover, this chapter does not take into account aircraft variance, which is important in regard to emissions analysis and forecast. and obviously, the estimation of the LTO number is based on the average aircraft capacity, which means the calculation of the CO_2 emissions may not be that accurate, especially if Chinese passenger airlines would have ultra-high capacity aircraft to be operated in the future. For the technology impact, the model does not include the use of alternative energy as well, which could also contribute to emissions mitigation; however, this analysis is focusing the direct CO_2 emissions and biofuels will mostly contribute to lifecycle CO_2 mitigation, not direct values. The allowances price and CERs price assumed in the scenario analysis may be not able to be fulfilled since both of them remain at a very low level.

Even so, we do believe that carbon tax and emissions trading scheme discussed are likely to have a significant influence on overall demand levels and emissions abatement, and this is evident from results. On the other hand, the reduction of CO_2 emissions under the carbon offset scheme is not that reliable since it is highly depending on the travellers' WTP. It is still doubtful whether the WTP that has been assumed in the scenario analysis can be achieved in the future.

Although there are some limitations about the simulation model, this analysis at least establishes a framework to compare three different economic instruments for mitigating direct CO_2 emissions from the Chinese air passenger transport sector and to estimate their cost effects on passenger behaviour, airfares, CO_2 emissions and airline revenues. To look at the cost impact on both domestic and international flights carried by Chinese passenger airlines of integration about aviation into the carbon taxation, emissions trading or carbon offset, a simple model is developed to estimate current and future CO_2 emissions, the cost of paying a carbon tax, acquiring allowances or offsetting carbon footprints and demand-side effects of shifting the cost burden onto passengers under different design options.

The analysis in this chapter indicates all mechanisms would cause the increase in airfares, which could result in the growth of extra costs and slower the demand growth. Although, by the end of 2030, CO_2 emissions will be reduced greatly, the extra costs will have increased greatly relative to the baseline. By comparing CO_2 emissions from these three major scenarios with the baseline activity, it seems like that the carbon offset is more appealing; however, we cannot conclude which one is better for Chinese airlines because it also depends on other considerations when a policy is going to be adopted. In particular, as an instrument that highly depends on passengers' choices, the effectiveness of the carbon offset is still questioned. The public has always questioned the effectiveness of the carbon offset due to CDM projects chose by airlines. Furthermore, as addressed in the scenario analysis, there will be more incomes to the government and airlines due to the auctioning revenue and increased airfare.

From the perspective of extra costs, the carbon taxation and the carbon offset seem more appealing to airlines because there are no extra costs for them, especially no extra increase in airfare under the carbon offset scheme that would not lead to a demand drop. However, from the perspective of airline revenues, the emissions trading scheme seem more attractive to aircraft carriers than the carbon offset because there will be more transport incomes for them. Therefore, no matter what perspective we look through, the emissions trading is more favourable than the other two alternatives. In particular, as we discussed in the scenario analysis, both the Chinese government and airlines would have extra revenues under the emissions trading scenario, which could be invested into programmes that could improve operational and fuel efficiency, i.e. infrastructure development, aircraft replacement and alternative energy research. Also, if the extra revenue could not cover the increased costs for aircraft operators, it would force airline companies to adopt more ways to reduce aircraft emissions in order to save costs on purchasing emissions allowances.

In conclusion, because of the huge amount of CO_2 emissions from the baseline scenario, the Chinese government should pursue a mechanism to reduce the CO_2 emissions even though China does not have a mandatory obligation for mitigating emissions of GHGs. As a major player in the international negotiation, China should participate in the global MBM for the international aviation industry—specifically, CORSIA through ICAO. Finally, China should build its own mitigating mechanism to achieve its environmental and political targets along with the economic growth.

Chapter 7 Case Study: The Effect of the International Aircraft Emissions Mitigation Scheme on Airline Competition

This chapter firstly reviews airline competition in a given year and selects the market of flights between China and EEA countries as a case study to analyse how an international aircraft emissions mitigation scheme would influence airline competition. Two instruments are included in the analysis: the EU ETS and CORSIA. Future passenger demand in the market of EEA—China has been projected under the influences of these two mechanisms. Then, two different types of model are formulated to compare future market shares under different approaches.

7.1 Introduction

In the early development stage, the aviation industry has been strictly regulated by their governments (Scharpenseel 2001), which can be seen in every aspect of the industry (i.e. market entry, flying networks, airfare, investments and technology). In the 1970s, the US first transformed its aviation industry from highly regulated to deregulated (Good, Röller and Sickles 1993). Following a decade effort, most developed countries had completed their transformation of the airline industry, which is airlines can operate and compete freely instead of under government regulations. Although the EU also finished its conversion into one single European market in 1993, it still took time to liberalise among counties since liberalisation always begins with country-pairs.

China, one of the most significant airline industry participants, also transformed its aviation industry starting in the 1980s. However, the contestability of Chinese airlines is still weak in the international market. To overcome this problem, CAAC started to reform the aviation industry to improve the international market share of Chinese airlines. As we presented in Chapters Two and Five, air passenger transport has dramatically grown since 2004, which because of a bilateral agreement between the EU and China as well as the successful reformation of both EU and Chinese airlines. This has led to the market between the EU and China becoming one of the largest international markets in the world. Therefore, this chapter will explore this market respectively to see whether emissions abatement instruments would result in competition distortion.

As previously discussed, there are multiple options for mitigating international aircraft emissions, which influences the air travel and aircraft emissions to different extents under each scenario. This chapter explores a specific case to study whether the emissions trading and carbon offsetting would affect the airline competition, and in particular, how extra costs from mitigation instruments influence passengers' choices and the effect on airline market share and future capacity. This chapter integrates a region-pair demand model with the simulation model built in Chapter Six to study how the EU ETS and CORSIA would influence future airfares and airline frequencies for each airline cluster. Then, this chapter adopts two different methodologies to project future market shares of each airline cluster.

Firstly, a market share model will be built up here to project airline market shares up to 2030 based solely on their frequency[60] shares. In comparison, we conduct the discrete choice analysis to forecast how emissions mitigation influences the number of passengers expected to travel with each airline between any region pair, and we could also get the result of airline market share during the same period. The reason why we use two different approaches is to justify the result of the market share. The discrete choice analysis explores several different variables that could influence the functionality of each airline competing in the EEA–China market, such as the average ticket price; which could offer a better understanding for the public about whether extra costs from mitigation policies would change passengers' decisions on which airline to travel with. These results indicate whether it is fair or not in competition under carbon control and will contribute to the further

[60] airline frequency mentioned in this chapter means the number of flights operated by airline companies per year.

design of international aviation emissions abatement instruments and the co-operation of different mechanisms.

This chapter is divided into five sections. It begins with a review of the existing literature on airline competition either without carbon constraints or under emissions mitigation instruments, and in particular, the research on methods for market share modelling and discrete choice analysis. The next section introduces the methodology used in this chapter. It starts with the demand module to project future air travel demand between EEA countries and China. The market share model is then introduced to assess the relationship between the passenger shares and the frequency share. In the following, a discrete choice module is established to test the significance of each variable corresponding to the market share. Then the following section is an empirical analysis about future demand, frequency share competition, passengers' choices and the forecast of airline market share under emissions trading. Finally, the fifth section concludes main findings of this chapter and discusses limitations of the methodology.

7.2 Airline Competition Review

For most regions that have high air travel demand and open skies policy, international markets are highly competitive. In the marketplace between EEA countries and China, such example can be found for most region pairs, such as Beijing–London and Shanghai–Paris. Taking the region pair Beijing–London as an example, 20 airlines are serving more than hundreds of itineraries between these two regions to attract more travellers for their services. To gain competitive advantages, airlines serving on the same routes actively implement several competition strategies to expand their market share, includes lower prices, convenient connecting routes, flight safety and onboard services. In the highly competitive market between China and EEA countries, it is vital for airlines to study how to improve their air services to attract more travellers and enlarge their market share. If one carrier changes its service quality, the market share of other competitors serving on the same route could be affected accordingly. Service quality includes several aspects that can be assessed through different approaches to investigate which factor would influence the market share most.

The simplest one is the market share model based on frequency competition only, which studies the relationship between market share and flight frequency operated by an airline and its competitors (Vaze and Barnhart 2012). Brueckner and Flores-Fillol (2007) compared airfares and airline schedules for between two duopoly carriers with evenly spaced flights, which showed the equilibrium frequencies tend to be inefficiently low. Except for the airline frequency, several factors could influence the market share of each carrier. Jou et al. (2008) described a decision model to capture passengers' choices on international air carriers by investigating several quantitative and qualitative variables. Their empirical evidence suggests that air passengers not only value the price of travel when they choose which carrier to fly with but also value safety, convenience and service quality. Bitzan, Kones and Peoples (2014) suggest that airline competition is major determinants of airfares for international routes by constructing several pricing equations based on air traffic data from US–international routes.

Airfare also could affect the airline competition the opposite way because lower prices could attract more passengers. Carlson and Löfgren (2006) investigated the domestic air travel market in Sweden and concluded that the frequent flyer programme is a significant factor that would influence airline market shares. In their study, the major carrier in the Swedish domestic air traffic market—SAS—could monopolise the market by using a frequent flyer programme because there are more switching costs for travellers if they want to choose an airline other than SAS. Pels, Nijkamp and Rietveld (2000) incorporated both airport and airline competition into a nested logit demand model to study how passengers would respond to the accessibility to airports, airfares, the departure time and the frequency. They concluded that improvements in the accessibility of an airport would reduce the passenger charge, which leads to a redistribution of traffic among airlines and changes in airfares; and, a considerably large increase of the accessibility of an airport may result in a natural monopoly for one of the airlines. By investigating customer services, customer satisfaction and corporate performance in the US airline industry, Dresner and Xu (1995) used the management logistics to analyse the importance of several factors, including on-time performance, ticket oversales and mishandled bags, to the customers' satisfaction and corresponding airline market shares. In particular, their results showed improvements in mishandled baggage would increase airline carrier performance, which leads to a more significant market share. From the perspective of customer service, passengers tend to pay more to have better qualities of airline services (Wen and Lai 2010).

According to previous literature, most airline competition analysis are based on revealed preference (RP) data, which is using the existing real-market data (actual travellers' behaviours) to reveal elasticities of each attribute to passengers' choices (Richter 1966). However, this kind of method cannot show what alternatives passengers dropped during the choosing process; therefore, some researchers implement the stated choice experiment to overcome this kind of problem. Investigators designed stated preference based on various factors for the public to choose under different business scenarios (Wardman 1998).

Similar to the result from the model based on the RP data was found by Hensher, Stopher and Louviere (2001) through designing a stated choice experiment to investigate how passengers flying between Australia and New Zealand would choose among all airlines operating in this market. The empirical results of different choice models indicate the membership in different frequent flyer programmes is relatively significant to travellers when they are choosing which carrier to fly by comparing airfares, onboard services and legroom of the economy class. Studies using RP survey data often fail to reveal fare coefficients; thus, Hess, Adler and Polak (2007) apply the stated preference survey to their analysis in airport and airline competition. The results present the ground-level distance plays a significant role in airport choice behaviour and also the membership in frequent flyer programmes is a major factor in airline preferences. By using the stated preference method and the latent class model, Wen and Lai (2010) analysed passengers' choices among flights operating between Taipei and Tokyo or Hong Kong based on several services attributes, i.e. airfare, schedule time difference, flight frequency, on-time preference, check-in service, in-flight seat space and cabin crew service. They also proved elasticities tend to over- or under-estimate the sensitivity of service factors in airline choices in the context of international flights under the standard multinomial logit model. This is why they incorporated the latent class model into their analysis to study elasticities for distinct segments.

From the previous literature, we can learn that the most common method to project future airline market shares is the market share model that based on airline frequencies only. However, by estimating elasticities of airline service attributes to travellers' choices, the discrete choice analysis could use the utility function of different aircraft carriers to simulate passengers' preferences among all competing airlines. Both methodologies have their own strengths and weakness. Therefore, this chapter adopts both to project future airline market shares to justify the final results.

7.3 Methodology

7.3.1 Air passenger demand model

The objective to develop the airline market share model is to examine how emissions trading for international aviation industry influence airline competition. Airline competition means flight carriers compete on passengers and market share, which based on frequency or capacity of service on each route served, ticket price to the extent that regulation allows for price competition, quality of service and products offered in-flight (Belobaba, Odoni and Barnhart 2009). For each region pair, multiple airlines served to transport passengers between EEA countries and China on a daily basis. Given an estimate of total demand on a route, the market share of each airline depends on its own frequency or capacity, as well as on the competitor's frequency or capacity. Nonetheless, each passenger chooses combinations of flight schedules, prices and product quality that maximises the utility of air travel, which means passengers would like to have the best service on a flight that departs at the most convenient time, for the lowest price. In this chapter, the discrete choice analysis assigns passenger share (market share) to each airline based on the relevant importance of ticket price, flight schedule, travel time and direct or connected flights to passengers.

Instead of the demand model built in Chapter 5 and Chapter 6, this chapter modelled future air travel demand based on region pair data (NUTS3 regions and major Chinese cities[61]). A simple one-equation logarithm-type model was adopted here. This demand model was built originally as part of the AIM model (Dray, et al. 2010); and, in this chapter, we keep most of the original model but eliminate some variables that do not fit our needs.

$$\boldsymbol{D_{ij} = exp\{\, \alpha + \beta_1 log(P_i P_j) + \beta_2 log(I_i I_j) + \beta_3\, log(AF_{ij} + VOT * TT_{ij}) + \beta_4 SpecA_{ij} + \beta_5 SpecB_{ij} + \beta_6 Direct_{ij} + \beta_7 Airport_{ij}\}} \tag{10}$$

The dependent variable is the number of passengers travelled between EEA countries and China in a year. The independent variables include regional population (P), personal income which is the national GDP (I), generalised travel costs ($AF_{ij} + VOT * TT_{ij}$, AF_{ij} is airfare between region i and j, VOT is the value of time[62] and TT_{ij} denotes the average travel time between region i and j), two dummy variables for special regions ($SpecA_{ij}$ and $SpecB_{ij}$, which indicate whether both regions are special regions or whether both regions are not special regions). Special regions in this model present the capital city. Furthermore, $Direct_{ij}$ in the demand model is a dummy variable to describe whether there is a direct flight between region i and j.

[61] NUTS 3 regions are defined according to the EUROSTAT, which are small regions in the EU area that are quite close to the city scope; however, for certain metropolitan area, we aggregate the data to NUTS2 region (i.e. London, Frankfurt, etc.). Major cities in China means Chinese cities have air routes connecting to EEA countries.

[62] The value of time refers to the cost of time spent on the travel including waiting, commuting as well as actual travel (Litman 2009).

$Airport_{ij}$ denotes whether either the origin or destination region has more than one airports or not. Both population and personal income data are obtained from Eurostat and the National Bureau of Statistics of China. Demand data and airfare data for each region pair between EEA countries and China are obtained from the Sabre Data[63]. Travel time is calculated by dividing the travel distance obtained from Sabre as well with the average ground speed for large aircraft and plus connecting time (assumed to be two hours per stop). The data of value of time is obtained from the guidebook by Landau, et al. (2015), which is 51 USD per hour. This is the VOT for flight time (incl. connections) only, which is consistent with the travel time we use in the model. All data was inputted into the model is for the year of 2013.

By projecting future demand, we could get future airline flight frequencies. As we described in the simulation model in Chapter 6, we could calculate airline flight frequencies by multiplying the estimated passenger numbers with the average load factor for international long-haul flights and dividing it by the average aircraft capacity. Then, we could learn about how much share each airline could occupy in the future through the following model.

7.3.2 Market share model

The most commonly used mathematical expression for the S-curve relationship (Simpon 1970; Belobaba 2009a) is given by,

$$\boldsymbol{MS_i} = \boldsymbol{FS_i^{\alpha}} / \textstyle\sum_{j=1}^{n} \boldsymbol{FS_j^{\alpha}} \text{ , and} \tag{11}$$

where MS_i is the market share (passenger share) of airline i in a given year, FS_i is the frequency share of airline i in a given year, n is the number of competing airlines and $\alpha \geq 1$ is a model parameter. In the S-curve relationship, a higher frequency share is always

[63] Sabre data is a databased similar to the OAG (Official Airline Guide) that contains the airline schedule data However, it also beyond that because Sabre AirVision Market Intelligence delivers up to date global passenger traffic data from more than 40 industry sources including all three of the major global distribution systems (GDS) and other government sources. This produces a robust set of historical, advanced booking, schedule, capacity, segment and origin and destination information.

associated with a higher market share and the relationship has been presented below. As we can learn from

Figure 48 that for airlines which have the frequency share over 50% would gain extra market share; thus, this could provide incentives for passenger airlines to add more flights instead of upgauge[64] their aircraft

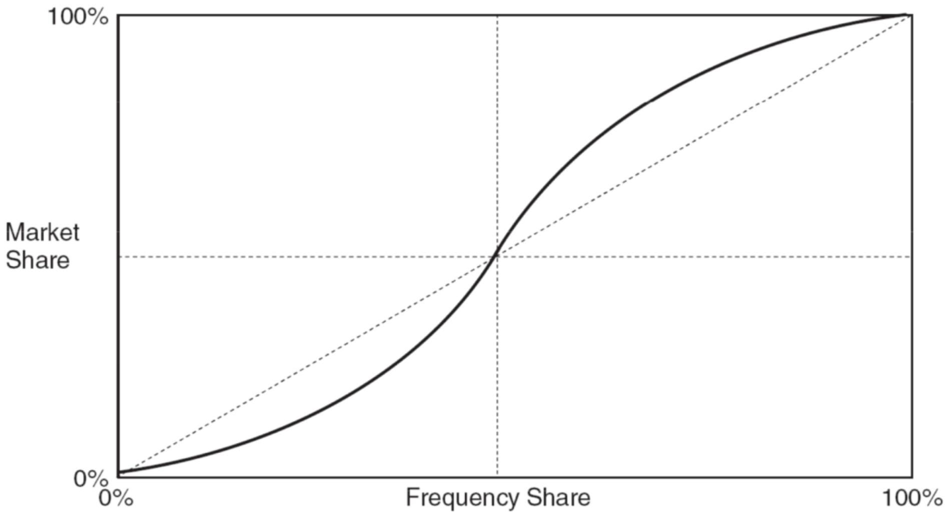


Figure 48 The S-curve relationship between airline market share and frequency share

In this chapter, we will estimate the market share only based on the future airline frequencies to compare with the market share projected by the discrete choice model to justify the forecasting result. There are further restrictions to project future market share based on airline frequencies.

$$\sum \boldsymbol{AF_i D_i} - \sum \boldsymbol{C_i F_i} > \mathbf{0} \tag{12}$$

$$\boldsymbol{LF_{avg} S_{avg} F_i} \ \geq \ \boldsymbol{D_i} \tag{13}$$

where AF_i indicates airfare of airline i, D_i means passenger numbers carried by each airline during the given year, C_i means operating costs of each aircraft, and F_i is the frequency in a year. The Eq. (16) aims to ensure the total frequencies operated by all airlines can meet

[64] See footnote 10.

the passenger air travel demand and also at least will cover the operating costs of those aircraft. Then, Eq. (17) presents the restrictions of airline frequencies subject to the future passenger demand. LF_{avg} represents the average load factor[65] of flights flying between EEA countries and China, S_{avg} means the average available seats for international flights, and again, F_i is the operating frequencies of airline i in a given year.

7.3.3 Discrete choice model

The discrete choice analysis is the modelling of choice from a set of mutually exclusive and collectively exhaustive alternatives (Ben-Akiva and Lerman 1985). The early transportation applications of discrete choice models were made for a binary choice of travel mode (e.g. Warner 1962; Lisco 1967). Some of these studies placed focus on the estimation of a ‘value of time’, the trade-off between travel time and travel cost implied by a travel demand model. This value has been used to assign a monetary value to the travel time savings in the evaluation of alternative transportation projects (Bruzelius 1979). Other researchers emphasised the development of policy-sensitive models for predictions of the market shares of alternative modes (Stopher and Lisco 1970). Further progress in transportation applications following these early studies was accompanied by improved discrete choice modelling methods.

In following the application of discrete choice analysis to road transport, there are more and more researchers adopted the discrete choice model to investigate passengers’ choices on air transport. There have been two categories for the discrete choice model on air transport: airline choice and itinerary choice. Airline choice model studies how different service factors and other social-economic factors would influence passengers’ decisions on choosing which carrier to fly. Regarding itinerary choice modelling, it is a modelling framework that forecasts the number of passengers expected to travel on each itinerary between any region pair (Coldren, et al. 2003) . Further, the development of itinerary choice model provides

[65] See footnote 11.

airlines with a better understanding of the relative importance of different service factors that can be modified to increase market share. Itinerary choice model for passenger supports long- and intermediate-term decision-making. For instance, this kind of model provides the basis for airlines in performing merger and acquisition scenarios, route schedule analysis, code-share scenarios, minimum connection time studies, price-elasticity studies, hub location and hub build-up studies, as well as equipment purchasing decisions. An accurate itinerary choice model is, therefore, a robust and powerful tool for flight planning and decision-making both at the tactical and strategic level.

The dependent variable in the model is the number of passengers who booked journey through each airline in a given year. This is determined by itinerary data recorded in Sabre database. The choice (alternative) sets are modelled as the set of all itineraries operated by airlines operating between each region pair for each day of the year of 2013. For instance, all itinerary provided by all airlines operating between London and Beijing constitute an alternative set, as did all itineraries provided between Paris and Shanghai. The share of passengers assigned to each itinerary between a region-pair for the given year is presented by the following equation:

$$\boldsymbol{S_i = \exp(V_i) \,/\, \sum_j \exp(V_i)}, \tag{14}$$

where S_i is the passenger share assigned to itinerary i, $\exp()$ is the exponential function, V_i is the value of itinerary i and the summation is over all itineraries scheduled between the region pair of the given year. The airline value, the utility of each itinerary, is described as follow:

$$\boldsymbol{V_i = \beta_1 Frequency_i + \beta_2 AF_i + \beta_3 TT_i + \beta_4 Direct_i + \beta_5 ALL_i + \beta_6 ONE_i},$$

(15)

where V_i is a linear utility function of the explanatory variables. The explanatory variables used in Eq. (19) includes $Frequency_i$ (total flight number operated by each airline under the same itinerary), AF_i (average airfare of each airline operating the same itinerary), TT_i (travel time between the origin airport to the destination airport), $Direct_i$ (a dummy variable to indicate whether the itinerary is direct or not), and ALL_i (a dummy variable denotes if all three clusters: EU airlines, Chinese airlines and Other airlines served on each itinerary), and ONE_i(a dummy variable indicates whether there was only one airline cluster served on each itinerary). All travel data is acquired from the Sabre Data for the year of 2013. Parameter estimates provide an understanding of the relative importance of different service factors on itinerary choices. Estimation results will be generated through the Biogeme[66] (Bierlaire 2003) and reported in this chapter.

7.4 Results

7.4.1 Elasticities of air transport demand

Different from time series analysis has been taken in Chapter 5, this chapter just uses data for one year (2013) only to estimate elasticities of air transport demand. Although it is only one-year data, it is a set of region pair data, which includes 2,143 pairs of regions between EEA countries and China. As stated in the methodology section, the demand model comprises several independent variables to explain demand growth, which is population (POP), personal income (GDP), air travel cost (COST) and four dummy variables (SPECA, SPECB, DIRECT and AIRPORT). All independent variables are region-paired. Table 27 presents estimation results of elasticities of different independent variables. Because each area of EEA countries has their own characteristics, especially when we consider the national GDP or travel distance from China. Therefore, the demand model mentioned in Eq.(10) has been run by different groups individually. As can be learned from Table 27, there are four

[66] Biogeme is an open source freeware designed for the estimation of discrete choice models for transportation.

groups have been estimated, including flights between Western EEA countries and China, Northern EEA countries and China, Southern EEA countries and China, as well as Middle-Eastern EEA countries and China[67].

As can be seen from the table below, population elasticities of demand (POP) are positive for most groups. However, for flights between East&Middle EEA countries and China, the population elasticity is negative, which means the demand will increase with the decrease in the population. This could be the result of several reasons. The most possible reason is people may leave their original residence regions for other regions to work; and in the meantime, they may have to travel frequently between their home regions and working regions. Similarly, students who study abroad would have similar situations. On the other hand, the most likely problem here is that there may be some errors in this set of data from Sabre.

In addition, income elasticities (GDP) are all positive, which means the demand will grow as they increase. On the other hand, the cost elasticity (COST) is negative, which means the demand will grow as it decreases, which means travellers of air transport are sensitive to cost changes. However, this is a generalised cost elasticity, not a fare elasticity; and, for the airfare elasticity, it should be less negative, which consistent with previous studies as we mentioned in Chapter 5 that international passengers are price inelastic due to lack of substitution transports. Elasticities of two dummy variables (SPECA and SPECB) indicate the special region is essential for demand growth. If both regions have capital cities, it will contribute to demand growth and vice versa. Also, if there is a direct flight for each region pair or there is one more airport in either origin or destination regions, the demand would increase as well.

Table 27 Estimation of elasticities of air travel demand from Eq. (10)[68]

[67] Western EEA countries include Belgium, France, Ireland, Luxembourg, the Netherlands and the United Kingdom. Northern EEA countries include Iceland, Denmark, Norway, Sweden, Finland, Estonia, Latvia and Lithuania. Southern EEA countries include Croatia, Spain, Italy, Greece, Malta, Portugal and Republic of Cyprus. Middle-Eastern EEA countries include Austria, Bulgaria, Czech Republic, Germany, Hungary, Poland, Romania, Slovakia, and Slovenia. This classification is mostly based on the geographical definition.

[68] Full estimates for each travel group are showed in Appendix C.

Dependent Variable: Demand (number of passengers)
Method: Least Squares
Total Sample: 2143

Group	West EEA-China	North EEA-China	South EEA-China	East&Middle EEA-China
Included Observations:	909	167	435	632
Variable	Coefficients			
C	-5.5909191	-32.3583995	-24.8557678	-22.5118061
POP	0.740725	0.8083562	0.7823824	-0.5506954
GDP	1.3634754	3.185698	2.4678968	3.8407082
COST	-1.9789893	-0.8559353	-0.7322424	-0.3497680
SPECA	1.3936445	1.2249487	1.9202058	3.1231617
SPECB	-0.4906082	-0.0025778	-0.6801825	-0.8783139
DIRECT	3.6655265	2.3459673	2.5336792	3.8181860
AIRPORT	1.3675310	0.2811359	0.8908729	1.7507728
R-squared	0.5348253	0.6626524	0.4866541	0.4211794

7.4.2 Future demand

According to estimates results and historical analysis, the future market can be projected as Eq. (10). We assume both population and income would increase by the historical growth rate for past 30 years; and, the historical data for all NUTS3 regions comes from the EUROSTAT and the historical data for Chinese cities comes from the national Statistics in China. In terms of airfare, we assume it would grow along with the historical growth of the unit revenue (revenue per passenger kilometre) of international flights carried by Chinese airlines for previous 30 years. The reason why we assume the airfare would ascend at this rate is we cannot get historical prices or revenues for all airlines. Also, we could not use aviation fuel price to project future airfare because future aviation fuel price is uncertain, and in the meantime, we could not know what the proportion is that the fuel cost accounting for the air ticket price of each airline. Therefore, the best we can do here is to assume there are no airfare differences among all airlines operating in the market (EEA-China). Furthermore, the forecast here assumes the VOT and the travel time remain constant and there will not be direct flights for those region-pairs which do not have direct flights in 2013 over the period of 2014-2030.

By the end of 2020 and 2025, the RPK will be increased to 65 and 81 billion passenger kilometres for flights between EEA countries and China; and the RPK will continue to ascend to 102 billion by the end of 2030. The number here indicate air travel market between EEA countries and China will successively increase with an average annual growth of 4.6%, which is basically consistent with but a little bit below the forecast from Boeing and ICAO, 5.1% and 5.2%, respectively.

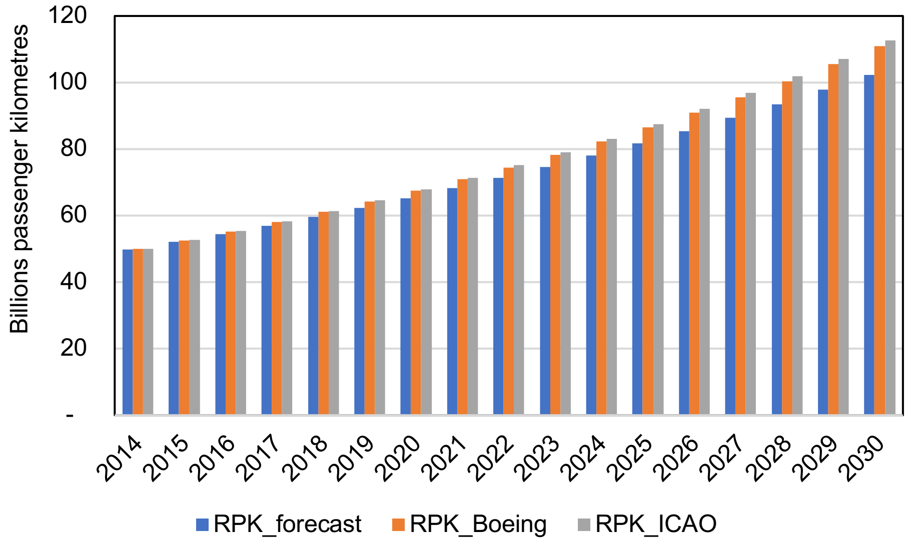


Figure 49 Air passenger travel demand between EEA countries and China during 2014-2030

(Data source: Boeing 2016; ICAO 2015)

However, the annual increase is estimated only based on the perfect historical growth of population and GDP. Population and regional GDP projections also need other variables to be included instead of simulating based on historical changes rate only, which means the result of future air passenger demand for flights between EEA countries and China would be different if we have a different growth rate of population and regional GDP. On the other hand, the airfare may not be going to increase as the historical trend as well because airlines operating in this market would have different price strategies, including regional aviation fuel prices, other operating costs, or some political factors. Especially, with the increase of personal income, passengers may change their subjective feelings about their value of times. Thus, it is understandable the forecast in our analysis is not quite the same as others' results; however, the difference is not much which means the projection should be accurate.

7.4.3 Airline market share

Regardless of what has been discussed in the above sections, another critical factor that would influence airline market share should be introduced, airline frequency. If an airline has more frequencies on an air route, it will attract more passengers. Market share of a flight path can be modelled by an airline's operating frequency and its competitors' frequency by a so-called 'S-curve' relationship. However, this kind of relationship has been always questioned in real cases. Figure 50 presents the relationship between market share and frequency share of the air passenger transport market between EEA countries and China. It indicates there is no such 'S-curve' exists in the sample data. However, it does not prove the 'S-curve' relationship does not exist because the data chosen in the analysis is for economy class only, which means the 'S-curve' could exist in other travel classes. On the other hand, the frequency is significant for airline market share no matter whether the 'S-curve' relationship exists. Furthermore, Figure 50 illustrates that the market share of a carrier highly depends on its frequency share on each route, which means we can project future airline market shares based on frequency simulation.

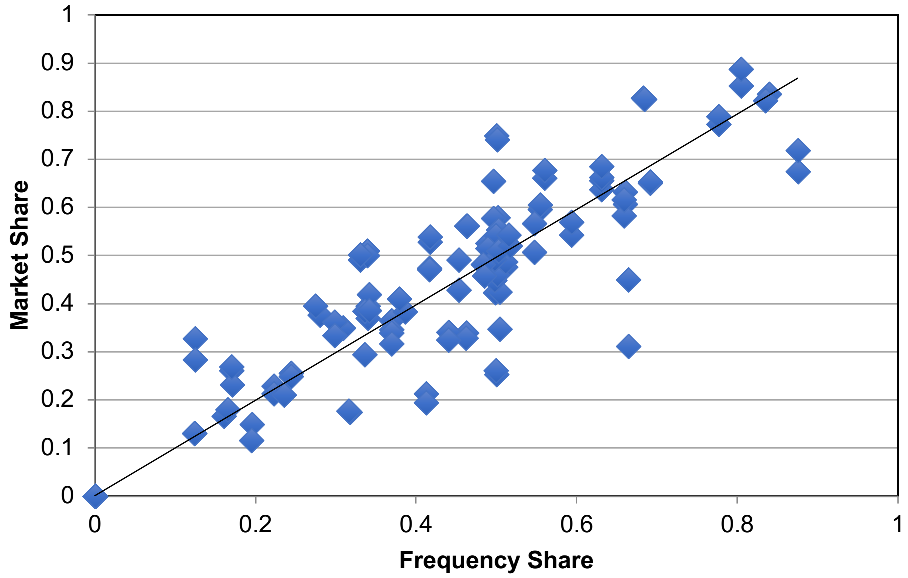


Figure 50 Relationship between the market share and the frequency share in 2013

As can be seen from Figure 51, there are three categories of airlines operating in EEA–China market: EU airlines, Chinese airlines and other airlines. In 2013, EU airlines and Chinese airlines shared most of the market while other carriers only have 1% of the market. The average ticket price for EU airlines, Chinese airlines and other airlines in 2013 is \$723.51, \$632.4 and \$593.89, respectively. It indicates that other airlines have smallest market share although they have the lowest ticket price, which corresponds to conclusions made in section 7.4.1 that air travel between EEA and China is not price elastic. Similarly, Figure 51 also indicates EU airlines and Chinese airlines have the account for most of the frequency share; however, the frequency share of other airlines is 10%, which is quite different from the market share. On the other hand, EU airlines have more market shares while the Chinese airlines have more frequency shares. This situation is not consistent with either what we have in Figure 50 or previous literature we discussed in section 7.2.

Due to the long travel distance between EEA countries and China, the aircraft type and load factors do not have many differences among all airlines operating in this market. This character is captured by Figure 50 as well. As a result, we can learn that the most possible cause for the inverse proportionate relationship between the market share and the frequency share could be the lack of the information about codeshare flights. For most cases, there would be one more marketing airlines for one flight not only because they are members of one airline alliance but also because they have those codeshare agreements allowing them to optimise their profitability with lower costs by sharing some flights in the same market. By sharing their flights with member airlines enables airline companies to have more frequencies could be shown to potential travellers and attract them to purchase tickets from those airlines.

Furthermore, the huge gap between the market share and the frequency share of other airlines is caused by the same reason to some extent but there is another reason that could lead to this happen. Because we are focusing on the market of flights between EEA countries and China, we did not include passengers arriving/departing outside these two areas; therefore, although other airlines have 10% frequency share, they may not have the same share of passengers because most passengers who chose other airlines could just transfer at these two areas and fly to somewhere else. Thus, due to the complexity of the market between EEA and China, it is not that accurate to project future market share only based on the frequency share and that is why we bring the discrete choice analysis into this chapter.

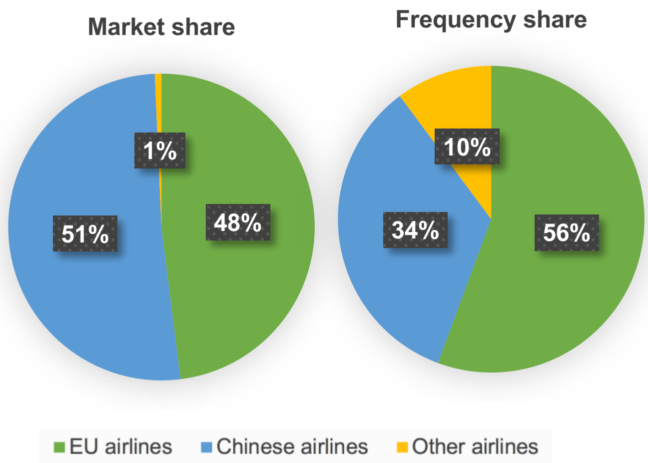


Figure 51 Airline market share and frequency share in 2013

7.4.4 Discrete choice analysis

The market share model (Eq. (11)) calculating market share of each airline is based only on their frequencies and competitors' frequencies. However, in real cases, passengers choose airlines not only based on their frequencies but also with other factors, such as airfares, travel time, direct flight or not, airline clusters. As shown in Table 28, the frequency is not the only important factor that would influence passengers' choices. Normally, a passenger would consider several factors when they make decisions on which itinerary to fly with, such as frequency, airfare, travel time, direct or not, and what airline choices they have on the itinerary. As can be learned from Table 28, all coefficients for the airline frequency are positive, which means travellers have preferences to choose itineraries with high frequency over itineraries with low frequency. This is consistent with the market share model that an airline company could attract more passengers by adding more flights to each itinerary.

Again, air travel for international flights is not price elastic, which is mainly because there is no alternative transport mode for passenger travel between EEA countries and China with similar travel times. Except for the group of South EEA to China, all coefficients for airfare is negative, which clearly indicates that fewer passengers would choose those itineraries with high airfare. However, it is a different case for the group of South EEA to China. There are several reasons this situation may result in: 1) airlines operating on those itineraries with higher airfares may have better onboard services (i.e. more choices on food and drinks or larger legroom); 2) more passengers have joined the alliance of those expensive airlines which are operating on itineraries between South EEA and China, which could allow them to cumulate mileages or exchange reward flights; 3) the most significant reason may be those expensive itineraries in this specific group including tourism attractive destinations.

In terms of direct flights, it is quite obvious that European airlines have competitive advantages since they are based in EEA states, which allows them to add more connecting flights between EEA countries and China because they have more hubs in the EEA territory than Chinese and other airlines. However, for Chinese and other airlines, they may only be able to add direct flights to their hub in EEA countries, which limits their air networks establishments and profoundly increases their travel time to destinations that are not their hub in EEA countries. In particular, the result of the group of West EEA to China concerning the direct flights' effect is different from other groups. This will be explained by the following discussion of the travel time.

When it comes to the travel time, for most groups the coefficient of travel time is consistent with the expectation that the coefficient is negative. In most cases, fewer passengers would choose itineraries with the increase of the travel time on those itineraries. However, it is absolutely no exceptions. As we can see from Table 28, for the group West EEA-China, the coefficient of the travel time is positive; this indicates travellers prefer paying for the longer journey. Previous studies also identify that there may be the presence of unobserved objective factors if the coefficient of the travel time is positive (Young and Morris 1981; Salomon and Mokhtarianb 1998; Mokhtarian and Salomon 2001). In this case, the reason for the positive coefficient of travel time of group West EEA-China may be: 1) the departure time of most passengers cannot meet the departure time of the itinerary with short travel time; 2) passengers would like to fly with airlines that they joined the membership even the itinerary they offer has longer journey time; 3) some passengers would like to stay at certain hubs for a longer time in order to purchase duty-free goods or even take a short visit in the connecting city. As we addressed in the model specification, for the same origin and destination pair, direct flights have the shortest travel time and connecting flights would add two more hours for each connecting stop. Therefore, if travellers between West EEA countries and China prefer travelling with itineraries with longer journey time, it is not surprising that they do not favour direct flights.

In terms of Class_All and Class_ONE, these are two dummy variables that indicate whether all three airlines clusters (EU, Chinese, other) operate on the same itinerary or not and whether there is only one airline cluster operate on the itinerary or not. For itineraries between West EEA and China, we can learn from the result listed below that there are no much differences for passengers for how many airline clusters operating on those itineraries. The reason for this case may be itineraries between West EEA countries and China are in high demand; therefore, no matter which airline is operating, travellers would travel anyway. For itineraries between North EEA and China, the coefficient of Class_ALL is zero but it does not mean there is no such case that all airline clusters operating on the same itinerary. The most possible reason here is the itinerary with all three airline clusters is quite rare in comparing with other itineraries in the sample data. On the other hand, we can learn from the negative coefficient of Class_ONE that passengers tend to choose itineraries with more airline choices than itineraries are operated by one airline cluster only. This is not surprising because passengers have their preferences for airline services and different membership schemes. In terms of the result showed for South EEA-China and Middle&East EEA-China, we can learn that travellers prefer to choose itinerary with more airline choices and we have explained why it is the case above.

In addition, the t statistics showed in Table 28 indicates Direct or not and how many airlines serving each itinerary are not significant to passengers' choices on itineraries. The most critical impact factors are frequencies, airfare and travel time. However, even those three dummy variabales are not quite significant in statistics, they still provide us with some understandings about how international travellers between EEA countries and China value each itinerary when they are making choices.

Table 28 Estimation result of discrete choice analysis[69]

Dependent Variable: Value of itineraries
Method: Maximum likelihood estimation
Total sample size: 1,215,467 (total passengers travelled between EEA and China in 2013)
Total chosen alternatives: 227 (total itinerary available between EEA and China in 2013)
() indicates standard errors
[] indicates t statistics

	Frequency	Airfare	Travel Time	Direct	Class_All	Class_ONE
West EEA-China	0.00681	-0.00152	0.317	-36.2	27.2	27.5
North EEA-	0.0207	-0.00223	-0.384	N/A	0	-30.2

[69] Full estimates results are presented in Apendix C.

China	(0.000425) [48.71]	(0.000139) [-16]	(0.0111) [-34.55]		(1.80e+308) [0]	(1.80e+308) [-0]
South EEA-China	0.00435 (1.17) [0]	0.00789 (0.000741) [10.66]	-0.0384 (0.0356) [-1.08]	8.76 (5.95e+3) [0]	0.509 (1.96e+4) [-0]	-19 (448) [-0.04]
Middle&East EEA-China	0.0259 (0.0187) [13.84]	-0.00372 (0.000959) [-3.88]	-0.0565 (0.0518) [-1.09]	24.8 (6.28e+03) [0]	3.05 (1.063+03) [0]	-21.2 (5.67e+03) [-0]

Note: There is no connecting flights between North EEA and China in the sample data, thus we did not include Direct as one of the explanatory variables.

As we mentioned travel time, it highly depends on whether the flight is non-stop since aircraft performances for all airlines on the same route have few differences. When it comes to airline competition, each carrier does not have much choice on changing their airline cluster, direct or not or travel time due to regulation and technology restrictions. Therefore, they can only compete on the frequency and airfare.

EU airlines Chinese airlines Other airlines

Figure 52 also presents market share of three category airlines in 2013, which indicates passengers favour Chinese airlines over other two categories. As illustrated in Table 29, EU airlines have most direct flights and highest operating frequencies; however, Chinese airlines have the largest market share. This has been explained in section 7.4.3 that the reason why Chinese airlines have more market share than EU airlines when they do not have more frequencies than that of EU airlines is the model could not detect the impact of codeshare agreements between airlines. For example, a flight flying from Shanghai to Paris is operated by Air France could have two marketing airlines[70]—Air France and China Southern Airline. In this case, passengers would definitely go for the airline with lower airfare, and that could explain why EU airlines have more frequencies but they could not attract more passengers than Chinese airlines.

Concerning travel time, there is not much difference among these three airlines on travel time, and international flights are not price elastic, which indicates passengers value direct flights and high frequency more than others when they make decisions. Compared to

[70] Marketing airline is a distinct concept with operating airline. Marketing airline means the airline could sell available seats on the flights and operating airline means the airline actually operates the flight. Each flight could have only one operating airline but normally it could have two marketing airlines.

the frequency share shown in Figure 51, the simulation market share presented in ■EU airlines ■Chinese airlines ■Other airlines

Figure 52 is closer to the real market share showed in the same graph below. Therefore, it proves that, although the airline frequency is a significant factor that could influence passengers' preferences, we still need to consider other impact factors, especially the airfare. Although international passengers are not price elastic, they would definitely willing to pay to the marketing airline with lower airfare for a codeshare flight.

To assess the impact of international aircraft emissions mitigation instruments on passenger airlines competition the market share model cannot achieve the objective by itself. Thus, we need to adopt airfare into the model at least. Yet the discrete choice analysis not only includes airline frequencies and airfares into the estimation but also involves other variables in the study. As a result, the discrete choice model will offer a more accurate simulation result although the airline frequency is a more crucial factor than airfare that would influence airlines market share. In particular, the result illustrated in Figure 52 indicates the simulation from the discrete choice analysis is closer to the real market share than the simulation from the market share model based on frequency share only. However, without the accurate data about how airlines share each codeshare flight and which flight is a codeshare flight, we could not get exactly the same market share as the real market share.

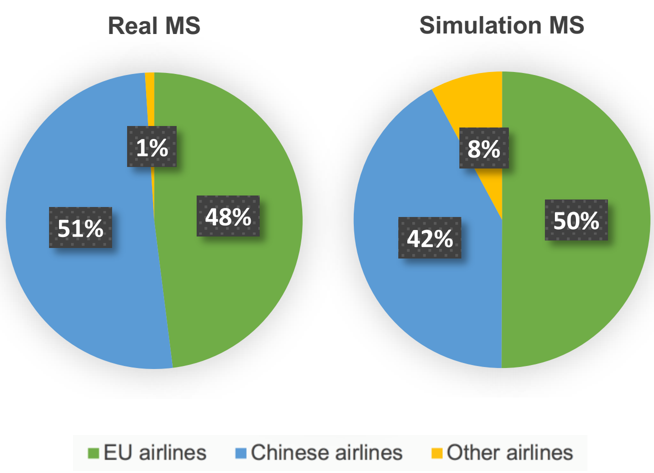


Figure 52 Real market share and market share simulation based on the discrete choice analysis in 2013

Table 29 Data description

Airline	MS	Average airfare	Travel time (h)	Frequencies	Direct
EU airlines	48%	$723.51	11.09	57475	207
Chinese airlines	51%	$632.40	10.67	35317	140
Other airlines	1%	$593.89	11.67	10493	60

7.4.5 Future market share simulation

As discussed in Chapter 4, ICAO has launched an international carbon offsetting scheme for the global aviation industry that called CORSIA. This abatement instrument will start to operate in 2020 for the voluntary phase. However, it is still unclear that how Member States of ICAO will react to CORSIA even though they have already agreed to the establishment of this MBM, especially for the EU. Since EU initiated the inclusion of the international airline industry into the emissions trading scheme, it is possible the EU will continue to apply its emissions trading system to international flights flying between EEA countries and other countries as this is one policy option addressed in their updated impact assessment. However, other countries opposed this severely in 2012 and led to a one-year suspension of the EU ETS in 2013. Therefore, if the EC would implement the EU ETS to international flights remaining unpriced, the most acceptable solution is to allow airlines from other countries to trade CERs or equivalent permits with EUAs to get emitting allowances under the European skies. As assumed in Chapter Six, many projects can be chosen by different airlines; thus, for the simplification of the simulation, the projection model assumes that all airlines that will join CORSIA are going to purchase CERs from the International Exchange to offset their footprints. Because WTP is uncertain due to different CER prices, the remaining CO_2 emissions will be offset by operating airlines.

Although international flights are not price elastic as presented in the previous analysis, it still needs to be verified whether changes in price from the extra cost of emissions trading or carbon offset would influence airline competition. In this section, we use the model that was built in Chapter Six to project future airfares and demand changes[71] for different airlines under the EU ETS or CORSIA and also forecast the corresponding demand changes on each route. However, in this section, we replace the demand model built in the simulation model with our one-equation gravity type model (Eq.10). For the price scenario, there are three different levels of allowances price and CERs price. Because the chapter assumes EU airlines will join the EU ETS, they will purchase EUAs to get their emissions allowances that still required. Thus, we project future EUAs prices based on historical trends and the OECD's forecast, which is $\sim N(6.9, 0.0856)$, $\sim N(50, 0.0856)$ and $\sim N(94.72, 0.0856)$ in USD. In addition, the CERs price has been forecasted in Chapter Six, which is $\sim N(0.45, 0.02)$, $\sim N(5.17, 1)$ and $\sim N(13.74, 0.04)$ in USD. The WTP of passengers travelling between EEA countries and China is also using the value that has been assumed in Chapter Six, which is 0%–20% under the lowest price scenario, 0%-15% under the middle price scenario, and 0%-10% under the highest price scenario for the period of 2020–2030.

As presented in Table 30, there are no differences for unit price and operating frequencies of each category of airlines in 2015 and 2020 because the model assumes the EU ETS and CORSIA will be implemented from 2020. Moreover, we can see from results in 2025 and 2030 that the operating frequencies will decrease with the increase of unit airfare, which means the overall travel demand will be affected by the implementation of international aircraft emissions mitigation mechanisms.

Table 30 Simulation results of unit prices and frequencies up to 2030 under different price scenarios

Year	Airline	Low price scenario		Middle price scenario		High price scenario	
		Unit price ($/RPK)	Frequency	Unit price ($/RPK)	Frequency	Unit price ($/RPK)	Frequency

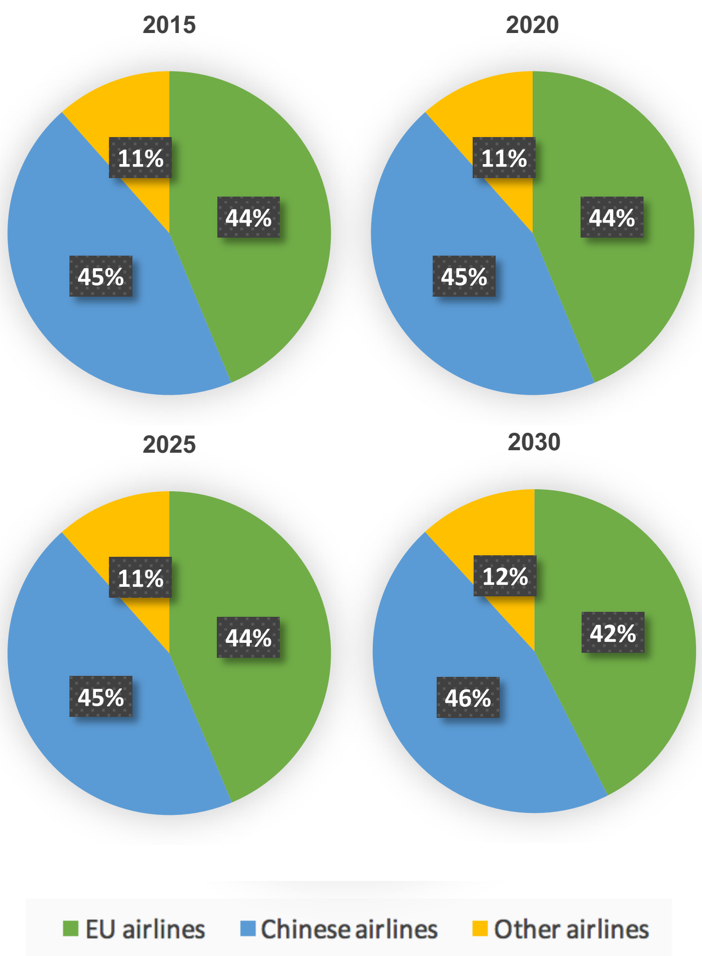
[71] As showed in Chapter 5, the price elasticity of demand does not have much differences due to different methods; therefore, we could calculate demand changes to baseline demand growth from extra costs by using equation from the simulation model showed in Chapter 6.

2015	EU airlines	0.0838	66310	0.0838	66310	0.0838	66310
	Chinese airlines	0.0749	40746	0.0749	40746	0.0749	40746
	Other airlines	0.0636	12106	0.0636	12106	0.0636	12106
2020	EU airlines	0.1105	70419	0.1105	70419	0.1105	70419
	Chinese airlines	0.0988	44599	0.0988	44599	0.0988	44599
	Other airlines	0.0839	15674	0.0839	15674	0.0839	15674
2025	EU airlines	0.1468	70213	0.1527	69922	0.1588	69849
	Chinese airlines	0.1303	44211	0.1304	44098	0.1306	44199
	Other airlines	0.1107	15046	0.1108	14936	0.1110	15039
2030	EU airlines	0.1943	70102	0.2061	69890	0.2184	69937
	Chinese airlines	0.1720	43908	0.1722	43777	0.1725	43902
	Other airlines	0.1461	14544	0.1463	14414	0.1467	14541

Then, this chapter explores the future market share of all three clusters of airlines up to 2030 based on their operating frequencies between EEA and Chinese airports only. As can be seen from the graph below (Figure 53), the market share of all three airline clusters are quite stable over the period 2015-2025, which accounts for 44%, 45% and 11% individually by EU, Chinese and other airlines. However, in 2030, there is 2% of passengers will choose Chinese and other airlines over European airlines, which result from the higher frequency growth of Chinese and other carriers. This is due to the assumption of the airline frequency competition, which has been explained in the methodology.

In particular, we assume aircraft carriers will compete with each other on their frequencies under the 'MYOPIC' game theory. To be more specific, this kind of strategy is short-sighted because airlines place their focus on the operating frequency only; it allows airline companies to add one more flight on a route between EEA and China when their competitors add one more flight until the total frequency meet the travel demand. In this process, aircraft carriers do not consider any other factors but only the response of other airlines' frequency changes. Thus, in this chapter, baseline future frequencies will be projected based on the total future demand under the BAU[72] scenario; and, the total frequency increase is allocated to all three airline clusters evenly.

The reason why partial passengers transfer from EU airlines to Chinese and other airlines is the increase in airfare coming from the EU ETS on EU airlines is higher than the increase in airfare coming from the CORSIA. Especially, some passengers are willing to offset their own carbon footprints by themselves which ease the cost burden of airline companies and lead to fewer costs that would be passed on airfare. Therefore, the result from the market share model shows even in the short period there would not have much impact on the airline market share due to different policies on competitors in the same market; but in the long term there would be competition distortion between EU airlines and all other airlines because they are facing more extra costs from aircraft emissions abatement.



[72] BAU here not only means there is no aircraft emissions mitigation policy but also means the average aircraft capacity will remain at the same with what we adopted in Chapter 6 for international flights.

Figure 53 Airline frequency share up to 2030 under the EU ETS and CORSIA

Furthermore, this section explores future market share of three airline clusters under the EU ETS and CORSIA based on the projection ticket prices and operating frequencies with discrete choice analysis. There are two assumptions: 1) all other factors remain the same, only prices and frequencies are changing due to emissions trading and carbon offset in the future; 2) emissions trading only applies to EU airlines of the market between EEA and China and Chinese and other carriers will join CORSIA. Because all extra costs from emissions trading and carbon offset would pass to passengers, EU airlines, therefore, would have the highest ticket price among the three. Figure 54 presents the market share of all three categories of carriers up to 2030 under three different levels of EUAs and CERs prices. As the model assumes the EU ETS and CORSIA will be applied to international flights between EEA countries and China from 2020, there will be no differences for the year of 2015 and 2020 under different price scenarios. Although there are very little differences of the market share under different levels of extra costs, the graph could not show them; thus, Figure 54 only presents one figure for the year 2025 and 2030, but the different market share values under different price scenarios are illustrated in Table 31.

By looking at the airline share that calculated by the discrete choice analysis in 2015 and 2020, the composition is different from the result of the market share model. In 2015, the frequency share for EU airlines, Chinese airlines and other airlines is 44%, 45% and 11%, respectively, while the market share of each category of carriers is 48%, 39% and 13%, respectively; and in 2020, the market share under both methods remain at the same. The differences between these two results come from the estimation process; the discrete choice analysis includes more explained variables that could influence airline market shares, especially the dummy variable Direct (whether the flight is direct or not).

Nevertheless, the operating frequency still is the most significant factor that would affect the airline market share since there is a direct proportion between airline frequencies and their market shares if we take out of the effect of codeshare flights. However, in the table below, we can learn that the demand changes caused by different levels of extra costs from EU ETS and CORSIA will not lead to differences in future frequency. However, EU airlines cannot add the same number flights as Chinese airlines and other airlines as we assumed in the baseline scenario because they will face more costs than the other two clusters of airlines in the model assumption. As can be seen from Table 31, the airline share of EU airlines keeps decreasing due to the increased airfare and slower frequency growth due to EU ETS.

Therefore, we can learn that different policies applied to competitors in the same market would definitely result in competition distortion because they do not face the same extra cost. In particular, we addressed above that for the codeshare flight passengers would absolutely pay to the airline with lower fares; therefore, applying two different policies in the same market is not fair for the company which is facing more costs.

In general, although having the highest ticket price as presented in Table 31, EU airlines still hold the largest market share during the whole investigated period although there may be a small drop due to the cost impact of the EU ETS. However, this is a situation without considering codeshare flights, which means EU airlines may have a smaller market share in the future.

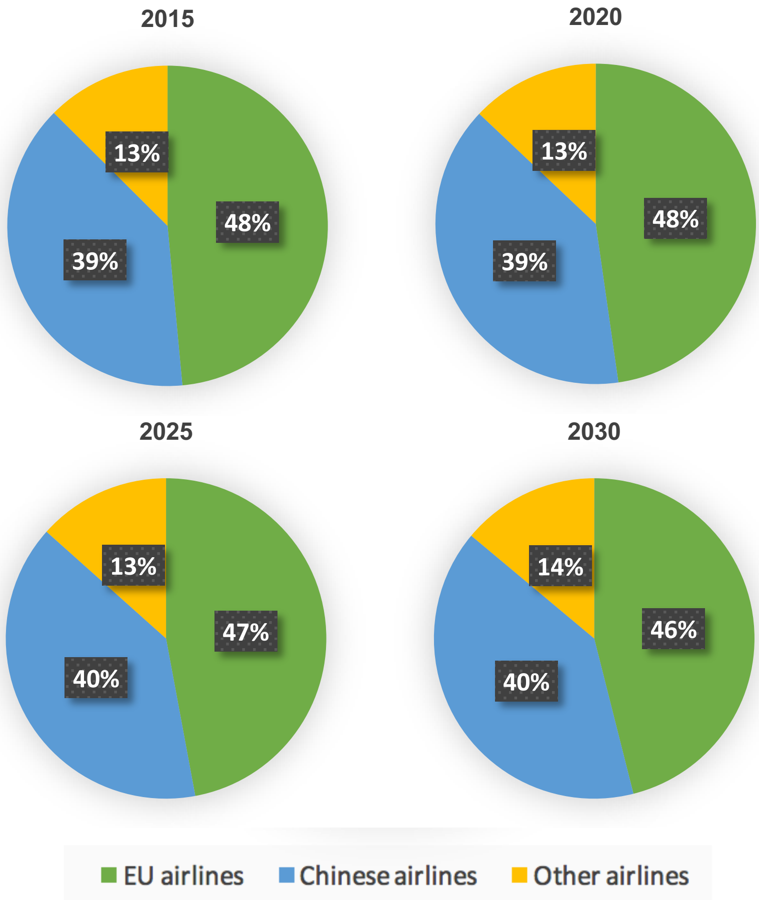


Figure 54 Airline market share of the market between EEA countries and China under the EU ETS and CORSIA up to 2030

Table 31 Projection results of market share, airfare and frequencies up to 2030 under different carbon price scenarios by discrete choice analysis

	Year	Airlines	Market share	Airfare ($/passenger)	Frequency
Low carbon price	2015	EU airlines	48.52%	867.13	66310
		Chinese airlines	38.94%	768.94	40746
		Other airlines	12.54%	654.96	12106
	2020	EU airlines	47.74%	1111.98	70419
		Chinese airlines	39.32%	986.07	44599
		Other airlines	12.94%	839.90	15674
	2025	EU airlines	47.08%	1433.24	70213
		Chinese airlines	39.53%	1264.57	44211
		Other airlines	13.39%	1077.14	15046
	2030	EU airlines	46.06%	1842.87	70102
		Chinese airlines	40.03%	1621.73	43908
		Other airlines	13.91%	1381.37	14544
Middle carbon price	2015	EU airlines	48.56%	867.13	66310
		Chinese airlines	38.86%	768.94	40746
		Other airlines	12.59%	654.96	12106
	2020	EU airlines	47.79%	1111.98	70419
		Chinese airlines	39.21%	986.07	44599
		Other airlines	13.00%	839.90	15674

	2025	EU airlines	46.84%	1473.79	70213
		Chinese airlines	39.67%	1264.50	44211
		Other airlines	13.49%	1077.07	15046
	2030	EU airlines	45.62%	1921.14	70102
		Chinese airlines	40.27%	1621.56	43908
		Other airlines	14.10%	1381.20	14544
High carbon price	2015	EU airlines	48.56%	867.13	66310
		Chinese airlines	38.94%	768.94	40746
		Other airlines	12.54%	654.96	12106
	2020	EU airlines	47.52%	1111.98	70419
		Chinese airlines	39.32%	986.07	44599
		Other airlines	12.94%	839.90	15674
	2025	EU airlines	46.56%	1516.73	70213
		Chinese airlines	39.53%	1264.50	44211
		Other airlines	13.39%	1077.07	15046
	2030	EU airlines	45.34%	2004.16	70102
		Chinese airlines	40.03%	1621.56	43908
		Other airlines	13.91%	1381.20	14544

7.5 Conclusions

This chapter has sufficiently explored several factors that would influence the airline competition. A case study of flights between EEA countries and China has been performed because both EU and China are major players in the international negotiation of global aircraft emissions abatement; thus, carbon control will highly likely to be put into this market. A baseline based on BAU scenario has been developed firstly to present the demand projection of this market. air travel demand between these two large areas will increase by 4.8% per annum in the future, which is consistent with other projections (i.e. Boeing, ICAO). The study continues to analyse how the EU ETS and CORSIA would influence the airline competition. It is learned that international flight is not price elastic and operating frequencies are more significant for market share distribution. Apart from these two factors, passengers placed more focus on whether the flight is direct or not, travel time and operating airlines when they make choices of booking flights. As discussed in the results, airlines do not have much choice on changing air route, travel time and their cluster due to regulations and technology. Consequently, airlines can only compete based on ticket prices and frequencies. It also indicates in the previous analysis, market share will not be affected a lot (around 2% at most) even though the emissions trading will be only applied to one airline cluster and the other two will join CORSIA under the leadership of ICAO.

However, there are several limitations of the study in this chapter. For demand model, future air travel demand is forecasted based on the historical growth of population and personal income, which is not precise since these two variables also would be affected by other variables; thereby, demand forecast may be different if the model including other variables to forecast population and personal income as well. To investigate market share, this chapter firstly modelled relationship between market share and frequency share. It is learned that there is no ‘S-curve’ between them in economy class. However, the market share model does not include other factors that could influence market share.

Furthermore, the study overcomes shortages of market share model by adopting discrete choice analysis on passengers’ choices. In the discrete choice analysis, this chapter modelled schedule data from Sabre Data of flights between EEA countries and China for itinerary choice. The intention at the beginning is to run airline choice analysis rather than itinerary choice. However, the dataset has been chosen does not include social economic factors, such as airline members, personal income and airline service level. Hence, the simulation result may vary if more variables are included to run airlines choice model. Even for the itinerary choice mode, the dataset we are using is lack of the information about the codeshare flight, this may lead to the market share of each airline cluster is not that accurate. Nonetheless, we are more interested in the changes of market shares of each cluster of airlines; therefore, it is not that important what the composition is for the real market share.

In summary, emissions trading will only lead to a very small competition distortion in the international aviation industry based on the analysis taken above; however, it is still not fair for EU airlines because they are facing more costs than their competitors. Therefore, EU should allow all flights departing from / arriving at EEA airports join the CORSIA no matter what airlines are operating.

Chapter 8 Conclusions

Prior to this thesis there had been limited studies about how air travel demand and aircraft emissions of Chinese airlines increased; and in terms of emissions abatement, studies had been only focussed on technology innovation and operational measures. Therefore, this thesis investigated historical drivers of increasing Chinese air travel volume and relative aircraft emissions; and also, build-up scenarios up to 2030 about international flights carried by Chinese airlines under the BAU scenario, emissions trading and carbon taxation. Furthermore, by conducting the case study of the market between China and EEA countries, the thesis also studied the significance of each service factor to passengers' choices and whether emissions abatement instruments would affect those decisions. In addition, there is a discussion about future co-operation of building global aviation emissions abatement scheme, which addressed both political and legal challenges and also argued possible actions for each category of mitigation policies.

As can be seen from previous chapters, absolute aircraft emissions abatement can only be achieved by reducing air travel demand. However, how policymakers and stakeholders would react to this situation would influence how international aviation emissions abatement go further. As can be seen from the negotiation during the establishment of CORSIA, developing countries are still fighting for their rights and interests, which is insisting on the principle of polluters (developed countries) pay. From the industry perspective, they intend to adopt technological or operational measures since these two kinds of options would not lead to revenue loss caused by demand drop. They tend to have national government support and generally point to the ambitious technological targets that the industry has set for itself.

The primary contribution of this work can be summarized as effectively answering the following question: investigating through modelling the possible outcomes of different market-based mechanisms for air travel demand, CO_2 emissions, airline revenue and the competitiveness of Chinese airlines, while using these model results as a basis for exploring potential political applications for further co-operation in establishing an international mitigation policy for aviation emissions.

In particular, this study investigates the climate impacts of the international aviation sector in China, as well as the effects on emissions abatement instruments. The analysis is drawn based on the discussions on the mitigation of aircraft emissions in different scopes. After examining of the outcomes and current situations in China, one of the major emitting countries in the world, this study overviews the domestic and global policies regarding emissions of aviation sectors. Applying different mitigation instruments and exploring political implications in a global scope, this study focuses on the impact to the Chinese aviation industry through a range of modelling work to examine the influences of carbon constraints on air travel demand, CO_2 emissions, airline revenue, and the competitiveness of Chinese airlines. Examining the climate impact of Chinese international aviation, the necessary to mitigate aircraft emissions has also been addressed internationally, which means international co-operation is needed for international aviation decarbonization. According to the findings achieved in this study, the following objectives have particularly been obtained.

8.1 Discussion on Different Mitigation Options for the Passenger Airline Industry

Different mitigation options are first overviewed regarding the progress of the decarbonisation in the passenger airline industry. The discussion has been drawn out based on why it is of necessity to decarbonise the civil aviation sector and what instruments can be applied to it. The discussion is then carried out on different economic instruments on the passenger air transport sector as well as the acceptability of these instruments for different existing or potential participants. By reviewing the existing literature on the establishment of economic measures for reducing aircraft emissions, the discussion mainly focuses on the mechanisms and how airlines and the Member States reacts to it. In addition, the discussion has also emphasized on the future development of aircraft emissions mitigation instruments beyond 2020. Choosing one of the most famous regional aircraft emissions abatement mechanism as an example, EU ETS, it is also discussed regarding the potential progress and design options for international aviation industry decarbonisation.

8.2 Examination of the Climate Impact of the Chinese Passenger Airline Industry

The examination of this objective has been explored based on the historical driving factors that push the growth of air travel demand and build a baseline scenario for future growth in Chinese aviation and relevant CO_2 emissions. The examination of the Chinese aviation industry has been conducted on both domestic and international emissions mitigation and in particular the potential role of a global aviation mitigation instrument. It firstly reviews the history of Chinese aviation industry and suggests there has been a spectacular growth in the Chinese aviation in recent decades associated with high volumes of aircraft emissions. The historical performance of Chinese airlines is examined on international passenger transport over the period 1986–2015 using a time series analysis. Specifically, several indicators are discussed as follows: RPK, transport revenue, price elasticity and income elasticity of demand, fuel consumption and efficiency, as well as CO_2 emissions. The purpose of examining these historical trends is firstly, to gain insights into the drivers of CO_2 emissions, and secondly, to establish parameters for a future baseline scenario.

By looking at the historical developments of the Chinese airlines in both domestic and international passenger transport markets, we can learn that there is a steady but heavy growth for Chinese airlines operation; and consequently, the Chinese passenger airline industry does contribute a lot of CO_2 emissions in the global aviation industry, in particular, China will become the largest emitter in the aviation sector by 2030. Furthermore, both domestic and international passengers in China are not price elastic according to our analysis. However, due to limited data, this analysis is only based on the national GDP in China and average ticket price from Chinese airlines; which means it may vary if there are more variables or data included to run a city pair analysis. Not all of the previous literature supports this decision because most research believes that domestic air travel should be price elastic, which indicates it will majorly influence the air travel demand if there is any extra cost due to emissions abatement instrument existing.

As we discussed in section 6.4.5, if domestic air travel is price elastic (ed=-1.06) and the airfare remains at the historical growth, the direct CO_2 emissions from Chinese airlines would decrease by 42% in comparing with the baseline scenario even the international passengers are still price inelastic (ed = -0.8), and there is no any mitigation schemes. The projected trends in demand for the most negative values of the price elasticity (-1.6 for domestic air travel and -1.058 for international air travel) used differ substantially from other projections of demand in the Chinese market and would seem to suggest that these values are not suitable for Chinese aviation demand. Therefore, the price elasticity of demand should be subject to further examination since it definitely affects whether there is a huge influence on passenger air travel due to emissions mitigation measures in the following research. It then describes the methodology used to examine the historical drivers of emissions in the Chinese passenger airline industry. Because no detailed and publicly available statistics have been carried out regarding CO_2 emissions, the two-tiered methodology in the ‘Greenhouse Gas Inventory Reference Manual’ is particularly selected as a framework in this study for estimating and reporting the emissions from the airline sector. The two-tiered methodology is:

- The first tier is the simplest methodology, based only on an aggregate number for fuel consumption to be multiplied with average emission factors; and

- The second tier methodology estimates emissions in two flying phases: LTO and cruise.

For cost impact calculations, all studies assumed that the cost of CO_2 allowances is passed on to consumers causing an increase in airfares. These calculations are based on the average fuel consumptions for different types of aircraft and flight distances, and on estimates for passenger payload and cost pass-through rate. For the observation of empirical analysis, the chose major carriers are conducted on both domestic and international flights. The demand model driven by ticket price and national GDP showed us the demand growth is mainly driven by GDP growth, which means the demand for air travel carried by Chinese airlines is highly likely to continue growing heavily if the economic growth in China remains rapidly (Maurice et al. 2001). It is clear that there is a huge increase in the air travel demand, mostly driven by GDP in China. According to the sensitivity analysis, if the national GDP would grow by 7% per annum in the government Five Year Plan, there would be 146 million tonnes CO_2 emissions from Chinese passenger airlines; however, if the national GDP would only increase by 5.5% each year, direct CO_2 emissions from the industry would be 25% less than the baseline scenario.

From the historical analysis, we also examined the price elasticity by using two different approaches. Both methodologies indicate passenger air travel is not price elastic in China no matter it is domestic or international and the value from two approaches are quite similar to each other. Although the PED of domestic air travel is not consistent with most previous literature, the result still falls in the range of elasticities of air travel based on previous studies. Moreover, the fuel consumption of aircraft was tremendous for both domestic and international air travel as can be seen form the historical analysis although the fuel efficiency has been improved by approximately 2% per year. Consequently, CO_2 emissions from Chinese airlines are remarkable as well.

8.3 Investigation of Possible Outcomes of Different Mitigation Instruments

The outcomes of the model are mainly on flights carried by Chinese airlines only and the competitiveness of Chinese airlines based on the exploring of the future baseline scenario in the absence of any significant mitigation policy.

- Firstly, it reviews existing literature on the projection of climate impact from the passenger airline industry. It then describes the demand model built here for forecasting future passenger air travel demand and its relevant carbon CO_2 emissions. The demand model consists of two levels to analyse two different sub-scopes of the international aviation sector: one is for all international flights carried by Chinese airlines and another is for international flights between EEA countries and China. The first level of the demand model is only based on one state's situation to project the demand and relevant CO_2 emissions of Chinese domestic and international passenger air transport. It suggests Chinese passenger airline industry will definitely contribute a lot of emissions (146 million tonnes of direct CO_2 emissions for both domestic and international air passenger travel) without carbon constraints by the end of 2030. The second level of the demand model is based on region pair, which includes both EEA NUTS3 regions and Chinese major cities. According to the projection, the air travel demand of flights between EEA countries and China would increase by 4.8% per year;
- Secondly, modelling flights by Chinese airlines, in particular, examines the impacts of applying a carbon tax, building a domestic emissions trading scheme, or applying voluntary carbon offsetting scheme on airfares, passenger behaviours, extra costs, emission reductions and airline revenue loss. Because the baseline activity and CO_2 emissions from flights carried by Chinese airlines up to 2030 have been projected first, this study projects the effect of carbon taxation or the

effect of emissions trading carbon offsetting by modelling the price impact on travel behaviour and the subsequent impact of this on emissions in the future. By comparing the modelling results for both direct CO_2 emissions abatement and revenue changes, emissions trading seems more appealing to the Chinese government and passenger airlines because it could reduce 6.7% of CO_2 emissions in 2030 in comparing with the amount of baseline scenario in the same year; and, it would raise the revenue for both the government and airline companies;

- Thirdly, it is found that the sensitivity analysis performed for several variables—price elasticity of demand, market growth and efficiency growth—could influence the main output to a great extent. Combining the discrete choice model on air travel demand with market share model on airline competition together to examine how emissions mitigation instruments influence passengers' choice on airlines and how airlines would compete with each other under carbon constraints. It examines drivers of how passengers choose airlines and how passengers' choices influence the airline market share. Then it compares frequency competition analysis and discrete choice analysis to justify the final forecast of future market shares. This chapter chooses international flights between EEA countries and China as the case to perform competition analysis under emissions mitigation instruments. It shows airlines from different regions or countries are having different extent of advantages or disadvantages under carbon constraints since some of them may have lower costs under different scenarios, which lead to the result of competition distortion.

8.4 Policy implications for Chinese passenger airlines in reducing aircraft emissions

8.4.1 Policy implications for the domestic passenger airlines industry

As we discussed the cost impacts on direct CO_2 emissions from Chinese passenger airlines in Chapter 6, all three mitigation policies—carbon taxation, emissions trading and carbon offsetting—would have different effects on aircraft emissions and Chinese passenger airlines. From the perspective of direct CO_2 emissions abatement, the carbon tax seems to be the most effective instrument; however, it would result in revenue loss in comparing with the baseline scenario. Carbon taxation is a mitigation policy that reduces aircraft emissions purely by suppressing the air travel demand. Because all taxation is going be paid by passengers, which means there are no extra costs for passenger airline companies and it would not provide incentive or pressure for aircraft carriers to reduce direct emissions by innovating technologies or improving air traffic management.

When it comes to carbon offsetting, we can clearly see that there are no extra costs for airline companies as well, but it does not have a significant impact on aircraft emissions because the reduction is fully based on the passengers' wiliness to pay for carbon offsetting. Therefore, if no one or only small proportion of passengers would like to pay, there would not be many emission reductions can be achieved. Nonetheless, Chinese passenger airlines could also apply the carbon offsetting with their customers because it is a good way to raise passengers' awareness on the issue of climate change induced by human activity.

Emissions trading seems to have more advantages than carbon taxation and carbon offsetting because it could raise extra revenues for both the government and airline companies and in the same time to reduce aircraft emissions by suppressing the growth of passenger air travel demand. Moreover, Chapter 6 discussed the method of free allowances allocation over different time periods and the different price scenarios, it may provide some insights for the Chinese government to include passenger airlines into the nationwide emissions trading scheme as they only have the guidance for the electricity industry at this moment. Especially, if the Chinese government would allow the airline industry to purchase allowances from the electricity industry, it would lead to extra emission reductions from the electricity industry as well.

In conclusion, China should include the aviation industry in their domestic emissions trading scheme to achieve the sustainable growth for the airline industry and also to reach their emissions reduction target as they promised under the Paris Agreement. The first reason why we choose emissions trading has been discussed above, which is it could raise revenues for both airline companies and the Chinese government. From the airlines' perspective, the extra revenue from the increased airfare due to emissions trading could be used in technology innovation for reducing aircraft emissions. From the point of view of the government, the revenue from allowances auction could be used to sponsor any technology research that could contribute to emissions reductions or build infrastructures for high-speed rail. In the meantime, the Chinese government could also encourage airlines to apply carbon offsetting schemes with their flights and it may contribute to more aircraft emissions abatement.

8.4.2 The role of China in the international cooperation for aircraft emissions abatement

As the largest emitter, China has its responsibility to reduce aircraft emissions. From our simulation in Chapter 6, CO_2 emissions from the Chinese air passenger transport are projected to grow to 146 million tonnes with an annual increase of 6% and becomes the largest emitter in the aviation sector as well. Therefore, even China cannot join any international or regional emissions mitigation scheme at this stage. The need for aviation emissions abatement is quite urgent.

As has been discussed in Chapters 3 and 4, there are several measures to mitigate carbon emissions from the aviation sector: technology innovation, alternative energy, operational management improvement, regulatory approach, market-based mechanism and other voluntary approaches or commitments. In particular, past literature has strongly supported the cost-efficient and the effectiveness in reducing aircraft emissions of the MBMs. In China, there have been seven pilot schemes in different cities to mitigate GHG emissions for diverse industries. In particular, Shanghai is the only one among the six airlines (China Eastern, Shanghai Airlines, Chunqiu Airlines, etc.) based in its territory and its local emissions trading scheme. This is an admirable action, but it also raised the concern about the fairness in competition because it did not equally treat competing airlines on the same routes.

To ensure fairness in competition, in 2017, these seven pilot schemes started to be incorporated into a national emissions trading scheme, which includes several industries (i.e. aviation). Although this nationwide scheme has not started yet, it still establishes a solid foundation for China to participating international negotiations for global aircraft emissions abatement and may provide opportunities to co-operate with other regional schemes, such as the EU ETS.

The air transport sector is quite different from other energy-intensive industries since aircraft emissions spill across borders because the source of emissions is flying across different countries. For instance, an international flight will lead to environmental damage in all countries the aeroplane passed through. Therefore, all governments and airlines should drop their ‘beggar-thy-neighbour’ tactics to seek international co-operation in mitigating global aircraft emissions. From the perspective of China, the most reasonable option is to join CORSIA. However, the creditability and efficiency of this scheme are still questioned by researchers and it will start in 2020. Therefore, at this point, China may need to find other co-operation to reduce emissions from international flights. In the meantime, the EU ETS re-includes international flights into its regional system, which provides another option to China for international co-operation. However, this requires several stages of discussions on how to co-operate or linking with the Chinese domestic emissions trading scheme.

During negotiations led by ICAO, China does not oppose to reduce international aircraft emissions through market-based mechanisms but insist with the ‘common but differentiated responsibilities’ principle, which means to ask developed countries to abatement emissions first and to allow developing countries having more time to progress. However, the US, the EU and other developed countries argued there is no such rule in the Chicago Convention; thus, it cannot be applied to aircraft emissions abatement globally.

Regarding economic growth and corresponding GHG emissions for China, Brazil, India, and similarly situated countries, it is impossible for them to be treated differently or exempted from the scheme in the long term. This can be also seen from the setting in CORSIA. Although the pilot phase and first phase are voluntary for all Member States, ICAO requires all airlines from the Member States to participate in CORSIA during the second phase. Therefore, in future negotiations, China could apply the CBDR from a different angle, which transfers the identity from a country to a specific carrier. To be more specific, we could fight for exemptions for airlines having higher fuel efficiency; this would also lead to an incentive for airlines to accelerate their technology innovation and improvements in operational management. Then, we could ask for a transitional period for aircraft carriers from developing countries, which means they could be exempted from the scheme for a short period (up to 5 years). Furthermore, an emissions reduction fund could be established under ICAO that could be used to sponsor developing countries to achieve their carbon neutralisation obligations under CORSIA.

8.5 Future Research Directions

The thesis addresses a key research gap in the aircraft emissions abatement in the Chinese passenger airline industry.

Further research is required in this area to enable greater understanding of the outcomes of applying economic mitigation instruments to both domestic and international flights carried by Chinese airlines. This research places focus on impacts of different economic instruments that may be applied to the domestic flights in the future and the influence of CORSIA on international flights operated by Chinese airlines. A system dynamic model was constructed to assess the cost impact of each instrument on air transport demand, airfare, airline revenue and CO_2 emissions. However, it does not model impacts of each mechanism on other aspects, including welfare, taxes reform, sector interactions and revenue distribution. Therefore, the first area that can be investigated in the future is to assess all those aspects by building an integrated model that involves multiple sectors. By comparing all impacts from carbon taxation, emissions trading and carbon offsetting on all settings, we can get a better understanding about which policy instrument is more suitable for the Chinese passenger airline industry.

Secondly, the case study can be applied to any international markets. However, in further research about airline competitions under the emissions abatement mechanism, researchers could combine the revealed preference data and stated preference data together to get a more accurate result about how passengers would react for different policies. By designing the stated preference experiment, we could learn more about travellers' socio-economic characteristics, such as gender, age, personal income and membership in frequent flyer programmes. All these factors could affect passengers' choices on different airlines, and they could reveal which kind of travellers would be more sensitive to the changes induced by emissions reduction measures.

Finally, further research can be explored is the linkage between China's emissions trading scheme and other regional emissions trading schemes, such as the EU ETS. Although China opposed joining the EU ETS on the inclusion of the aviation, it does not mean China thinks it is not necessary to reduce aircraft emissions globally. As the second largest air transport market, China is obligated to seek measures to reduce emissions from the airline sector. Except for domestic efforts, China needs to pursue international co-operation to achieve its abatement objectives.

As policy focus turns to the post-2020 period, it seems that more and more countries will pursue cost-efficient methods to abate aircraft emissions domestically and globally. In particular, since there is no CBDR principle existing in the Chicago Convention, developing countries are also obligated to reduce aircraft emissions under the lead of ICAO. Although there are doubts about the efficiency of CORSIA for international aircraft emissions neutralisation, it is a huge step for international co-operation on mitigating global aviation emissions.

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Appendix A

A.1 Unit root test

Table A.1. 1 Unit root test for LGRPK_D at level with constant only

Exogenous: Constant				
Lag Length: 2 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			0.757808	
Test critical values:	1% level			-2.650145
	5% level			-1.953381
	10% level			-1.609798
*MacKinnon (1996)				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1988 2015				
Included observations: 28 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	0.014182	0.018714	0.757808	0.4557
D(GLSRESID(-1))	0.351316	0.188704	1.861728	0.0744
D(GLSRESID(-2))	0.323496	0.173505	1.864479	0.074
R-squared	-0.462202	Mean dependent var		0.133378
Adjusted R-squared	-0.579178	S.D. dependent var		0.094753
S.E. of regression	0.119072	Akaike info criterion		-1.31722
Sum squared resid	0.354453	Schwarz criterion		-1.174484
Log likelihood	21.44108	Hannan-Quinn criter.		-1.273584
Durbin-Watson stat	1.992621			

Table A.1. 2 Unit root test for LGRPK_D at level with constant and linear trend

Null Hypothesis: LGRPK_D has a unit root			
Exogenous: Constant, Linear Trend			
Lag Length: 2 (Automatic - based on AIC, maxlag=5)			
			t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-1.805245	
Test critical values:	1% level		-3.77
	5% level		-3.19
	10% level		-2.89
*Elliott-Rothenberg-Stock (1996, Table 1) Warning: Test critical values calculated for 50			

observations and may not be accurate for a sample size of 28				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1988 2015				
Included observations: 28 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.264826	0.146698	-1.805245	0.0831
D(GLSRESID(-1))	0.097546	0.195192	0.499745	0.6216
D(GLSRESID(-2))	0.066286	0.181076	0.366069	0.7174
R-squared	0.111006	Mean dependent var		-0.009128
Adjusted R-squared	0.039887	S.D. dependent var		0.094753
S.E. of regression	0.092844	Akaike info criterion		-1.814828
Sum squared resid	0.215502	Schwarz criterion		-1.672092
Log likelihood	28.40759	Hannan-Quinn criter.		-1.771192
Durbin-Watson stat	1.882515			

Table A.1. 3 Unit root test for LGRPK_D at first differences with constant only

Null Hypothesis: D(LGRPK_D) has a unit root				
Exogenous: Constant				
Lag Length: 1 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-2.569798	
Test critical values:	1% level			-2.650145
	5% level			-1.953381
	10% level			-1.609798
*MacKinnon (1996)				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1988 2015				
Included observations: 28 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.586347	0.228168	-2.569798	0.0163
D(GLSRESID(-1))	-0.161185	0.191576	-0.841361	0.4078
R-squared	0.362367	Mean dependent var		-0.006429
Adjusted R-squared	0.337843	S.D. dependent var		0.139411
S.E. of regression	0.113443	Akaike info criterion		-1.446277
Sum squared resid	0.334604	Schwarz criterion		-1.35112
Log likelihood	22.24788	Hannan-Quinn criter.		-1.417186
Durbin-Watson stat	1.864236			

Table A.1. 4 Unit root test for LGRPK_D at first differences with constant and linear trend

Null Hypothesis: D(LGRPK_D) has a unit root				
Exogenous: Constant, Linear Trend				
Lag Length: 1 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-3.553653	
Test critical values:	1% level			-3.77
	5% level			-3.19
	10% level			-2.89
*Elliott-Rothenberg-Stock (1996, Table 1) Warning: Test critical values calculated for 50 observations and may not be accurate for a sample size of 28				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1988 2015				
Included observations: 28 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.924001	0.260014	-3.553653	0.0015
D(GLSRESID(-1))	-0.001867	0.190927	-0.009776	0.9923
R-squared	0.465322	Mean dependent var		-0.001362
Adjusted R-squared	0.444758	S.D. dependent var		0.139411
S.E. of regression	0.103882	Akaike info criterion		-1.622375
Sum squared resid	0.280578	Schwarz criterion		-1.527218
Log likelihood	24.71325	Hannan-Quinn criter.		-1.593285
Durbin-Watson stat	1.868674			

Table A.1. 5 Unit root test for LGRPK_I at the level with constant only

Null Hypothesis: LGRPK_I has a unit root				
Exogenous: Constant				
Lag Length: 5 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-0.095396	
Test critical values:	1% level			-2.66072
	5% level			-1.95502
	10% level			-1.60907
*MacKinnon (1996)				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				

Sample (adjusted): 1991 2015				
Included observations: 25 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.003131	0.03282	-0.095396	0.925
D(GLSRESID(-1))	-0.003236	0.217061	-0.014911	0.9883
D(GLSRESID(-2))	0.161636	0.198616	0.813812	0.4258
D(GLSRESID(-3))	0.250852	0.18872	1.329232	0.1995
D(GLSRESID(-4))	0.247529	0.187754	1.318369	0.2031
D(GLSRESID(-5))	0.342801	0.192817	1.777862	0.0914
R-squared	-0.202425	Mean dependent var		0.140057
Adjusted R-squared	-0.518852	S.D. dependent var		0.121686
S.E. of regression	0.149968	Akaike info criterion		-0.751227
Sum squared resid	0.427318	Schwarz criterion		-0.458697
Log likelihood	15.39033	Hannan-Quinn criter.		-0.670091
Durbin-Watson stat	2.166998			

Table A.1. 6 Unit root test for LGRPK_I at the level with constant and linear trend

Null Hypothesis: LGRPK_I has a unit root				
Exogenous: Constant, Linear Trend				
Lag Length: 0 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-4.402439	
Test critical values:	1% level			-3.77
	5% level			-3.19
	10% level			-2.89
*Elliott-Rothenberg-Stock (1996, Table 1) Warning: Test critical values calculated for 50 observations and may not be accurate for a sample size of 30				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1986 2015				
Included observations: 30 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.806514	0.183197	-4.402439	0.0001
R-squared	0.40059	Mean dependent var		0.00046
Adjusted R-squared	0.40059	S.D. dependent var		0.137154
S.E. of regression	0.106187	Akaike info criterion		-1.614468
Sum squared resid	0.326994	Schwarz criterion		-1.567761
Log likelihood	25.21702	Hannan-Quinn criter.		-1.599526
Durbin-Watson stat	1.85815			

Table A.1. 7 Unit root test for LGRPK_I at first differences with constant only

Null Hypothesis: D(LGRPK_I) has a unit root				
Exogenous: Constant				
Lag Length: 0 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-6.639058	
Test critical values:	1% level			-2.64712
	5% level			-1.95291
	10% level			-1.610011
*MacKinnon (1996)				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1987 2015				
Included observations: 29 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-1.237004	0.186322	-6.639058	0
R-squared	0.61068	Mean dependent var		0.010237
Adjusted R-squared	0.61068	S.D. dependent var		0.223134
S.E. of regression	0.139226	Akaike info criterion		-1.071567
Sum squared resid	0.542746	Schwarz criterion		-1.024419
Log likelihood	16.53772	Hannan-Quinn criter.		-1.056801
Durbin-Watson stat	1.945154			

Table A.1. 8 Unit root test for LGRPK_I at first differences with constant and linear trend

Null Hypothesis: D(LGRPK_I) has a unit root				
Exogenous: Constant, Linear Trend				
Lag Length: 0 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-7.106202	
Test critical values:	1% level			-3.77
	5% level			-3.19
	10% level			-2.89
*Elliott-Rothenberg-Stock (1996, Table 1) Warning: Test critical values calculated for 50 observations and may not be accurate for a sample size of 29				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				

Sample (adjusted): 1987 2015				
Included observations: 29 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-1.284601	0.180772	-7.106202	0
R-squared	0.643054	Mean dependent var		0.005794
Adjusted R-squared	0.643054	S.D. dependent var		0.223134
S.E. of regression	0.133311	Akaike info criterion		-1.158385
Sum squared resid	0.497614	Schwarz criterion		-1.111237
Log likelihood	17.79658	Hannan-Quinn criter.		-1.143619
Durbin-Watson stat	2.042966			

Table A.1. 9 Unit root test for LGATP_D at the level with constant only

Null Hypothesis: LGATP_D has a unit root				
Exogenous: Constant				
Lag Length: 0 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-1.056671	
Test critical values:	1% level			-2.644302
	5% level			-1.952473
	10% level			-1.610211
*MacKinnon (1996)				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1986 2015				
Included observations: 30 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.036382	0.034431	-1.056671	0.2994
R-squared	-0.156882	Mean dependent var		0.060136
Adjusted R-squared	-0.156882	S.D. dependent var		0.136282
S.E. of regression	0.146583	Akaike info criterion		-0.969685
Sum squared resid	0.62311	Schwarz criterion		-0.922979
Log likelihood	15.54528	Hannan-Quinn criter.		-0.954743
Durbin-Watson stat	0.999732			

Table A.1. 10 Unit root test for LGATP_D at the level with constant and linear trend

Null Hypothesis: LGATP_D has a unit root				
Exogenous: Constant, Linear Trend				
Lag Length: 0 (Automatic - based on AIC, maxlag=5)				
				t-Statistic

Elliott-Rothenberg-Stock DF-GLS test statistic			-0.843444	
Test critical values:	1% level			-3.77
	5% level			-3.19
	10% level			-2.89

*Elliott-Rothenberg-Stock (1996, Table 1) Warning: Test critical values calculated for 50 observations and may not be accurate for a sample size of 30

DF-GLS Test Equation on GLS Detrended Residuals

Dependent Variable: D(GLSRESID)

Method: Least Squares

Sample (adjusted): 1986 2015

Included observations: 30 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.066676	0.079053	-0.843444	0.4059
R-squared	0.022854	Mean dependent var		-0.004477
Adjusted R-squared	0.022854	S.D. dependent var		0.136282
S.E. of regression	0.134716	Akaike info criterion		-1.138533
Sum squared resid	0.526302	Schwarz criterion		-1.091826
Log likelihood	18.07799	Hannan-Quinn criter.		-1.123591
Durbin-Watson stat	1.155173			

Table A.1. 11 Unit root test for LGATP_D at first differences with constant only

Null Hypothesis: D(LGATP_D) has a unit root

Exogenous: Constant

Lag Length: 0 (Automatic - based on AIC, maxlag=5)

				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-3.139749	
Test critical values:	1% level			-2.64712
	5% level			-1.95291
	10% level			-1.610011

*MacKinnon (1996)

DF-GLS Test Equation on GLS Detrended Residuals

Dependent Variable: D(GLSRESID)

Method: Least Squares

Sample (adjusted): 1987 2015

Included observations: 29 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.570953	0.181847	-3.139749	0.004
R-squared	0.258407	Mean dependent var		-0.007715
Adjusted R-squared	0.258407	S.D. dependent var		0.151449
S.E. of regression	0.130422	Akaike info criterion		-1.202212
Sum squared resid	0.476276	Schwarz criterion		-1.155064
Log likelihood	18.43207	Hannan-Quinn criter.		-1.187445
Durbin-Watson stat	1.974518			

Table A.1. 12 Unit root test for LGATP_D at first differences with constant and linear trend

Null Hypothesis: D(LGATP_D) has a unit root				
Exogenous: Constant, Linear Trend				
Lag Length: 0 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-4.767643	
Test critical values:	1% level			-3.77
	5% level			-3.19
	10% level			-2.89
*Elliott-Rothenberg-Stock (1996, Table 1) Warning: Test critical values calculated for 50 observations and may not be accurate for a sample size of 29				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1987 2015				
Included observations: 29 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.898132	0.188381	-4.767643	0.0001
R-squared	0.448062	Mean dependent var		-0.000175
Adjusted R-squared	0.448062	S.D. dependent var		0.151449
S.E. of regression	0.112516	Akaike info criterion		-1.497577
Sum squared resid	0.354473	Schwarz criterion		-1.450429
Log likelihood	22.71487	Hannan-Quinn criter.		-1.482811
Durbin-Watson stat	1.903815			

Table A.1. 13 Unit root test for LGATP_I at the level with constant only

Null Hypothesis: LGATP_I has a unit root				
Exogenous: Constant				
Lag Length: 0 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-1.387038	
Test critical values:	1% level			-2.644302
	5% level			-1.952473
	10% level			-1.610211
*MacKinnon (1996)				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1986 2015				

Included observations: 30 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.075469	0.05441	-1.387038	0.176
R-squared	-0.005674	Mean dependent var		0.039208
Adjusted R-squared	-0.005674	S.D. dependent var		0.148217
S.E. of regression	0.148637	Akaike info criterion		-0.94186
Sum squared resid	0.640692	Schwarz criterion		-0.895154
Log likelihood	15.1279	Hannan-Quinn criter.		-0.926918
Durbin-Watson stat	1.251317			

Table A.1. 14 Unit root test for LGATP_I at the level with constant and linear trend

Null Hypothesis: LGATP_I has a unit root				
Exogenous: Constant, Linear Trend				
Lag Length: 0 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-1.763853	
Test critical values:	1% level			-3.77
	5% level			-3.19
	10% level			-2.89
*Elliott-Rothenberg-Stock (1996, Table 1) Warning: Test critical values calculated for 50 observations and may not be accurate for a sample size of 30				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1986 2015				
Included observations: 30 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.137185	0.077776	-1.763853	0.0883
R-squared	0.092895	Mean dependent var		0.009689
Adjusted R-squared	0.092895	S.D. dependent var		0.148217
S.E. of regression	0.141165	Akaike info criterion		-1.045015
Sum squared resid	0.577896	Schwarz criterion		-0.998308
Log likelihood	16.67523	Hannan-Quinn criter.		-1.030073
Durbin-Watson stat	1.299195			

Table A.1. 15 Unit root test for LGATP_I at first differences with constant only

Null Hypothesis: D(LGATP_I) has a unit root				
Exogenous: Constant				
Lag Length: 1 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-1.868278	

Test critical values:	1% level			-2.650145
	5% level			-1.953381
	10% level			-1.609798

*MacKinnon (1996)

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Sample (adjusted): 1988 2015
Included observations: 28 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.340455	0.182229	-1.868278	0.073
D(GLSRESID(-1))	-0.249386	0.183842	-1.356524	0.1866
R-squared	0.280739	Mean dependent var		-0.000155
Adjusted R-squared	0.253075	S.D. dependent var		0.172625
S.E. of regression	0.149191	Akaike info criterion		-0.898429
Sum squared resid	0.578707	Schwarz criterion		-0.803271
Log likelihood	14.578	Hannan-Quinn criter.		-0.869338
Durbin-Watson stat	2.099921			

Table A.1. 16 Unit root test for LGATP_I at first differences with constant and linear trend

Null Hypothesis: D(LGATP_I) has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on AIC, maxlag=5)

				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-4.552265	
Test critical values:	1% level			-3.77
	5% level			-3.19
	10% level			-2.89

*Elliott-Rothenberg-Stock (1996, Table 1) Warning: Test critical values calculated for 50 observations and may not be accurate for a sample size of 29

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Sample (adjusted): 1987 2015
Included observations: 29 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.848396	0.186368	-4.552265	0.0001
R-squared	0.425323	Mean dependent var		-0.000244
Adjusted R-squared	0.425323	S.D. dependent var		0.176297
S.E. of regression	0.133646	Akaike info criterion		-1.153366
Sum squared resid	0.500117	Schwarz criterion		-1.106218
Log likelihood	17.72381	Hannan-Quinn criter.		-1.1386

Durbin-Watson stat	1.869408

Table A.1. 17 Unit root test for LGGDP at the level with constant only

Null Hypothesis: LGGDP has a unit root				
Exogenous: Constant				
Lag Length: 3 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-0.437503	
Test critical values:	1% level			-2.653401
	5% level			-1.953858
	10% level			-1.609571
*MacKinnon (1996)				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1989 2015				
Included observations: 27 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.002432	0.005558	-0.437503	0.6658
D(GLSRESID(-1))	1.176593	0.186868	6.296396	0
D(GLSRESID(-2))	-0.666221	0.274866	-2.423803	0.0236
D(GLSRESID(-3))	0.467747	0.184008	2.541988	0.0182
R-squared	0.32127	Mean dependent var		0.090718
Adjusted R-squared	0.23274	S.D. dependent var		0.024154
S.E. of regression	0.021157	Akaike info criterion		-4.737696
Sum squared resid	0.010296	Schwarz criterion		-4.54572
Log likelihood	67.95889	Hannan-Quinn criter.		-4.680611
Durbin-Watson stat	1.880205			

Table A.1. 18 Unit root test for LGGDP at the level with constant and linear trend

Null Hypothesis: LGGDP has a unit root			
Exogenous: Constant, Linear Trend			
Lag Length: 1 (Automatic - based on AIC, maxlag=5)			
			t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-3.620517	
Test critical values:	1% level		-3.77
	5% level		-3.19
	10% level		-2.89

*Elliott-Rothenberg-Stock (1996, Table 1) Warning: Test critical values calculated for 50 observations and may not be accurate for a sample size of 29

DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1987 2015				
Included observations: 29 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.337154	0.093123	-3.620517	0.0012
D(GLSRESID(-1))	0.709961	0.146074	4.860293	0
R-squared	0.510728	Mean dependent var		-0.001667
Adjusted R-squared	0.492606	S.D. dependent var		0.023719
S.E. of regression	0.016896	Akaike info criterion		-5.257048
Sum squared resid	0.007708	Schwarz criterion		-5.162752
Log likelihood	78.2272	Hannan-Quinn criter.		-5.227516
Durbin-Watson stat	1.624657			

Table A.1. 19 Unit root test for LGGDP at first differences with constant only

Null Hypothesis: D(LGGDP) has a unit root				
Exogenous: Constant				
Lag Length: 1 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-3.840378	
Test critical values:	1% level			-2.650145
	5% level			-1.953381
	10% level			-1.609798
*MacKinnon (1996)				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1988 2015				
Included observations: 28 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.644767	0.167892	-3.840378	0.0007
D(GLSRESID(-1))	0.442632	0.175682	2.519511	0.0182
R-squared	0.367289	Mean dependent var		-0.001739
Adjusted R-squared	0.342954	S.D. dependent var		0.022663
S.E. of regression	0.01837	Akaike info criterion		-5.087423
Sum squared resid	0.008774	Schwarz criterion		-4.992265
Log likelihood	73.22392	Hannan-Quinn criter.		-5.058332
Durbin-Watson stat	1.784772			

Table A.1. 20 Unit root test for LGGDP at first differences with constant and linear trend

Null Hypothesis: D(LGGDP) has a unit root				
Exogenous: Constant, Linear Trend				
Lag Length: 1 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-3.868593	
Test critical values:	1% level			-3.77
	5% level			-3.19
	10% level			-2.89
*Elliott-Rothenberg-Stock (1996, Table 1) Warning: Test critical values calculated for 50 observations and may not be accurate for a sample size of 28				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1988 2015				
Included observations: 28 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.65775	0.170023	-3.868593	0.0007
D(GLSRESID(-1))	0.446493	0.175518	2.543858	0.0173
R-squared	0.371567	Mean dependent var		-0.001485
Adjusted R-squared	0.347397	S.D. dependent var		0.022663
S.E. of regression	0.018308	Akaike info criterion		-5.094207
Sum squared resid	0.008715	Schwarz criterion		-4.99905
Log likelihood	73.3189	Hannan-Quinn criter.		-5.065117
Durbin-Watson stat	1.777424			

Table A.1. 21 Unit root test for LGPOP at the level with constant only

Null Hypothesis: LGPOP has a unit root				
Exogenous: Constant				
Lag Length: 5 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			1.171017	
Test critical values:	1% level			-2.66072
	5% level			-1.95502
	10% level			-1.60907
*MacKinnon (1996)				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1991 2015				
Included observations: 25 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.

GLSRESID(-1)	0.00111	0.000948	1.171017	0.2561
D(GLSRESID(-1))	1.387402	0.213131	6.509615	0
D(GLSRESID(-2))	-0.885877	0.335244	-2.642487	0.0161
D(GLSRESID(-3))	0.771004	0.336852	2.288849	0.0337
D(GLSRESID(-4))	-0.604298	0.278414	-2.170499	0.0428
D(GLSRESID(-5))	0.276064	0.130485	2.11567	0.0478
R-squared	0.990848	Mean dependent var		0.007369
Adjusted R-squared	0.988439	S.D. dependent var		0.002691
S.E. of regression	0.000289	Akaike info criterion		-13.25213
Sum squared resid	1.59E-06	Schwarz criterion		-12.9596
Log likelihood	171.6516	Hannan-Quinn criter.		-13.17099
Durbin-Watson stat	2.272904			

Table A.1. 22 Unit root test for LGPOP at the level with constant and linear trend

Null Hypothesis: LGPOP has a unit root

Exogenous: Constant, Linear Trend

Lag Length: 5 (Automatic - based on AIC, maxlag=5)

			t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-0.957593	
Test critical values:	1% level		-3.77
	5% level		-3.19
	10% level		-2.89

*Elliott-Rothenberg-Stock (1996, Table 1) Warning: Test critical values calculated for 50 observations and may not be accurate for a sample size of 25

DF-GLS Test Equation on GLS Detrended Residuals

Dependent Variable: D(GLSRESID)

Method: Least Squares

Sample (adjusted): 1991 2015

Included observations: 25 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.006943	0.007251	-0.957593	0.3503
D(GLSRESID(-1))	1.661187	0.21538	7.712818	0
D(GLSRESID(-2))	-1.038153	0.383567	-2.706574	0.014
D(GLSRESID(-3))	0.970895	0.382706	2.536923	0.0201
D(GLSRESID(-4))	-0.900671	0.30181	-2.984231	0.0076
D(GLSRESID(-5))	0.301121	0.163764	1.838757	0.0816
R-squared	0.98766	Mean dependent var		-0.001222
Adjusted R-squared	0.984412	S.D. dependent var		0.002691
S.E. of regression	0.000336	Akaike info criterion		-12.95327
Sum squared resid	2.15E-06	Schwarz criterion		-12.66074
Log likelihood	167.9158	Hannan-Quinn criter.		-12.87213
Durbin-Watson stat	2.186403			

Table A.1. 23 Unit root test for LGPOP at first differences with constant only

Null Hypothesis: D(LGPOP) has a unit root				
Exogenous: Constant				
Lag Length: 3 (Automatic - based on AIC, maxlag=5)				
				t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic			-0.919104	
Test critical values:	1% level			-2.656915
	5% level			-1.954414
	10% level			-1.609329
*MacKinnon (1996)				
DF-GLS Test Equation on GLS Detrended Residuals				
Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1990 2015				
Included observations: 26 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.01763	0.019182	-0.919104	0.368
D(GLSRESID(-1))	0.615524	0.203082	3.03092	0.0061
D(GLSRESID(-2))	-0.034936	0.21445	-0.16291	0.8721
D(GLSRESID(-3))	0.283764	0.153896	1.843866	0.0787
R-squared	0.331535	Mean dependent var		-0.000386
Adjusted R-squared	0.24038	S.D. dependent var		0.00043
S.E. of regression	0.000375	Akaike info criterion		-12.79825
Sum squared resid	3.09E-06	Schwarz criterion		-12.6047
Log likelihood	170.3773	Hannan-Quinn criter.		-12.74252
Durbin-Watson stat	1.642182			

Table A.1. 24 Unit root test for LGPOP at first differences with constant and linear trend

Null Hypothesis: D(LGPOP) has a unit root		
Exogenous: Constant, Linear Trend		
Lag Length: 3 (Automatic - based on AIC, maxlag=5)		
		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-1.966083
Test critical values:	1% level	-3.77
	5% level	-3.19
	10% level	-2.89
*Elliott-Rothenberg-Stock (1996, Table 1) Warning: Test critical values calculated for 50 observations and may not be accurate for a sample size of 26		
DF-GLS Test Equation on GLS Detrended Residuals		

Dependent Variable: D(GLSRESID)				
Method: Least Squares				
Sample (adjusted): 1990 2015				
Included observations: 26 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.134912	0.06862	-1.966083	0.062
D(GLSRESID(-1))	0.619802	0.19288	3.213403	0.004
D(GLSRESID(-2))	-0.080728	0.205977	-0.391929	0.6989
D(GLSRESID(-3))	0.300594	0.153828	1.954085	0.0635

R-squared	0.438906	Mean dependent var	3.00E-05
Adjusted R-squared	0.362393	S.D. dependent var	0.00043
S.E. of regression	0.000344	Akaike info criterion	-12.97335
Sum squared resid	2.60E-06	Schwarz criterion	-12.7798
Log likelihood	172.6536	Hannan-Quinn criter.	-12.91761
Durbin-Watson stat	1.642048		

A.2 Johansen cointegration test

Table A.2. 1 Full cointegration test results for domestic demand model (constant only)

Sample (adjusted): 1987 2015
Included observations: 29 after adjustments
Trend assumption: Linear deterministic trend
Series: LGRPK_D LGATP_D LGGDP
Lags interval (in first differences): 1 to 1

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.1 Critical Value	Prob.**
None *	0.416596	28.51200	27.06695	0.0698
At most 1	0.281305	12.88462	13.42878	0.1191
At most 2 *	0.107724	3.305401	2.705545	0.0690

Trace test indicates 1 cointegrating eqn(s) at the 0.1 level
* denotes rejection of the hypothesis at the 0.1 level

**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.1 Critical Value	Prob.**
None	0.416596	15.62738	18.89282	0.2474
At most 1	0.281305	9.579220	12.29652	0.2411
At most 2 *	0.107724	3.305401	2.705545	0.0690

Max-eigenvalue test indicates no cointegration at the 0.1 level
* denotes rejection of the hypothesis at the 0.1 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegrating Coefficients (normalized by b'*S11*b=I):			
LGRPK_D	LGATP_D	LGGDP	
-2.786601	-1.714753	3.921847	
-15.64783	5.561600	19.10510	
-5.578914	-0.963642	9.730662	
Unrestricted Adjustment Coefficients (alpha):			
D(LGRPK_D)	0.017156	0.047458	-0.00011
D(LGATP_D)	0.064139	-0.016532	-0.018485
D(LGGDP)	-0.001719	0.005274	-0.004093
1 Cointegrating Equation(s):	Log likelihood	139.8593	
Normalized cointegrating coefficients (standard error in parentheses)			
LGRPK_D	LGATP_D	LGGDP	
1.000000	0.615356	-1.407395	
	(0.32405)	(0.24028)	
Adjustment coefficients (standard error in parentheses)			
D(LGRPK_D)	-0.047808		
	(0.05219)		
D(LGATP_D)	-0.17873		
	(0.05661)		
D(LGGDP)	0.004791		
	(0.00915)		
2 Cointegrating Equation(s):	Log likelihood	144.6489	
Normalized cointegrating coefficients (standard error in parentheses)			
LGRPK_D	LGATP_D	LGGDP	
1.000000	0.000000	-1.289207	
		(0.05439)	
0.000000	1.000000	-0.192064	
		(0.14529)	
Adjustment coefficients (standard error in parentheses)			
D(LGRPK_D)	-0.790419	0.234522	
	(0.25477)	(0.09329)	
D(LGATP_D)	0.079956	-0.201926	
	(0.31840)	(0.11659)	
D(LGGDP)	-0.077744	0.032283	
	(0.04928)	(0.01804)	

Table A.2. 2 Full cointegration test results for domestic demand model (constant and trend)

Sample (adjusted): 1987 2015

Included observations: 29 after adjustments

Trend assumption: Linear deterministic trend (restricted)

Series: LGRPK_D LGATP_D LGGDP

Lags interval (in first differences): 1 to 1

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.1 Critical Value	Prob.**
None	0.437191	34.49082	39.75526	0.2666
At most 1	0.338244	17.82118	23.34234	0.3560
At most 2	0.182632	5.848301	10.66637	0.4798

Trace test indicates no cointegration at the 0.1 level
* denotes rejection of the hypothesis at the 0.1 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.1 Critical Value	Prob.**
None	0.437191	16.66965	23.44089	0.4859
At most 1	0.338244	11.97288	17.23410	0.4177
At most 2	0.182632	5.848301	10.66637	0.4798

Max-eigenvalue test indicates no cointegration at the 0.1 level
* denotes rejection of the hypothesis at the 0.1 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegrating Coefficients (normalized by b'*S11*b=I):

LGRPK_D	LGATP_D	LGGDP	86
2.219954	1.627674	-15.16932	1.127641
9.069604	-2.348806	6.102043	-1.616795
15.06251	-4.2392	-38.79508	1.778867

Unrestricted Adjustment Coefficients (alpha):

D(LGRPK_D)	-0.001558	-0.050533	-0.014542
D(LGATP_D)	-0.05983	-0.014192	0.030921
D(LGGDP)	0.005006	-0.007233	0.003008

1 Cointegrating Equation(s):	Log likelihood	140.3805	

Normalized cointegrating coefficients (standard error in parentheses)

LGRPK_D	LGATP_D	LGGDP	86
1.000000	0.733202	-6.83317	0.507957
	(0.42773)	(3.57450)	(0.34803)

Adjustment coefficients (standard error in parentheses)

D(LGRPK_D)	-0.003458
	(0.04229)
D(LGATP_D)	-0.132819
	(0.04630)
D(LGGDP)	0.011112
	(0.00697)

2 Cointegrating Equation(s):	Log likelihood	146.3669	

Normalized cointegrating coefficients (standard error in parentheses)

LGRPK_D	LGATP_D	LGGDP	86
1.000000	0.000000	-1.286388	0.000851
		(1.15005)	(0.10894)

0.000000	1.000000	-7.56515	0.691632
		(3.52679)	(0.33407)
Adjustment coefficients (standard error in parentheses)			
D(LGRPK_D)	-0.461772	0.116157	
	(0.14956)	(0.04577)	
D(LGATP_D)	-0.261536	-0.064049	
	(0.19285)	(0.05902)	
D(LGGDP)	-0.054485	0.025135	
	(0.02586)	(0.00792)	

Table A.2. 3 Full cointegration test results for international demand model (constant only)

Sample (adjusted): 1988 2015

Included observations: 28 after adjustments

Trend assumption: Linear deterministic trend

Series: LGRPK_I LGATP_I LGGDP

Lags interval (in first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.15 Critical Value	Prob.**
None *	0.510614	26.10307	25.32938	0.1257
At most 1	0.193222	6.094154	12.14738	0.6844
At most 2	0.002937	0.082361	2.072251	0.7741

Trace test indicates 1 cointegrating eqn(s) at the 0.15 level

* denotes rejection of the hypothesis at the 0.15 level

**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.15 Critical Value	Prob.**
None *	0.510614	20.00892	17.49272	0.0712
At most 1	0.193222	6.011793	11.08502	0.6117
At most 2	0.002937	0.082361	2.072251	0.7741

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.15 level

* denotes rejection of the hypothesis at the 0.15 level

**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegrating Coefficients (normalized by b'*S11*b=I):

LGRPK_I	LGATP_I	LGGDP
1.091664	3.699598	-1.170383
17.85263	1.387302	-24.03698
-4.521702	1.626697	4.383636

Unrestricted Adjustment Coefficients (alpha):

D(LGRPK_I)	0.048677	-0.03453	0.001878
D(LGATP_I)	-0.067398	-0.005862	0.004645
D(LGGDP)	0.007126	0.002520	0.000646

1 Cointegrating Equation(s):	Log likelihood	127.4133
Normalized cointegrating coefficients (standard error in parentheses)		
LGRPK_I	LGATP_I	LGGDP
1.000000	3.388954	-1.07211
	(0.82451)	(0.33586)
Adjustment coefficients (standard error in parentheses)		
D(LGRPK_I)	0.053139	
	(0.02397)	
D(LGATP_I)	-0.073576	
	(0.02660)	
D(LGGDP)	0.007779	
	(0.00365)	

2 Cointegrating Equation(s):	Log likelihood	130.4192
Normalized cointegrating coefficients (standard error in parentheses)		
LGRPK_I	LGATP_I	LGGDP
1.000000	0.000000	-1.352849
		(0.04230)
0.000000	1.000000	0.082840
		(0.09704)
Adjustment coefficients (standard error in parentheses)		
D(LGRPK_I)	-0.563307	0.132182
	(0.36764)	(0.08121)
D(LGATP_I)	-0.178228	-0.257477
	(0.43526)	(0.09615)
D(LGGDP)	0.052771	0.029858
	(0.05896)	(0.01302)

Table A.2. 4 Full cointegration test results for international demand model (constant and trend)

Sample (adjusted): 1988 2015

Included observations: 28 after adjustments

Trend assumption: Linear deterministic trend (restricted)

Series: LGRPK_I LGATP_I LGGDP

Lags interval (in first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.15 Critical Value	Prob.**
None *	0.528839	42.52425	37.72801	0.0547
At most 1	0.424983	21.45270	21.74377	0.1610
At most 2	0.191692	5.958749	9.532765	0.4656

Trace test indicates 1 cointegrating eqn(s) at the 0.15 level

* denotes rejection of the hypothesis at the 0.15 level

**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.15 Critical Value	Prob.**
None	0.528839	21.07155	21.94281	0.1875
At most 1	0.424983	15.49395	15.88976	0.1683
At most 2	0.191692	5.958749	9.532765	0.4656

Max-eigenvalue test indicates no cointegration at the 0.15 level

* denotes rejection of the hypothesis at the 0.15 level

**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegrating Coefficients (normalized by b'*S11*b=I):

LGRPK_I	LGATP_I	LGGDP	86
-6.303214	-4.081236	-12.41328	1.943909
11.52528	0.021057	29.02080	-4.206533
16.84810	1.305340	-26.56575	0.364510

Unrestricted Adjustment Coefficients (alpha):

D(LGRPK_I)	-0.033935	-0.043436	-0.032157
D(LGATP_I)	0.087444	-0.028779	-0.001563
D(LGGDP)	-0.003579	-0.00919	0.003141

1 Cointegrating Equation(s):	Log likelihood	127.9446	
Normalized cointegrating coefficients (standard error in parentheses)			
LGRPK_I	LGATP_I	LGGDP	86
1.000000	0.647485	1.969358	-0.3084
	(0.14084)	(1.39998)	(0.13286)
Adjustment coefficients (standard error in parentheses)			
D(LGRPK_I)	0.213900		
	(0.14688)		
D(LGATP_I)	-0.551181		
	(0.13202)		
D(LGGDP)	0.022562		
	(0.02280)		

2 Cointegrating Equation(s):	Log likelihood	135.6915	
Normalized cointegrating coefficients (standard error in parentheses)			
LGRPK_I	LGATP_I	LGGDP	86
1.000000	0.000000	2.519565	-0.365143
		(0.92747)	(0.08778)
0.000000	1.000000	-0.849761	0.087637
		(2.56295)	(0.24257)
Adjustment coefficients (standard error in parentheses)			
D(LGRPK_I)	-0.286711	0.137583	
	(0.27825)	(0.08645)	
D(LGATP_I)	-0.882868	-0.357487	
	(0.26184)	(0.08135)	
D(LGGDP)	-0.083355	0.014415	
	(0.03910)	(0.01215)	

Appendix B

B.1 Sensitivity analysis of price elasticity of demand

Table B.1. 1 CO_2 emissions in tonnes with different values of price elasticity of demand under the baseline and carbon taxation scenarios

	All demand are price inelastic				**Domestic demand is price elastic and international demand is price inelastic**				**All demand are price elastic**			
	CO2_baseline	**CO2_CT1**	**CO2_CT2**	**CO2_CT3**	**CO2_baseline**	**CO2_CT1**	**CO2_CT2**	**CO2_CT3**	**CO2_baseline**	**CO2_CT1**	**CO2_CT2**	**CO2_CT3**
2016	63,180,674	63,180,674	63,180,674	63,180,674	60,962,455	60,962,455	60,962,455	60,962,455	58,927,846	58,927,846	58,927,846	58,927,846
2017	67,010,582	66,737,940	66,453,146	66,168,352	62,379,683	61,681,835	60,972,547	60,263,260	58,283,785	57,321,145	56,347,683	55,374,220
2018	71,096,161	70,529,459	69,959,993	69,400,407	63,842,995	62,481,404	61,144,529	59,842,861	57,657,267	55,845,978	54,084,229	52,380,624
2019	75,442,081	74,569,788	73,713,133	72,884,201	65,342,323	63,356,476	61,458,273	59,652,861	57,037,537	54,485,072	52,080,782	49,823,250
2020	80,065,395	78,874,547	77,725,845	76,629,340	66,878,603	64,303,203	61,897,894	59,656,983	56,424,523	53,223,969	50,293,151	47,611,690
2021	84,984,292	82,730,940	81,269,379	79,890,273	68,452,793	64,606,578	61,725,380	59,088,795	55,818,150	51,506,281	48,131,910	45,113,711
2022	90,218,169	87,600,630	85,826,478	84,168,707	70,065,882	65,675,755	62,364,712	59,381,883	55,218,347	50,425,052	46,688,973	43,412,117
2023	95,787,720	92,788,399	90,690,694	88,747,816	71,718,883	66,808,723	63,098,742	59,802,914	54,625,040	49,411,942	45,376,520	41,898,467
2024	101,715,016	98,314,835	95,880,596	93,644,186	73,412,838	68,003,914	63,920,679	60,338,597	54,038,160	48,459,537	44,175,896	40,541,612
2025	108,023,603	104,201,797	101,416,337	98,875,844	75,148,817	69,259,964	64,825,129	60,978,161	53,457,636	47,561,227	43,071,945	39,316,556
2026	114,738,596	110,472,658	107,319,606	104,462,826	76,927,920	70,575,830	65,807,731	61,713,352	52,883,399	46,711,316	42,052,110	38,203,790

2027	121,886,789	117,152,407	113,613,567	110,426,339	78,751,276	71,950,763	66,864,838	62,537,055	52,315,379	45,904,884	41,105,729	37,186,811
2028	129,496,767	124,267,872	120,323,116	116,789,582	80,620,048	73,384,393	67,993,558	63,443,786	51,753,509	45,137,825	40,223,905	36,252,473
2029	137,599,024	131,847,450	127,474,905	123,577,405	82,535,429	74,876,301	69,191,560	64,428,996	51,197,723	44,406,224	39,399,078	35,389,756
2030	146,226,096	139,921,627	135,097,392	130,816,552	84,498,645	76,426,428	70,456,936	65,489,058	50,647,952	43,706,851	38,624,729	34,589,535

Table B.1. 2 CO_2 emissions in tonnes with different values of price elasticity of demand under the baseline and emissions trading scenarios

	All demand are price inelastic				Domestic demand is price elastic and international demand is price inelastic				All demand are price elastic			
	CO2_baseline	**CO2_ETS1**	**CO2_ETS2**	**CO2_ETS3**	**CO2_baseline**	**CO2_ETS1**	**CO2_ETS2**	**CO2_ETS3**	**CO2_baseline**	**CO2_ETS1**	**CO2_ETS2**	**CO2_ETS3**
2016	63,180,674	63,180,674	63,180,674	63,180,674	60,962,455	60,962,455	60,962,455	60,962,455	58,927,846	58,927,846	58,927,846	58,927,846
2017	67,010,582	66,974,406	66,792,016	66,606,109	62,379,683	62,270,761	61,816,512	61,353,507	58,283,785	58,129,417	57,505,983	56,870,531
2018	71,096,161	71,004,251	70,642,963	70,264,620	63,842,995	63,605,335	62,749,325	61,858,149	57,657,267	57,336,212	56,200,470	55,023,153
2019	75,442,081	75,289,555	74,737,569	74,173,572	65,342,323	64,976,634	63,732,090	62,474,444	57,037,537	56,561,079	54,964,445	53,364,031
2020	80,065,395	79,847,051	79,106,091	78,341,258	66,878,603	66,385,589	64,795,176	63,179,194	56,424,523	55,803,362	53,829,898	51,847,750
2021	84,984,292	83,965,779	83,018,835	82,052,156	68,452,793	67,122,780	65,201,914	63,278,635	55,818,150	54,520,024	52,219,945	49,949,817
2022	90,218,169	89,107,866	87,907,705	86,718,034	70,065,882	68,599,412	66,281,582	64,039,398	55,218,347	53,811,912	51,126,952	48,574,473
2023	95,787,720	94,591,758	93,126,180	91,702,497	71,718,883	70,140,077	67,443,520	64,898,469	54,625,040	53,145,618	50,123,048	47,327,441
2024	101,715,016	100,425,530	98,688,918	97,033,096	73,412,838	71,718,140	68,673,116	65,862,558	54,038,160	52,487,730	49,184,615	46,204,298
2025	108,023,603	106,638,569	104,610,142	102,713,491	75,148,817	73,345,853	69,955,266	66,896,493	53,457,636	51,850,123	48,290,309	45,158,224
2026	114,738,596	113,234,871	110,933,188	108,780,258	76,927,920	74,989,455	71,321,120	68,019,150	52,883,399	51,195,650	47,467,703	44,201,217
2027	121,886,789	120,266,144	117,623,740	115,173,765	78,751,276	76,693,310	72,677,570	69,105,516	52,315,379	50,569,860	46,619,933	43,207,577
2028	129,496,767	127,745,262	124,753,430	122,003,418	80,620,048	78,433,764	74,097,482	70,283,385	51,753,509	49,946,829	45,818,239	42,298,353
2029	137,599,024	135,716,295	132,357,710	129,282,358	82,535,429	80,233,302	75,589,241	71,529,495	51,197,723	49,346,990	45,066,170	41,445,601
2030	146,226,096	144,199,394	140,458,824	137,047,859	84,498,645	82,075,428	77,140,198	72,852,305	50,647,952	48,752,769	44,348,108	40,651,656

Table B.1. 3 CO_2 emissions in tonnes with different values of price elasticity of demand under the baseline and carbon offsetting scenarios

	All demand are price inelastic				Domestic demand is price elastic and international demand is price inelastic				All demand are price elastic			
	CO2_ baseline	CO2_ OFFSET1	CO2_ OFFSET2	CO2_ OFFSET3	CO2_ baseline	CO2_ OFFSET1	CO2_ OFFSET2	CO2_ OFFSET3	CO2_ baseline	CO2_ OFFSET1	CO2_ OFFSET2	CO2_ OFFSET3
2016	63,180,674	63,180,674	63,180,674	63,180,674	60,962,455	60,962,455	60,962,455	60,962,455	58,927,846	58,927,846	58,927,846	58,927,846
2017	67,010,582	66,084,416	66,352,507	66,533,468	62,379,683	61,517,647	61,767,211	61,935,667	58,283,785	57,478,482	57,711,661	57,869,056
2018	71,096,161	69,089,706	69,615,914	70,071,013	63,842,995	62,041,441	62,513,967	62,922,638	57,657,267	56,030,461	56,457,206	56,826,282
2019	75,442,081	72,226,568	73,041,494	73,803,600	65,342,323	62,557,577	63,263,408	63,923,491	57,037,537	54,606,984	55,223,109	55,799,301
2020	80,065,395	75,499,834	76,636,976	77,742,086	66,878,603	63,065,381	64,015,242	64,938,346	56,424,523	53,207,689	54,009,077	54,787,891
2021	84,984,292	78,914,408	80,410,415	81,897,923	68,452,793	63,564,150	64,769,157	65,967,318	55,818,150	51,832,217	52,814,818	53,791,836
2022	90,218,169	82,475,175	84,368,828	86,279,382	70,065,882	64,053,062	65,523,337	67,006,382	55,218,347	50,480,077	51,637,623	52,804,190
2023	95,787,720	86,187,190	88,522,396	90,903,105	71,718,883	64,531,400	66,279,028	68,059,924	54,625,040	49,151,017	50,480,004	51,832,273
2024	101,715,016	90,055,574	92,880,087	95,782,522	73,412,838	64,998,451	67,035,744	69,128,043	54,038,160	47,844,830	49,341,465	50,875,792
2025	108,023,603	94,085,327	97,451,364	100,931,641	75,148,817	65,453,323	67,793,132	70,210,671	53,457,636	46,561,090	48,221,768	49,934,238
2026	114,738,596	98,281,457	102,246,079	106,365,638	76,927,920	65,895,109	68,550,841	71,308,166	52,883,399	45,299,414	47,120,704	49,007,732
2027	121,886,789	102,648,960	107,274,360	112,100,044	78,751,276	66,322,887	69,308,396	72,420,391	52,315,379	44,059,466	46,037,918	48,095,703
2028	129,496,767	107,192,892	112,546,772	118,151,531	80,620,048	66,735,828	70,065,367	73,547,516	51,753,509	42,841,077	44,973,158	47,198,028
2029	137,599,024	111,918,006	118,074,259	124,537,560	82,535,429	67,132,836	70,821,294	74,689,595	51,197,723	41,643,789	43,926,166	46,314,434
2030	146,226,096	116,829,075	123,868,101	131,276,587	84,498,645	67,512,927	71,575,641	75,846,730	50,647,952	40,467,347	42,896,622	45,444,726

B.2 Sensitivity analysis of national GDP growth rate

Table B.2. 1 CO_2 emissions in tonnes with different values of annual GDP growth under the baseline and carbon taxation scenarios

	Annual GDP growth = 7%				Annual GDP growth = 6%				Annual GDP growth = 5.5%			
	CO2_baseline	**CO2_CT1**	**CO2_CT2**	**CO2_CT3**	**CO2_baseline**	**CO2_CT1**	**CO2_CT2**	**CO2_CT3**	**CO2_baseline**	**CO2_CT1**	**CO2_CT2**	**CO2_CT3**
2016	63,180,674	63,180,674	63,180,674	63,180,674	62,318,652	62,318,652	62,318,652	62,318,652	61,974,924	61,974,924	61,974,924	61,974,924
2017	67,010,582	66,737,940	66,453,146	66,168,352	65,192,526	64,923,654	64,642,944	64,362,234	64,474,621	64,207,253	63,928,170	63,649,088
2018	71,096,161	70,529,459	69,959,993	69,400,407	68,219,490	67,668,815	67,115,627	66,572,079	67,094,628	66,550,278	66,003,512	65,466,291
2019	75,442,081	74,569,788	73,713,133	72,884,201	71,395,593	70,560,232	69,740,082	68,946,586	69,828,757	69,007,822	68,201,928	67,422,271
2020	80,065,395	78,874,547	77,725,845	76,629,340	74,728,428	73,604,441	72,520,561	71,486,140	72,682,160	71,584,023	70,525,200	69,514,774
2021	84,984,292	82,730,940	81,269,379	79,890,273	78,225,982	76,127,069	74,767,819	73,485,571	75,660,223	73,620,461	72,300,357	71,055,163
2022	90,218,169	87,600,630	85,826,478	84,168,707	81,896,657	79,491,834	77,865,586	76,346,437	78,768,581	76,444,438	74,874,204	73,407,545
2023	95,787,720	92,788,399	90,690,694	88,747,816	85,749,288	83,031,781	81,136,573	79,381,768	82,013,127	79,401,456	77,582,156	75,897,838
2024	101,715,016	98,314,835	95,880,596	93,644,186	89,793,169	86,755,370	84,587,687	82,596,798	85,400,026	82,496,967	80,428,185	78,528,373
2025	108,023,603	104,201,797	101,416,337	98,875,844	94,038,077	90,671,422	88,226,572	85,997,463	88,935,725	85,736,609	83,416,845	81,302,063
2026	114,738,596	110,472,658	107,319,606	104,462,826	98,494,295	94,789,284	92,061,492	89,590,841	92,626,968	89,126,353	86,553,135	84,222,805
2027	121,886,789	117,152,407	113,613,567	110,426,339	103,172,642	99,118,854	96,101,209	93,384,315	96,480,808	92,672,515	89,842,376	87,294,652
2028	129,496,767	124,267,872	120,323,116	116,789,582	108,084,495	103,670,706	100,355,148	97,386,238	100,504,625	96,381,864	93,290,348	90,522,438
2029	137,599,024	131,847,450	127,474,905	123,577,405	113,241,827	108,455,774	104,833,334	101,605,544	104,706,136	100,261,307	96,903,219	93,911,392
2030	146,226,096	139,921,627	135,097,392	130,816,552	118,657,228	113,485,745	109,546,367	106,051,893	109,093,415	104,318,247	100,687,507	97,467,252

Table B.2. 2 CO_2 emissions in tonnes with different values of annual GDP growth under both the baseline and emissions trading scenarios

	Annual GDP growth = 7%				Annual GDP growth = 6%				Annual GDP growth = 5.5%			
	CO2_baseline	**CO2_ETS1**	**CO2_ETS2**	**CO2_ETS3**	**CO2_baseline**	**CO2_ETS1**	**CO2_ETS2**	**CO2_ETS3**	**CO2_baseline**	**CO2_ETS1**	**CO2_ETS2**	**CO2_ETS3**
2016	63,180,674	63,180,674	63,180,674	63,180,674	62,318,652	62,318,652	62,318,652	62,318,652	61,974,924	61,974,924	61,974,924	61,974,924
2017	67,010,582	66,974,406	66,792,016	66,606,109	65,192,526	65,156,730	64,976,954	64,793,714	64,474,621	64,438,977	64,260,244	64,078,066
2018	71,096,161	71,004,251	70,642,963	70,264,620	68,219,490	68,130,068	67,779,080	67,411,541	67,094,628	67,006,188	66,659,265	66,295,989
2019	75,442,081	75,289,555	74,737,569	74,173,572	71,395,593	71,249,417	70,720,876	70,180,885	69,828,757	69,685,064	69,165,679	68,635,063
2020	80,065,395	79,847,051	79,106,091	78,341,258	74,728,428	74,522,238	73,822,946	73,101,218	72,682,160	72,480,671	71,797,487	71,092,422
2021	84,984,292	83,965,779	83,018,835	82,052,156	78,225,982	77,275,692	76,394,788	75,495,672	75,660,223	74,736,093	73,880,461	73,007,197
2022	90,218,169	89,107,866	87,907,705	86,718,034	81,896,657	80,873,686	79,773,198	78,682,524	78,768,581	77,778,801	76,716,068	75,662,889
2023	95,787,720	94,591,758	93,126,180	91,702,497	85,749,288	84,661,368	83,336,732	82,050,204	82,013,127	80,965,896	79,694,107	78,458,998
2024	101,715,016	100,425,530	98,688,918	97,033,096	89,793,169	88,635,278	87,088,124	85,613,229	85,400,026	84,291,237	82,814,398	81,406,642
2025	108,023,603	106,638,569	104,610,142	102,713,491	94,038,077	92,810,580	91,029,294	89,364,046	88,935,725	87,766,459	86,075,962	84,495,710
2026	114,738,596	113,234,871	110,933,188	108,780,258	98,494,295	97,179,309	95,186,959	93,323,725	92,626,968	91,381,078	89,501,205	87,743,295
2027	121,886,789	120,266,144	117,623,740	115,173,765	103,172,642	101,774,347	99,519,792	97,429,820	96,480,808	95,163,133	93,048,164	91,087,738
2028	129,496,767	127,745,262	124,753,430	122,003,418	108,084,495	106,593,750	104,077,567	101,765,192	100,504,625	99,107,502	96,760,754	94,604,252
2029	137,599,024	135,716,295	132,357,710	129,282,358	113,241,827	111,661,179	108,876,949	106,327,982	104,706,136	103,232,883	100,651,153	98,287,749
2030	146,226,096	144,199,394	140,458,824	137,047,859	118,657,228	116,979,068	113,922,518	111,135,792	109,093,415	107,537,937	104,720,081	102,151,157

Table B.2. 3 CO_2 emissions in tonnes with different values of annual GDP growth under both the baseline and carbon offsetting scenarios

	Annual GDP growth = 7%				Annual GDP growth = 6%				Annual GDP growth = 5.5%			
	CO2_ baseline	CO2_ OFFSET1	CO2_ OFFSET2	CO2_ OFFSET3	CO2_ baseline	CO2_ OFFSET1	CO2_ OFFSET2	CO2_ OFFSET3	CO2_ baseline	CO2_ OFFSET1	CO2_ OFFSET2	CO2_ OFFSET3
2016	63,180,674	63,180,674	63,180,674	63,180,674	62,318,652	62,318,652	62,318,652	62,318,652	61,974,924	61,974,924	61,974,924	61,974,924
2017	67,010,582	66,084,416	66,352,507	66,533,468	65,192,526	64,291,503	64,552,321	64,728,372	64,474,621	63,583,526	63,841,472	64,015,585
2018	71,096,161	69,089,706	69,615,914	70,071,013	68,219,490	66,294,245	66,799,162	67,235,847	67,094,628	65,201,138	65,697,730	66,127,215
2019	75,442,081	72,226,568	73,041,494	73,803,600	71,395,593	68,352,587	69,123,803	69,845,032	69,828,757	66,852,547	67,606,838	68,312,240
2020	80,065,395	75,499,834	76,636,976	77,742,086	74,728,428	70,467,244	71,528,588	72,560,035	72,682,160	68,537,678	69,569,960	70,573,163
2021	84,984,292	78,914,408	80,410,415	81,897,923	78,225,982	72,638,863	74,015,903	75,385,119	75,660,223	70,256,382	71,588,256	72,912,563
2022	90,218,169	82,475,175	84,368,828	86,279,382	81,896,657	74,867,933	76,586,888	78,321,155	78,768,581	72,008,352	73,661,637	75,329,639
2023	95,787,720	86,187,190	88,522,396	90,903,105	85,749,288	77,154,970	79,245,382	81,376,462	82,013,127	73,793,305	75,792,610	77,830,784
2024	101,715,016	90,055,574	92,880,087	95,782,522	89,793,169	79,500,416	81,993,763	84,555,796	85,400,026	75,610,888	77,982,205	80,418,807
2025	108,023,603	94,085,327	97,451,364	100,931,641	94,038,077	81,904,475	84,834,566	87,863,958	88,935,725	77,460,520	80,231,568	83,096,473
2026	114,738,596	98,281,457	102,246,079	106,365,638	98,494,295	84,367,244	87,770,366	91,306,296	92,626,968	79,341,522	82,541,841	85,866,981
2027	121,886,789	102,648,960	107,274,360	112,100,044	103,172,642	86,888,693	90,803,671	94,887,934	96,480,808	81,253,106	84,914,060	88,733,221
2028	129,496,767	107,192,892	112,546,772	118,151,531	108,084,495	89,468,746	93,937,057	98,614,458	100,504,625	83,194,450	87,349,286	91,698,429
2029	137,599,024	111,918,006	118,074,259	124,537,560	113,241,827	92,106,961	97,173,100	102,491,561	104,706,136	85,164,405	89,848,542	94,765,839
2030	146,226,096	116,829,075	123,868,101	131,276,587	118,657,228	94,802,835	100,514,334	106,525,191	109,093,415	87,161,781	92,412,772	97,938,823

B.3 Sensitivity analysis of fuel efficiency growth

Table B.3. 1 CO_2 emissions in tonnes with different annual fuel efficiency improvements under both the baseline and carbon taxation scenarios

	Annual fuel efficiency growth = 1%				Annual fuel efficiency growth = 1.5%				Annual fuel efficiency growth = 2%			
	CO2_baseline	**CO2_CT1**	**CO2_CT2**	**CO2_CT3**	**CO2_baseline**	**CO2_CT1**	**CO2_CT2**	**CO2_CT3**	**CO2_baseline**	**CO2_CT1**	**CO2_CT2**	**CO2_CT3**
2016	63,180,674	63,180,674	63,180,674	63,180,674	62,861,637	62,861,637	62,861,637	62,861,637	62,542,600	62,542,600	62,542,600	62,542,600
2017	67,010,582	66,737,940	66,453,146	66,168,352	66,335,417	66,067,067	65,786,566	65,506,065	65,663,670	65,399,570	65,123,318	64,847,066
2018	71,096,161	70,529,459	69,959,993	69,400,407	70,024,378	69,470,636	68,913,825	68,366,602	68,963,421	68,422,410	67,878,031	67,342,957
2019	75,442,081	74,569,788	73,713,133	72,884,201	73,929,506	73,083,344	72,251,666	71,446,646	72,439,790	71,619,102	70,811,785	70,030,097
2020	80,065,395	78,874,547	77,725,845	76,629,340	78,063,862	76,916,986	75,809,525	74,751,811	76,102,559	74,998,232	73,930,706	72,910,584
2021	84,984,292	82,730,940	81,269,379	79,890,273	82,441,308	80,276,473	78,876,822	77,555,085	79,962,055	77,882,556	76,542,444	75,275,938
2022	90,218,169	87,600,630	85,826,478	84,168,707	87,076,559	84,579,499	82,891,884	81,313,316	84,029,190	81,647,439	80,042,479	78,539,666
2023	95,787,720	92,788,399	90,690,694	88,747,816	91,985,235	89,143,912	87,161,694	85,323,356	88,315,490	85,624,301	83,751,648	82,012,660
2024	101,715,016	98,314,835	95,880,596	93,644,186	97,183,916	93,985,130	91,699,877	89,596,992	92,833,132	89,824,355	87,679,515	85,702,732
2025	108,023,603	104,201,797	101,416,337	98,875,844	102,690,204	99,119,434	96,521,267	94,147,145	97,594,977	94,259,386	91,836,578	89,618,609
2026	114,738,596	110,472,658	107,319,606	104,462,826	108,522,784	104,564,178	101,641,821	98,988,343	102,614,615	98,941,921	96,234,164	93,770,338
2027	121,886,789	117,152,407	113,613,567	110,426,339	114,701,492	110,337,844	107,078,537	104,135,923	107,906,401	103,885,263	100,884,330	98,168,527
2028	129,496,767	124,267,872	120,323,116	116,789,582	121,247,388	116,460,211	112,849,661	109,606,738	113,485,501	109,103,619	105,800,024	102,824,952
2029	137,599,024	131,847,450	127,474,905	123,577,405	128,182,830	122,952,088	118,974,666	115,418,816	119,367,937	114,611,839	110,995,047	107,752,226
2030	146,226,096	139,921,627	135,097,392	130,816,552	135,531,555	129,835,746	125,474,269	121,591,543	125,570,638	120,425,780	116,484,043	112,963,932

Table B.3. 2 CO_2 emissions in tonnes with different annual fuel efficiency improvements under both the baseline and emissions trading scenarios

	Annual fuel efficiency growth = 1%				Annual fuel efficiency growth = 1.5%				Annual fuel efficiency growth = 2%			
	CO2_baseline	**CO2_ETS1**	**CO2_ETS2**	**CO2_ETS3**	**CO2_baseline**	**CO2_ETS1**	**CO2_ETS2**	**CO2_ETS3**	**CO2_baseline**	**CO2_ETS1**	**CO2_ETS2**	**CO2_ETS3**
2016	63,180,674	63,180,674	63,180,674	63,180,674	62,861,637	62,861,637	62,861,637	62,861,637	62,542,600	62,542,600	62,542,600	62,542,600
2017	67,010,582	66,974,406	66,792,016	66,606,109	66,335,417	66,300,408	66,122,422	65,941,005	65,663,670	65,629,812	65,456,169	65,279,179
2018	71,096,161	71,004,251	70,642,963	70,264,620	70,024,378	69,936,288	69,587,869	69,223,021	68,963,421	68,879,060	68,543,207	68,191,542
2019	75,442,081	75,289,555	74,737,569	74,173,572	73,929,506	73,785,040	73,259,060	72,721,288	72,439,790	72,303,114	71,802,289	71,289,905
2020	80,065,395	79,847,051	79,106,091	78,341,258	78,063,862	77,859,590	77,161,642	76,440,765	76,102,559	75,911,749	75,255,020	74,576,320
2021	84,984,292	83,965,779	83,018,835	82,052,156	82,441,308	81,466,597	80,584,162	79,682,184	79,962,055	79,029,438	78,208,269	77,367,868
2022	90,218,169	89,107,866	87,907,705	86,718,034	87,076,559	86,023,287	84,916,368	83,816,270	84,029,190	83,030,263	82,011,114	80,995,608
2023	95,787,720	94,591,758	93,126,180	91,702,497	91,985,235	90,860,227	89,522,350	88,217,865	88,315,490	87,257,555	86,038,827	84,846,044
2024	101,715,016	100,425,530	98,688,918	97,033,096	97,183,916	95,981,673	94,412,165	92,908,298	92,833,132	91,712,665	90,297,735	88,935,209
2025	108,023,603	106,638,569	104,610,142	102,713,491	102,690,204	101,410,342	99,595,663	97,888,111	97,594,977	96,412,874	94,794,214	93,261,257
2026	114,738,596	113,234,871	110,933,188	108,780,258	108,522,784	107,147,547	105,106,992	103,185,945	102,614,615	101,357,668	99,554,683	97,846,129
2027	121,886,789	120,266,144	117,623,740	115,173,765	114,701,492	113,232,646	110,910,689	108,742,260	107,906,401	106,576,139	104,543,358	102,631,073
2028	129,496,767	127,745,262	124,753,430	122,003,418	121,247,388	119,675,027	117,068,576	114,653,538	113,485,501	112,075,253	109,813,828	107,701,414
2029	137,599,024	135,716,295	132,357,710	129,282,358	128,182,830	126,508,186	123,607,202	120,928,142	119,367,937	117,880,010	115,385,483	113,061,879
2030	146,226,096	144,199,394	140,458,824	137,047,859	135,531,555	133,746,086	130,542,231	127,594,020	125,570,638	123,999,737	121,268,919	118,732,868

Table B.3. 3 CO_2 emissions in tonnes with different annual fuel efficiency improvements under both the baseline and carbon offsetting scenarios

	Annual fuel efficiency growth = 1%				Annual fuel efficiency growth = 1.5%				Annual fuel efficiency growth = 2%			
	CO2_ baseline	CO2_ OFFSET1	CO2_ OFFSET2	CO2_ OFFSET3	CO2_ baseline	CO2_ OFFSET1	CO2_ OFFSET2	CO2_ OFFSET3	CO2_ baseline	CO2_ OFFSET1	CO2_ OFFSET2	CO2_ OFFSET3
2016	63,180,674	63,180,674	63,180,674	63,180,674	62,861,637	62,861,637	62,861,637	62,861,637	62,542,600	62,542,600	62,542,600	62,542,600
2017	67,010,582	66,084,416	66,352,507	66,533,468	66,335,417	65,418,703	65,684,093	65,863,231	65,663,670	64,756,360	65,019,064	65,196,388
2018	71,096,161	69,089,706	69,615,914	70,071,013	70,024,378	68,048,361	68,566,638	69,014,878	68,963,421	67,017,535	67,527,961	67,969,411
2019	75,442,081	72,226,568	73,041,494	73,803,600	73,929,506	70,778,731	71,577,321	72,324,151	72,439,790	69,352,775	70,135,276	70,867,060
2020	80,065,395	75,499,834	76,636,976	77,742,086	78,063,862	73,612,788	74,721,509	75,798,997	76,102,559	71,763,671	72,844,541	73,894,964
2021	84,984,292	78,914,408	80,410,415	81,897,923	82,441,308	76,553,502	78,004,753	79,447,758	79,962,055	74,251,763	75,659,379	77,058,998
2022	90,218,169	82,475,175	84,368,828	86,279,382	87,076,559	79,603,748	81,431,510	83,275,617	84,029,190	76,818,457	78,582,301	80,361,951
2023	95,787,720	86,187,190	88,522,396	90,903,105	91,985,235	82,766,488	85,009,088	87,295,459	88,315,490	79,465,198	81,618,419	83,813,735
2024	101,715,016	90,055,574	92,880,087	95,782,522	97,183,916	86,044,664	88,743,500	91,516,903	92,833,132	82,193,368	84,771,520	87,421,006
2025	108,023,603	94,085,327	97,451,364	100,931,641	102,690,204	89,441,030	92,641,084	95,949,899	97,594,977	85,004,131	88,045,600	91,190,582
2026	114,738,596	98,281,457	102,246,079	106,365,638	108,522,784	92,958,273	96,708,386	100,605,253	102,614,615	87,898,552	91,444,752	95,129,909
2027	121,886,789	102,648,960	107,274,360	112,100,044	114,701,492	96,598,994	100,952,058	105,493,870	107,906,401	90,877,576	94,973,067	99,246,369
2028	129,496,767	107,192,892	112,546,772	118,151,531	121,247,388	100,365,770	105,378,998	110,627,455	113,485,501	93,942,091	98,634,761	103,547,900
2029	137,599,024	111,918,006	118,074,259	124,537,560	128,182,830	104,260,837	109,996,288	116,018,179	119,367,937	97,092,637	102,434,113	108,042,690
2030	146,226,096	116,829,075	123,868,101	131,276,587	135,531,555	108,286,369	114,811,148	121,678,843	125,570,638	100,329,671	106,375,424	112,739,313

Appendix C

C.1 OLS estimates for region pair demand model (Eq. (10))

Table C.1. 1 Full OLS estimates of air passenger travel demand between West EEA countries and China

Dependent Variable: DEMAND
Method: Least Squares
Sample: 1 699
Included observations: 699

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-5.590919	5.694001	-0.981896	0.3265
POP	0.370362	0.065562	5.649039	0
INC	0.681738	0.191565	3.558781	0.0004
COST	-1.978989	0.473952	-4.175502	0
SPECA	1.393644	0.484738	2.875045	0.0042
SPECB	-0.490608	0.160956	-3.048083	0.0024
DIRECT	3.665527	0.327041	11.20815	0
AIRPORT	1.367531	0.148785	9.191331	0

R-squared	0.534825	Mean dependent var	5.226931
Adjusted R-squared	0.530113	S.D. dependent var	2.126616
S.E. of regression	1.457759	Akaike info criterion	3.603057
Sum squared resid	1468.418	Schwarz criterion	3.655128
Log likelihood	-1251.269	Hannan-Quinn criter.	3.623187
F-statistic	113.4948	Durbin-Watson stat	1.572305
Prob(F-statistic)	0		

Table C.1. 2 Full OLS estimates of air passenger travel demand between North EEA countries and China

Dependent Variable: DEMAND
Method: Least Squares
Sample: 1 167
Included observations: 167

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-32.3584	7.041629	-4.595301	0
POP	0.404178	0.09396	4.301597	0
INC	1.592849	0.266754	5.971238	0
COST	-0.855935	0.696995	-1.228036	0.2212
SPECA	1.224949	0.416938	2.937966	0.0038
SPECB	-0.002578	0.18508	-0.013928	0.9889
DIRECT	2.345967	0.294436	7.967655	0
AIRPORT	0.281136	0.15349	1.831624	0.0689

R-squared	0.662652	Mean dependent var	6.16339
Adjusted R-squared	0.647801	S.D. dependent var	1.432044
S.E. of regression	0.849867	Akaike info criterion	2.559244
Sum squared resid	114.8415	Schwarz criterion	2.708609
Log likelihood	-205.6969	Hannan-Quinn criter.	2.619868
F-statistic	44.6177	Durbin-Watson stat	2.063503
Prob(F-statistic)	0		

Table C.1. 3 Full OLS estimates of air passenger travel demand between North EEA countries and China

Dependent Variable: DEMAND
Method: Least Squares
Sample: 1 435
Included observations: 435

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-24.85577	4.849602	-5.125322	0
POP	0.391191	0.064652	6.05075	0
INC	1.233948	0.173222	7.123515	0
COST	-0.732242	0.47605	-1.538162	0.1247
SPECA	1.920206	0.3076	6.242551	0
SPECB	-0.680183	0.129617	-5.247633	0
DIRECT	2.533679	0.402696	6.291796	0
AIRPORT	0.890873	0.141729	6.285751	0

R-squared	0.486654	Mean dependent var	6.004581
Adjusted R-squared	0.478239	S.D. dependent var	1.548704
S.E. of regression	1.118676	Akaike info criterion	3.080389
Sum squared resid	534.3633	Schwarz criterion	3.155337
Log likelihood	-661.9845	Hannan-Quinn criter.	3.10997
F-statistic	57.82826	Durbin-Watson stat	1.627529
Prob(F-statistic)	0		

Table C.1. 4 Full OLS estimates of air passenger travel demand between Middle & East EEA countries and China

Dependent Variable: DEMAND
Method: Least Squares
Sample: 1 632
Included observations: 632

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-22.51181	5.350796	-4.207188	0
POP	-0.275348	0.069837	-3.942708	0.0001
INC	1.920354	0.159358	12.05056	0
COST	-0.349768	0.576969	-0.606216	0.5446

SPECA	3.123162	0.664945	4.696873	0
SPECB	-0.878314	0.181967	-4.826765	0
DIRECT	3.818186	0.419442	9.103004	0
AIRPORT	1.750773	0.186581	9.383466	0

R-squared	0.421179	Mean dependent var	4.710014
Adjusted R-squared	0.414686	S.D. dependent var	2.36347
S.E. of regression	1.808192	Akaike info criterion	4.035109
Sum squared resid	2040.204	Schwarz criterion	4.091424
Log likelihood	-1267.094	Hannan-Quinn criter.	4.05698
F-statistic	64.86488	Durbin-Watson stat	1.585946
Prob(F-statistic)	0		

C.2 Discrete choice analysis estimates (Eq. (15))

Table C.2. 1 Full estimate results of discrete choice model for revealed passengers' choices on itineraries between West EEA countries and China

Number of draws:	7.30209E+17
Number of estimated parameters:	42
Sample size:	643204
Init log-likelihood:	-2304933.715
Final log-likelihood:	-1711340.768
Likelihood ratio test for the init. model:	1187185.894
Rho for the init. model:	0.258
Rho bar for the init. model:	0.258
Final gradient norm:	7.03E+00
Iterations:	133

Name	**Value**	**Std err**	**t-test**	**p-value**	**Robust Std err**	**Robust t-test**	**p-value**
itinerary1 cte.	9.23	0.152	60.8	0	0.0332	277.49	0
Frequency	0.00681	9.75E-05	69.86	0	4.82E-05	141.3	0
Airfare	-0.00152	9.77E-06	-155.56	0	7.87E-06	-192.97	0
Travel Time	0.317	0.00415	76.47	0	0.00401	79.06	0
Direct	-36.2	1.80e+308	0	1	0.2	-181.17	0
CALSS_ALL	27.2	3.94	6.92	0	1.80e+308	0	1
CLASS_ONE	27.5	5.29	5.19	0	1.80e+308	0	1
itinerary2 cte.	6.75	0.186	36.33	0	0.112	60.06	0
itinerary3 cte.	10.6	0.149	71.35	0	0.0167	636.61	0
itinerary4 cte.	10.2	0.149	68.58	0	0.0199	514.97	0
itinerary5 cte.	11.8	0.148	79.58	0	0.00886	1332.25	0
itinerary6 cte.	12	0.148	81.08	0	0.00864	1391.52	0

itinerary7 cte.	9.91	0.15	66.09	0	0.0239	414.51	0
itinerary8 cte.	11.6	0.148	78.1	0	0.0106	1090.2	0
itinerary9 cte.	9.04	0.153	59.24	0	0.0367	246.53	0
itinerary10 cte.	6.48	0.197	32.91	0	0.13	49.88	0
itinerary11 cte.	10.9	0.149	73.28	0	0.0145	754.07	0
itinerary12 cte.	11.2	0.149	75.5	0	0.0133	844.63	0
itinerary13 cte.	11.2	0.149	75.64	0	0.0126	890.03	0
itinerary14 cte.	8.94	0.153	58.54	0	0.0377	237.18	0
itinerary15 cte.	13.5	0.148	91.07	0	0.00573	2353.89	0
itinerary16 cte.	13.4	0.148	90.36	0	0.00563	2379.98	0
itinerary17 cte.	10.6	0.149	70.99	0	0.017	623.74	0
itinerary18 cte.	10.7	0.149	71.73	0	0.0163	655.22	0
itinerary19 cte.	10.1	0.15	67.59	0	0.0211	479.84	0
itinerary20 cte.	9.49	0.151	62.9	0	0.0289	328.31	0
itinerary21 cte.	10.2	0.15	68.18	0	0.0207	491.45	0
itinerary22 cte.	10.5	0.149	70.29	0	0.018	580.95	0
itinerary23 cte.	10.9	0.149	73.59	0	0.0144	757.85	0
itinerary24 cte.	9.51	0.151	63.06	0	0.0287	331.42	0
itinerary25 cte.	-19.7	1.80e+308	0	1	0.348	-56.48	0
itinerary26 cte.	13.6	0.148	92.12	0	0.00485	2813.36	0
itinerary27 cte.	12	0.148	80.89	0	0.00958	1253.33	0
itinerary28 cte.	11.6	0.148	78.18	0	0.0111	1046.57	0
itinerary29 cte.	13.3	0.148	89.72	0	0.00536	2478.63	0
itinerary30 cte.	11	0.149	74.16	0	0.0139	794.05	0
itinerary31 cte.	13.5	0.148	91.21	0	0.0058	2331.03	0
itinerary32 cte.	12	0.148	80.98	0	0.00899	1335.52	0
itinerary33 cte.	13.3	0.148	89.48	0	0.00523	2533.33	0
itinerary34 cte.	13.8	0.148	92.94	0	0.0057	2416.34	0
itinerary35 cte.	10.7	0.149	72.07	0	0.0158	677.37	0
itinerary36 cte.	9.62	0.151	63.9	0	0.0271	355.41	0

Table C.2. 2 Full estimate results of discrete choice model for revealed passengers' choices on itineraries between North EEA countries and China

Number of draws:	7.30209E+17
Number of estimated parameters:	19
Sample size:	109412
Init log-likelihood:	-288744.541
Final log-likelihood:	-239779.148
Likelihood ratio test for the init. model:	97930.784
Rho for the init. model:	0.17
Rho bar for the init. model:	0.17

Final gradient norm:	3.81E-01
Iterations:	78

Name	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	p-value
itinerary1 cte.	-18.2	1.80e+308	0	1	0.0118	-1540.37	0
Frequency	0.0207	0.000425	48.71	0	0.000615	33.67	0
Airfare	-0.002	0.000139	-16	0	0.00015	-14.86	0
Travel Time	-0.384	0.0111	-34.55	0	0.0117	-32.87	0
CALSS_ALL	0	1.80e+308	0	1	4.67E+04	0	1
CLASS_ONE	-30.2	1.80e+308	0	1	1.33	-22.66	0
itinerary2 cte.	-21.1	1.80e+308	0	1	0.0316	-667.92	0
itinerary3 cte.	-18.4	1.80e+308	0	1	0.0138	-1333.4	0
itinerary4 cte.	-18.8	1.80e+308	0	1	0.0118	-1583.25	0
itinerary5 cte.	-21.6	1.80e+308	0	1	0.044	-492.22	0
itinerary6 cte.	-18.9	1.80e+308	0	1	0.0123	-1534.48	0
itinerary7 cte.	-19.3	1.80e+308	0	1	0.014	-1381.78	0
itinerary8 cte.	-23.1	1.80e+308	0	1	0.0897	-257.51	0
itinerary9 cte.	-18.5	1.80e+308	0	1	0.00904	-2050.06	0
itinerary10 cte.	-18.3	1.80e+308	0	1	0.00995	-1835.63	0
itinerary11 cte.	-18.8	1.80e+308	0	1	0.0128	-1460.84	0
itinerary12 cte.	-47.7	1.80e+308	0	1	1.34	-35.61	0
itinerary13 cte.	-18.9	1.80e+308	0	1	0.0127	-1488.8	0
itinerary14 cte.	-22.1	1.80e+308	0	1	0.0509	-434.46	0

Table C.2. 3 Full estimate results of discrete choice model for revealed passengers' choices on itineraries between South EEA countries and China

Number of draws:	7.302E+17
Number of estimated parameters:	18
Sample size:	126335
Init log-likelihood:	-313930.68
Final log-likelihood:	-281847.82
Likelihood ratio test for the init. model:	64165.731
Rho for the init. model:	0.102
Rho bar for the init. model:	0.102
Final gradient norm:	1.42E+00
Iterations:	95

Name	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	p-value
itinerary1 cte.	-3.95	0.417	-9.46	0	0.0281	-140.3	0
Frequency	0.00435	1.17	0	1	0.0117	0.37	0.7
Airfare	0.00789	0.000741	10.66	0	0.000709	11.13	0
Travel Time	-0.0384	0.0356	-1.08	0.28	0.0356	-1.08	0.3
Direct	8.76	5.95E+03	0	1	1.80e+308	0	1
CALSS_ALL	0.509	1.96E+04	0	1	13.6	-0.04	1
CLASS_ONE	-19	448	-0.04	0.97	1.80e+308	0	1

itinerary2 cte.	-1.39	0.416	-3.33	0	0.00805	-172.29	0
itinerary3 cte.	-1.33	0.416	-3.18	0	0.0107	-123.49	0
itinerary4 cte.	-3.12	0.417	-7.49	0	0.0192	-162.41	0
itinerary5 cte.	-1.95	0.416	-4.69	0	0.0118	-165.27	0
itinerary6 cte.	-1.36	0.416	-3.27	0	0.00776	-175.55	0
itinerary7 cte.	-14.4	1.80e+308	0	1	1.80e+308	0	1
itinerary8 cte.	-1.12	0.416	-2.68	0.01	0.00589	-189.62	0
itinerary9 cte.	-2.14	0.416	-5.13	0	0.0133	-161.26	0
itinerary10 cte.	-1.83	0.416	-4.39	0	0.0123	-148.26	0
itinerary11 cte.	-1.52	0.416	-3.65	0	0.00882	-172.32	0
itinerary12 cte.	-1.3	0.416	-3.13	0	0.00828	-157.5	0

Table C.2. 4 Full estimate results of discrete choice model for revealed passengers' choices on itineraries between Middle & East EEA countries and China

Number of draws:	7.30209E+17
Number of estimated parameters:	36
Sample size:	336516
Init log-likelihood:	-1144557.33
Final log-likelihood:	-861274.618
Likelihood ratio test for the init. model:	566565.439
Rho for the init. model:	0.248
Rho bar for the init. model:	0.247
Final gradient norm:	4.36E-02
Iterations:	188

Name	**Value**	**Std err**	**t-test**	**p-value**	**Robust Std err**	**Robust t-test**	**p-value**
itinerary1 cte.	-0.00172	0.0239	-0.07	0.94	0.0264	-0.06	0.95
Frequency	0.259	0.0187	13.84	0	0.0447	5.8	0
Airfare	-0.00372	0.000959	-3.88	0	0.00091	-4.09	0
Travel Time	-0.0565	0.0518	-1.09	0.27	0.0629	-0.9	0.37
Direct	24.8	6.28E+03	0	1	578	0.04	0.97
CALSS_ALL	3.05	1.06E+03	0	1	97.4	0.03	0.97
CLASS_ONE	-21.2	5.67E+03	0	1	521	-0.04	0.97
itinerary2 cte.	0.749	0.0182	41.09	0	0.0214	35.03	0
itinerary3 cte.	-0.0587	0.0249	-2.36	0.02	0.0273	-2.15	0.03
itinerary4 cte.	-1.99	5.67E+03	0	1	523	0	1
itinerary5 cte.	1.22	0.0139	88.03	0	0.0178	68.64	0
itinerary6 cte.	3.25	0.00697	466.25	0	0.0131	247.57	0
itinerary7 cte.	3.3	0.00736	448.39	0	0.0133	247.17	0
itinerary8 cte.	-0.664	0.032	-20.76	0	0.0339	-19.59	0
itinerary9 cte.	-0.963	0.0372	-25.85	0	0.0387	-24.85	0
itinerary10 cte.	-0.769	0.0342	-22.47	0	0.036	-21.36	0

itinerary11 cte.	-6.16	0.5	-12.33	0	0.507	-12.15	0
itinerary12 cte.	-1.43	0.0474	-30.19	0	0.0486	-29.46	0
itinerary13 cte.	2.37	0.00966	245.04	0	0.0147	160.58	0
itinerary14 cte.	1.99	0.0101	196.51	0	0.015	132.13	0
itinerary15 cte.	1.13	0.0143	78.94	0	0.0182	62.33	0
itinerary16 cte.	0.717	0.0172	41.78	0	0.0205	35.04	0
itinerary17 cte.	3.26	0.00697	467.53	0	0.0131	248.02	0
itinerary18 cte.	2.08	0.00988	211.05	0	0.0149	140.03	0
itinerary19 cte.	1.75	0.0109	160.62	0	0.0156	112.36	0
itinerary20 cte.	1.06	0.0149	71.67	0	0.0186	57.32	0
itinerary21 cte.	0.619	0.0179	34.53	0	0.0211	29.34	0
itinerary22 cte.	3.39	0.00625	541.77	0	0.0128	265.2	0
itinerary23 cte.	-5.94	0.447	-13.28	0	0.455	-13.04	0
itinerary24 cte.	1.92	0.00984	194.8	0	0.0149	128.98	0
itinerary25 cte.	-1.1	0.0406	-27.03	0	0.0421	-26.04	0
itinerary26 cte.	-0.719	0.0333	-21.61	0	0.035	-20.56	0
itinerary27 cte.	-0.957	0.0364	-26.28	0	0.0381	-25.12	0
itinerary28 cte.	1.55	0.0108	144.36	0	0.0155	100.34	0
itinerary29 cte.	1.23	0.0139	88.82	0	0.0178	69.3	0
itinerary30 cte.	0.449	0.0192	23.46	0	0.0222	20.27	0