Asian Journal of Technology Innovation

ISSN: 1976-1597 (Print) 2158-6721 (Online) Journal homepage: https://www.tandfonline.com/loi/rajt20

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To cite this article: Slavo Radosevic & Esin Yoruk (2016) Why do we need a theory and metrics of technology upgrading?, Asian Journal of Technology Innovation, 24:sup1, 8-32, DOI: 10.1080/19761597.2016.1207415

To link to this article: https://doi.org/10.1080/19761597.2016.1207415

Published online: 21 Oct 2016.

Asian Journal of Technology Innovation, 2016
Vol. 24, No. S1, 8–32, http://dx.doi.org/10.1080/19761597.2016.1207415

Routledge
Taylor & Francis Group

Why do we need a theory and metrics of technology upgrading?

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This paper discusses why we need a theory and metrics of technology upgrading. It critically reviews existing approaches to technology upgrading, and proposes a theoretically relevant and empirically grounded intermediate conceptual and statistical framework to illustrate the types of challenges facing economies with different levels of income. It conceptualises technology upgrading as a three-dimensional process that considers the intensity and type of technology upgrading based on different types of innovation and technology activities; the broadening of technology upgrading through exploitation of technology and knowledge diversification; and interaction with the global economy via the import, adoption, and exchange of knowledge. We consider these to be necessary first steps towards a theory and metrics of technology upgrading and the generation of more relevant composite indicator of technology upgrading.

Keywords: technology upgrading, growth, composite indicators, middle-income economies, R&D and innovation

1. Introduction

Why do we need a theory of technology upgrading? There are three major motivations for our study. First, the search for universal growth factors is futile (see Easterly 2001). Theories of aggregate economic growth generally consider a single variable or a single factor when trying to explain economic growth. The search for a universal theory or a single set of factors able to explain growth at different levels of development and in different geographical areas faces huge empirical and methodological challenges. Similarly, technology as one of the major drivers of growth over the long term is not reducible to a single variable such as research and development (R&D) or total factor productivity (TFP) (Lee 2013). Improvements in technological capability stem from increased investment across a number of drivers of technology upgrading (Furman and Hayes 2004). It is important to identify which (if any) of these drivers are common, and which are country specific. In addition, the drivers of technology upgrading differ according to the stage of development and, thus, may be quite different for low-, middle-, and high-income economies.

Second, current technological upgrading metrics are either not theoretical or not rooted in the stylised facts related to technology upgrading and, thus, are not relevant to middle-income economies. For example, the Global Innovation Index and the EU Innovation Union Scoreboard (IUS) are pragmatic, but atheoretical analytical frameworks. By this we mean that they are not underpinned by an understanding of how technology upgrading takes place at different income levels.

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The frequently used Crépon, Duguet, and Mairesse (1998) or CDM model brings together within a simple framework, R&D, innovation, and productivity, giving the impression that it is theoretically grounded. However, we consider this framework to be of limited relevance to countries operating behind the technology frontier since it is based on R&D as an input into the innovation process which reduces its utility for middle-income economies. The World Economic Forum *Global Competiveness Reports* are considered theoretically and empirically grounded since they acknowledge differences in the drivers of growth, but this approach mixes technological and institutional variables which we consider to be problematic (see below).

Third, theoretically grounded, but not measurable frameworks are of limited value, as are metrics that are not based on stylised facts or theory. Such metrics could lead to irrelevant policies through their focus on issues not directly relevant to the specific growth challenges. A paradigmatic example of this is the contradiction in the current EU approach between its dominant metrics (cf. IUS), which assume identical technological paths and drivers of growth, and its aim to push countries along divergent 'smart specialisation' paths. The EU is encouraging countries and regions to formulate their own smart specialisation strategies to avoid what have been described as 'adding up' problems (Spence 2011, pp. 94–96) or the situation where too many regions are focusing on similar technologies and markets and, thus, out competing one another. However, the EU's dominant IUS metrics, which countries and regions are using as policy targets, are reinforcing imitative policies aimed at R&D-based growth with the result that metrics are determining policy rather than policy determining the metrics.

Based on these three factors, we argue that there is need to generate a theoretically relevant, but empirically grounded, middle-level conceptual and statistical framework which highlights the type of challenges that would seem to be relevant to a large number of countries classified by the World Bank as middle-income and 'lower' high-income countries (from \$1K–\$30 K per capita income) to escape the potential middle-income trap. Our notion of middle-income economies does not correspond strictly to the World Bank classification, which we consider out-dated. A more accurate definition of middle-income economies would include those countries currently classified as middle-income economies (from \$1046–\$12,745 per capita) and 'lower' high-income economies (\$12,745–\$30 K per capita) as opposed to 'upper' high-income economies (above \$30 K per capita). Our so-called broad middle-income group includes middle-income and lower high-income economies (see Appendix Tables A1 and A2).[1]

In order to avoid measurement without (some) theory or at least metrics grounded in the stylised facts of technology upgrading, we construct a composite indicator of technology upgrading which complements existing metrics, especially IUS, and which better reflects the drivers and patterns of technology upgrading in our broadly defined middle-income economies group.

We do not aim to use technology upgrading as a substitute for economic growth, but rather as a major determinant of economic growth. We recognise that some countries can achieve high levels of income without much technological capability. For example, resource-based economies and *entrepot* economies can earn high incomes without necessarily being innovators. Various income levels can be achieved based on a variety of institutional systems. From the perspective of technology upgrading we are concerned primarily with technology accumulation. We assume that very different institutional systems can lead to technology upgrading, or that institutional forms are secondary to the process of technology accumulation. Similar to functional views on innovation systems we are concerned primarily with technology activities that increase firm, sector, and country-level capabilities. The institutional context is a quite important variable which ultimately is necessary to explain different growth performance, but our primary concern is with technology upgrading via the accumulation of technology capabilities at different levels.

In what follows, we discuss technology upgrading in the context of the broad literature on this issue (Section 2). Section 3 discusses the conceptual framework and its assumptions which we propose as a way forward to theorising and measuring technology upgrading. We provide a brief discussion of technology upgrading in the context of the distinction between catch-up and post-catch-up (Section 4), and conclude in Section 5 by summarising the major points.

2. Past and current contributions to research on technology upgrading

2.1. *Past and recent contributions*

Considering growth from an upgrading perspective is not new. Marshall (1890) in his *Principles of Economics*, acknowledges the big variations in the dynamics among different economic sectors and their important aggregate effects on economic growth. Schumpeter's theory of 'Business Cycles' is firmly rooted in analysis of the emergence and decline of leading industries, which, in aggregate, lead to macroeconomic cycles. Kuznets in 'Secular, Movements in Prices and Production' (1930) recognised that shifts in the relative importance of leading industries follow sales and innovation patterns. Chenery and Syrquin (1975) in *Patterns of Development 1950-70* analysed the structural characteristics of the economy by grouping industries into early, middle and late. The idea of development as an evolving process that goes through several stages was first formulated by Rostow (1960) in his stages of growth model. This was based on the idea of industry life cycles and 'leading sectors', driving economic growth in specific stages. A common feature of these modes is the assumption that 'all nations [go] through the same stages in the same order, though not necessarily at the same time' (von Tunzelmann 1995, p. 69).

A similar logic of structural change, but in an international context has been conceptualised, based on Japanese experience, as the 'Flying-geese model' (Akamatsu 1962). This model depicts changing patterns of industry specialisation based on an import – domestic production – export sequence, which induces structural change in both leader and follower countries. Countries exhibit similarities also in terms of sequences of structural change in industrial development, of *capital goods following consumer goods* and *the progression from crude to simple goods to complex and refined goods*. This pattern accompanied by a sequential positioning of the developing countries lined up behind the advanced nations, allowing the former group to emulate, learn from and capitalie on growth stimuli/externalities via economic interactions.

A recent example of similar thinking about growth is Ozawa's (2009) structural growth stages model, which is a synthesis of stage theories of growth (i.e. Rostow and Akamatsu) and Schumpeter's model. Ozawa's model is based on actual historical industry (hence technological) developments or ladders of economic development, which are driven by innovation. Ozawa synthesises sequential growth across five stages involving a leading sector in each stage. Ozawa's stylisation of Japan's industry upgrading follows the sequence: labour-driven → scale-driven → assembly-driven → R&D-driven → IT-driven industries. Ozawa and other's contributions are based largely on history and map upgrading based on the leading economies' historical experience. This is a strength but also a weakness of these models since catching up countries may not adopt the same pattern as Lee (2013) shows.

The alignment of countries in the industrial upgrading process has been described as 'countries gradually mov[ing] up in technological development by following the pattern of countries just ahead of them in the development process' (Radelet and Sachs 1997, p. 52). However, the new structural economics of Lin (2011, p. 14) updates this to economic development as:

> a process of continuous industrial and technological upgrading in which any country, regardless of its level of development, can succeed if it develops industries that are consistent with its comparative advantage, determined by its endowment structure. The successful strategy for developing countries is to exploit the late-comer advantage by building up industries that are growing dynamically in more advanced countries that have endowment structures similar to theirs.

So, implicit in notions of new structural economics is the process of technology upgrading, which is considered to be based on the country's 'latent comparative advantages' (Lin 2011). The econometric evidence for this proposition is quite persuasive and has been tested in the context of the transition economies (Bruno, Douarin, Korosteleva, and Radosevic 2015). However, this approach seems largely applicable in the transformation from low to middle-income levels but less so to the transition from middle-income to (upper) high income. As Lee (2013) demonstrates countries that have successfully moved to high-income group did so by entering newly emerging short-cycle technologies rather than mature industries. Lee shows clearly how the role of structural change, especially technological diversification rather than imitation, is one of the major factors in catching up to high-income levels. While new structural economics accounts (Lin 2012a,b; Lin and Rosenblatt 2012) show the path to technology upgrading as based on 'copying industries' using latent comparative advantages in the transition from low to middle-income levels, Lee (2013) shows middle-income economies taking 'detours' and establishing their own paths to transition from middle to high income. A very recent contribution to our thinking about technology upgrading in the context of technology specialisation and growth is Foray's (2015) contribution which conceptually frames and theorises issues based on EU smart specialisation strategies.

A major addition to our understanding of technology upgrading came from the exploration of upgrading via global value chains (GVCs). In this literature, industrial upgrading is defined as substantial changes to a country's specialisation and knowledge base, which increase its capacity for value generation (Ernst 1998). Gereffi (1999, pp. 51–52) defines it as 'a process of improving the ability of a firm or an economy to move to more profitable and/or technologically sophisticated capital and skill-intensive economic niches'. Upgrading is usually defined as a gradual shift from lower to higher value-added activities; for example, from cheap and simple products to complex and expensive ones; from mass production of standardised products to flexible production of differentiated products; and, from simple assembly to more integrated forms of production (such as original equipment manufacturing (OEM), original design manufacturing (ODM), and original brand manufacturing (OBM)) (see Table 1). Hierarchy is a common feature of upgrading taxonomies (see Table 1, particularly Gereffi (1999) and Ernst (1998)). Some taxonomies are theory driven (Gereffi 1999; Ernst 2001) and some are the outcome of firm-level empirical work (firm-based case studies) (Hobday 1995; Humphrey and Schmitz 2004).

It is not surprising that technology upgrading is most often discussed in an international context. Ernst (1997) and Gereffi (1999) pioneered the analysis of upgrading via global production networks (GPNs) and a GVC framework. However, Yoruk (2013) shows that upgrading is currently unjustifiably reduced to upgrading within value chains or GPN. In the first in-depth study of technology upgrading through value chains, in the context of Central and Eastern Europe, she shows the major importance of both production networks and knowledge networks. Yoruk's research shows that learning by doing and learning by exporting have no statistically significant effect on functional upgrading. She shows that the opportunities offered by GVCs are of little use unless firms have the ability to internalise this external knowledge through their human resources, and through in house training and research. She shows also that managerial upgrading is important for technology upgrading, but global buyers do not support it. This highlights the

Table 1: Taxonomies of firm-level upgrading in international (GVC) context.

Authors	Taxonomy/trajectory	Locus of upgrading
Hobday (1995)	Original equipment manufacturing (OEM) Original design manufacturing (ODM) Original brand manufacturing (OBM)	International production networks
Gereffi (1999)	*Within* - factories, - inter-firm networks, - local or national economies, and - supranational macro-regions	Global value chains
Ernst (2001)	*hierarchy of* - industries, - factors of production, - consumption, - value chain stages, and - forward and backward linkages	Global production networks (2001, 2006), Global knowledge networks (2008), Global innovation networks (2009)
Humphrey and Schmitz (2004)	Process upgrading Product upgrading Functional upgrading Inter-sectoral upgrading	Global value chains

importance of organisational capabilities and suggests that the firm's structure is an important dimension of technology upgrading.

Do these contributions have insights that are relevant to our understanding of the theory and metrics of technology upgrading? First, existing contributions provide most qualitative insights, which have not been converted into models or stylisations of countries' technology upgrading. Rostow and Chenery's contributions have not been extended or applied in a new context. Nevertheless, these existing contributions assume a similar or identical path to upgrading. In light of recent contributions, especially Lee (2013) and Foray (2015), this assumption needs some qualification or needs to be relaxed, especially in relation to the transition from middle to high income. So, 'copying industries' may help in the transition from low to middle income (Lin 2012b), but diversity and variety of upgrading are more critical for subsequent upgrading. Second, technology upgrading is an interactive process between 'leaders' and 'followers' (Akamatsu 1962). The literature on GVC clearly shows the overwhelming importance of the international context of upgrading, but also its limits (Yoruk 2013). Third, several contributions on technology upgrading show that upgrading is a multi-level process that takes place at the firm, industry, inter-industry, and country levels. We discuss this important feature of technology upgrading in more depth below.

2.2. *Multi-level perspectives on technology upgrading*

The literature suggests that upgrading is multi-level phenomenon operating at the firm, industry, and country levels (see Table 2 for summary).

Table 2: Different perspectives on technology upgrading.

Types/levels	Conceptual framework
Intra-firm level	- Reverse product life cycle: a combination of the product life cycle model in advanced firms by Abernathy and Utterback (1978) and Kim's (1980) three-stage catch-up model of acquisition – assimilation – implementation - Importance of minor improvements during reverse learning trajectory (Hobday 1995; Hobday, Rush, and Bessant 2004)
Intra-industry and inter-industry level	- Industry life cycle and dominant design (Klepper 1997) - Upgrading towards high value-added industries (value chain upgrading)
Country level	Sequential upgrading of countries based on 'leading-sector' (Ozawa 2009) WEF rankings based on differing drivers of growth IUS innovation capacity of countries based on composite indicators of innovation activities

Innovation studies scholars were interested in technology upgrading at the firm level based on the so-called technology capabilities approach (Dahlman, Ross-Larson, and Westphal 1987; Lall 1992; Bell and Pavitt 1993; Dutrenit 2000). Firm-level evidence shows that the paths to upgrading of firms in developing countries encompass through a variety of interrelated, sometimes similar and sometimes unique taxonomies. Based on Korean experience, Kim (1980) proposes a three-stage catch-up model for developing country firms, going from the acquisition of foreign technology, to its assimilation and the implementation of new product lines. Hobday (1995) explores the path to technology accumulation among East Asian electronics firms during the 1960s–1990s. He shows that a best approximation of the process is the inverse product life cycle (PLC). In contrast to R&D and design led strategies typical of technology leaders and followers, East Asian latecomers began with minor improvements to the manufacturing process and moved to mastering elements of process technology through reverse engineering and finally mastering the elements of design capabilities.

As some of these countries have moved to the group of high-income economies, the issue of firm upgrading has become an issue of transition from catching up to post-catch up stages. The move to a post-catch up stage or the level of high-income economies involves countries operating at the technology frontier by solving problems that have not been solved by others. Unlike the catch-up stage where firms enter largely through a reverse PLC pattern, in the post-catch up stage firms enter at various stages in the PLC (Choung, Hwang, and Song 2014). They may enter the PLC via large firms in design and R&D stages; or via networks of new technology based firms immediately after dominant design has been established; or via cooperation between public R&D organisations and firms in early stages of new PLCs (Choung et al. 2014). Other firms can follow a 'strategic niche' strategy, 'which involves large number of public, private stakeholders through small-scale transition experiments that expand the scope of changes to a wider scale when the experiments succeed' (Seong, Kim, and Cho 2014).

The literature highlights a trend towards expansion from firm-level upgrading to 'industry-level linkages' or industry-level upgrading. The rationale is the realisation that countries' advancement of their firm-level upgrading is increasingly dependent on 'industry linkages' (Ernst 2008a). More broadly, Ernst (2008b) refers to three forms of 'industrial upgrading': (i) inter-industry upgrading from low value-added industries (e.g. light industries) to higher value-added industries (e.g. heavy and higher tech industries); (ii) inter-factor upgrading from endowed assets (i.e. natural resources and unskilled labour) to created assets (physical capital, skilled labour, and social capital); and (iii) upgrading of demand within a hierarchy of consumption, from necessities, to conveniences, to luxury goods.

How industries evolve and upgrade is much less well understood. The most developed stylisation of industry dynamics is the industry life cycle, which is either inseparable from or quite reliant on the already mentioned PLC (Abernathy and Utterback 1978). This view identifies three product evolution stages (Gort and Klepper 1982; Klepper and Graddy 1990; Suarez and Utterback 1995; Klepper 1997). A radical innovation leads to product innovations. In this stage, the entry barriers are low, R&D and capital requirements are limited, and new entrants are most often small firms. This is followed by the emergence of a dominant design, which induces a stream of process innovations, but which has a positive effect on cost performance ratios. Economies of scale increase and equipment becomes standardised. This increases the barriers to entry and leads to an industry shakeout. Finally, as the technology matures, a few incremental innovations are introduced, the industry becomes more concentrated and the barriers to entry increase further. Malerba and Orsenigo (1994) summarise the weaknesses in these stylisations. First, industries are reduced to products, which is too reductive. Second, the sequence of product innovations followed by process innovations does not hold in capital intensive industries such as commodity chemicals, synthetic fibres, plastics, and petrochemicals where innovations are mainly of the process type. Third, in some industries the emergence of a dominant design can lead to new discontinuities or to several dominant designs. Fourth, the radical product innovation that triggered the industry life cycle may be accompanied by very different industry dynamics in terms of entrants, industry concentration and incumbents. Entrants may be existing firms active in related industries while the links among firms may change continuously, and new type of actors emerge so that the industry boundaries are continuously being redefined. Thus, there seem not to be useful stylisations or regularities related to the metrics of technology upgrading. The upgrading process seems not to be correlated either to firm size or the type of innovation.

A critique of industry life cycle models shows that industry boundaries are ill-defined and changing, and need to include a variety of other non-business actors. This highlights the need to include infrastructure and infrastructural factor in the evolution and upgrading of industries and economies (see Ozawa 2009) (see below).

The rise in composite indicators has resulted in a proliferation of different attempts to measure progress in innovation and competiveness at the country level (see Archibugi, Denni, and Filippetti 2009 for a discussion and overview). Adopting a long-term historical perspective, Ozawa (2009) proposes a sequential upgrading process based on countries' leading sectors. The World Economic Forum (WEF) Global Competitiveness Report (GCR) ankings provide country rankings based on various drivers of economic growth and classify countries into factor, efficiency, and innovation based. The EU Innovation Scoreboard provides rankings based on composite indicators of innovation activities ranging from moderate, to followers, to innovation leaders. Among this group of models of upgrading we should highlight the indicator of economic complexity as a dimension used to measure upgrading of different countries based on the complexity of their export products. See Hausmann and Klinger (2006), Hausmann, Hwang, and Rodrik (2007), Hidalgo, Klinger, Barabasi, and Hausmann (2007), and Hidalgo and Hausmann (2009).

As already highlighted, technology upgrading is a multi-level process and the ultimate pattern of upgrading at country level is a complex interaction between the micro, mezzo, and macro levels. This is the most widespread perspective in the context of growth in East Asia and the integration of East Asian firms in GPNs. Aggregate explanations of growth do not provide satisfactory answers to the question of how these economies managed to achieve upper middle-income status in such short period. Hence, an industrial upgrading perspective is useful to shed light on the micro- and mezzo-level processes of technology accumulation, and provide a richer account of the drivers of growth than is possible based on variables such as TFP, or institutions.

In successful cases of catching up or forging ahead we observe high complementarity among different levels and various sub-systems, which generate increasing returns (Freeman and Louçã 2001; Freeman 2002). However, a favourable congruence between various sub-systems of society which have been positive for economic growth in one period of technological development, may be less favourable in the context of fundamental changes to technology (Freeman 2002). In short, history shows that technology upgrading is also an institutional process, and that institutional requirements also change over time. However, for analytical convenience, we abstract from institutional set-ups and focus only on the outcomes of learning processes demonstrated in technology upgrading activities. The complexities of the multi-levels at which technology accumulation takes place, the diversity of its patterns as depicted through structural change, and the interactive nature of technology upgrading are sufficient to justify our abstraction. Our fundamental assumption is rooted firmly in Schumpeterian theorising both formal (Aghion, Akcigit, and Howitt 2013) as well as of evolutionary and structuralist (Freeman and Louçã 2001, Perez 2010). We assume a relationship between modes of technology upgrading, and countries' positions in terms of level of development or distance from the technology frontier (Acemoglu, Zilibotti, and Aghion 2006). This is depicted in Figure 1 which suggests that technology upgrading paths vary as economies move from low to high incomes. Technology distant countries can grow based on imitative technology efforts similar to the logic in Lin (2012a,b). As they move from middle to high income, imitative technology is not sufficient and catching up countries need to find alternative paths involving technology diversification rather than imitation of technology leaders (Lee 2013). When they reach the post-catch stage they need to be operating at the technology frontier.

Figure 1 suggests that there is an association between income level groups and modes of technology upgrading. The modes of technology upgrading in right-hand column of Figure 1 are not the only possible modes, but are those that are considered to drive technology upgrading to achieve a higher income level. In reality, the technology activities of the technology leader countries include a mix of frontier and behind the technology frontier activities. Growth is driven by more effective diffusion of new technologies and management practices among the technology leaders compared to followers. Thus, Figure 1 should be considered a simplification, although a useful one because it conveys the idea that the dominant mode of technology differs as economies grow. However, this stylisation does not tell us anything about the transitions to different types of upgrading activities characterising different income levels. These are discussed in the form of the components of technology upgrading (depicted in Figure 3 and discussed in Sections 3.2–3.4).

Figure 1: Different patterns of technology upgrading at different income levels.
Note: Based on our discussion in Section 1 we define high income as 'upper high income' while middle income refers to 'broad middle income' category, which includes lower, upper middle income, and lower high-income groups.

So far, we have depicted technology upgrading as a stage process, and leave discussion of the transitions or transformations involved until we have a better empirical understanding of the modes of technology upgrading to different income groups. However, we would agree with an anonymous reviewer that the modes of technology upgrading as well as the transitions between different modes always involve a mix of types of technology activities. For example, our on-going empirical work which applies this conceptual framework, shows clearly that different types of technology upgrading activities exist at all income levels, but that their intensity and weight differs across different income groups (see Radosevic and Yoruk 2015). For example, production, R&D and technology capabilities are important at all income levels, but their composition varies. Also, all dimensions of structural change play a role in technology upgrading, but have different weights at different income levels.

Based on the different weight and intensity of the different components of technology upgrading, it follows the targets for countries operating behind technology frontier should not mimic those of high-income countries. Structural differences including differences in the levels and intensities of the different components of technology upgrading between countries, should be taken into account when considering appropriate policies (see Radosevic and Kaderabkova 2011 for an application of this thinking in the context of Eastern Europe).

3. Technology upgrading: conceptual issues

In this section, we outline some key criteria that must be satisfied in order to develop a theory of technology upgrading. We outline our conceptual approach, which includes the three dimensions of technology upgrading and its sub-components, and could be used as a basis for building a metrics of technology upgrading.

3.1. *Criteria for building a theory of technology upgrading*

We argue that a theory of technology upgrading, grounded in the stylised facts of economic growth, must comply with the following criteria:

(1) One of the keys to economic growth is improved technology capability, which is not reducible to a single variable (Lee 2013). Hence, our theory must be based on several drivers of technology capability.
(2) Technology upgrading is a multidimensional process that includes technology, structural change, and interaction with the global economy.
(3) Technology upgrading is based on a broader understanding of innovation which goes beyond R&D.
(4) Technology upgrading is a multi-level process with micro, mezzo, and macro foundations. Technological change is never entirely aggregate or entirely micro based, but primarily is a process of structural change which takes place at the micro, mezzo, and macro levels. Lee (2013) takes this into account by exploring the issue of catching up at all three levels.
(5) At the core of technology upgrading is structural change which is also a multidimensional process involving technological, industrial, and organisational change.
(6) Technology upgrading is an outcome of the interactions between global actors (embodied in international trade and investment flows) and local technology accumulation activities (pursued by host country firms and governments) (Berend and Ranki 1982; Ernst and Kim 2002; Lall 1992). The key to catch-up and post-catch-up is leveraging of domestic innovation efforts through global industry and knowledge networks (Ernst 2008a).

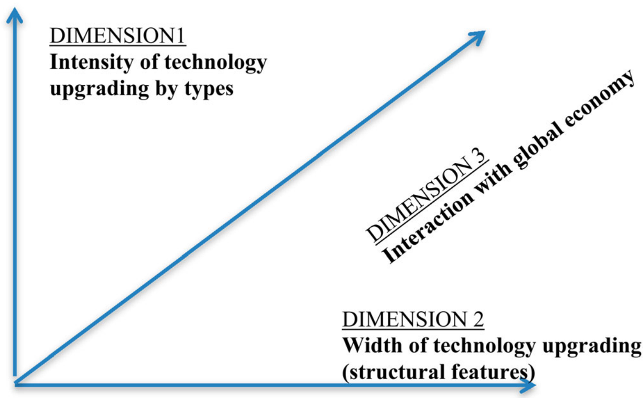

Figure 2: Dimensions of technology upgrading.

> Hence, the magnitude of knowledge inflows, and their coupling to domestic innovation efforts, are key dimensions of technology upgrading (Yoruk 2013).

Technology upgrading is also described as 'industrial upgrading', which we find problematic. Economic sectors are increasingly diverse conglomerates of technologies at different levels of complexity, and their boundaries are often arbitrary due in great part to the changing nature of industry and services (cf. tertiarisation of industry and industrialisation of services). The notion of industry is always context specific since its technological level is not discernible from the statistical definition of industry at whatever level of aggregation. However, we acknowledge that that there is degree of overlap between industry and technology upgrading since some industries are based on more complex technologies than others. In that respect, technology upgrading is about

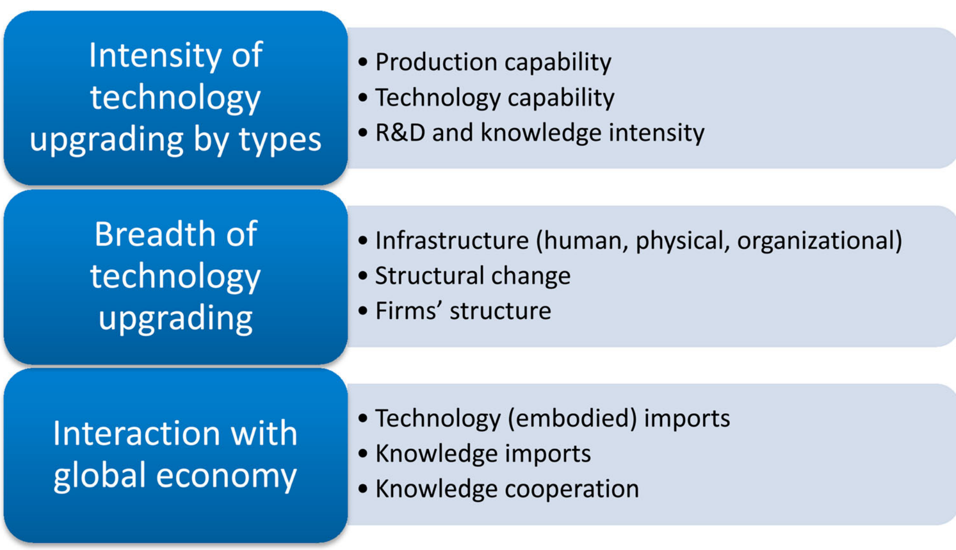

Figure 3: Dimensions and components of technology upgrading.

changes in technology intensity, but equally about structural change. In fact, as we argue below, the two are inextricably linked.

Based on a literature review, and at very general level, we conceptualise technology upgrading as a three-dimensional process (see Figure 2). It consists of dimension 1 (vertical axis) related to the intensity of technology upgrading exemplified by different types of innovation activities, dimension 2 (horizontal axis) which refers to the spread or breadth of the technology such as the diversity of technological knowledge, types of supporting infrastructure, and the firms' structure as the carrier of technology upgrading, and of dimension 3 (diagonal axis) which refers to knowledge inflows into the economy via a variety of channels such as trade, foreign direct investment (FDI) and GVCs. All three dimensions are grounded in the respective literatures on firm-level technology upgrading, structural change, and growth, and integration in the global economy (Figure 3).[2]

3.2. *Intensity and types of technology upgrading (scale)*

This dimension of upgrading is about the acquisition of different types of technology capabilities, which also are a reflection of countries' different technological levels. Economies that operate behind the technology frontier are more likely to grow based on production rather than technology capability, while high-income economies are more likely to grow based on technology frontier (R&D based) activities.

In clearly differentiating industry upgrading and technology upgrading and focusing only on the latter we are in danger of focusing only on disembodied knowledge and technology. Given the diversity of the forms in which technology is embodied, especially physical inputs and machinery, this would be problematic. Also, innovation activities in latecomer economies are largely about adoption of and improvements to imported machinery. Although, technology as a stock of knowledge should be separated from production, technological capacity and production capacity are strictly interconnected (Bell and Pavitt 1993). In this respect,

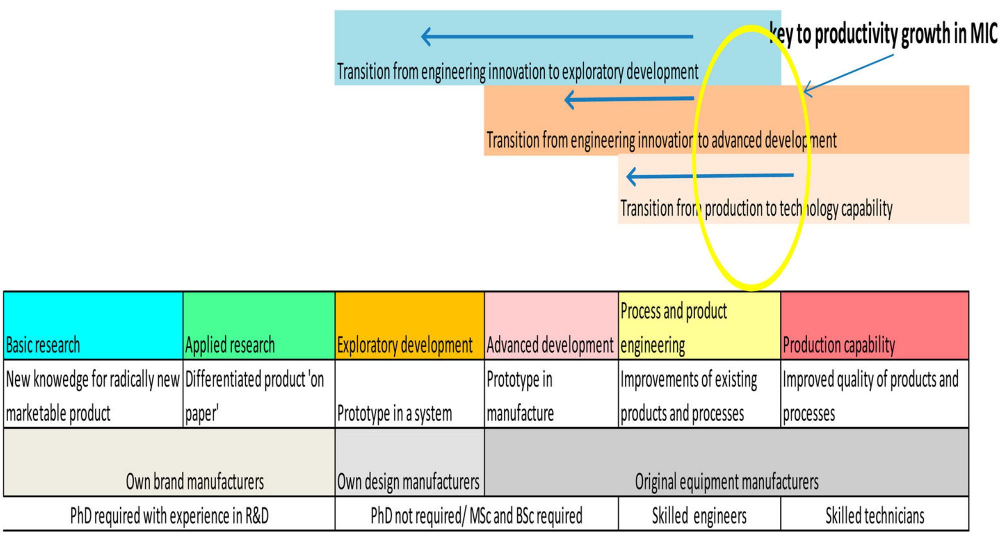

Figure 4: From production capability to technology capability.
Source: Based on and adapted from Amsden and Tschang (2003).

we differ from Archibugi and Coco (2005) who abstract production from technological capability.

Three types of capabilities, *production capability*, *technology capability*, and *R&D and knowledge intensity* are present in all economies, to different degrees. Their importance as drivers of growth vary according to their dependence on achieved income and their technology levels and the structural features of their economies. Majcen, Radosevic, and Rojec (2009) and Kravtsova and Radosevic (2011) show that, in Eastern Europe, production capability was a significant determinant of productivity growth at both the micro and macro levels. This is not unique to this region, but is a general feature of middle-income economies more generally, as highlighted in Figure 4 and in the literature on technological capabilities cited earlier. The types of technology capabilities are depicted in Figure 4 based on Amsden and Tschang's (2003) seminal discussion of R&D indicators.

Figure 4 differentiates between production capability, process and product engineering capability, advanced and exploratory development, applied research and basic research.

Production capability is the capability to produce at a given technology level at world levels of efficiency and productivity. This requires good operational efficiency and a skilled technical and blue-collar workforce.

A more complex capability is product and process engineering, which involves improvements to existing products and processes. This capability is largely dependent on skilled engineers. An extension of this capability is advanced development which Amsden and Tschang (2003) distinguish from exploratory development. Advanced development is about manufacturing prototypes while exploratory development is about system prototypes. There is an important threshold capability level between advanced development enabling manufacture, to own design manufacture. Production capability, process and product engineering, and advanced development are achievable by OEM enterprises, while exploratory development is a feature of ODM.

These stages are not necessarily hierarchically structured – that is, moving from advanced to exploratory development or from exploratory development to applied research or from applied research to basic research does not necessarily involve higher technology complexity (although it may); it simply involves a qualitatively different set of technology or knowledge requirements. Equally, upgrading to 'higher' stages is not automatically more rewarding in terms of value added – that is, upgrading may not necessarily lead to increased income, but might be necessary simply to maintain the existing income levels.

The literature on technological capabilities explores several cases of upgrading from production capability to design capability which can be considered paradigmatic. The best examples are cases in East Asia – a region that can be considered a paragon of technology upgrading and catch-up. Taiwan's IT industry is a good example of progress from production to design capability in a period of some 20–30 years (Ernst 2013). Hobday et al. (2004) explore the transformation of Korean firms from catch-up to post-catch up. Dutrenit (2000) provides an in-depth example of the transformation from production to OBM world-class capability among Mexican firms. In the case of Eastern Europe, Radosevic and Yoruk (2004) analyse the transformation of ex-socialist electronics conglomerates to contract manufacturers.

These examples show that technology upgrading is not a linear and autonomous process, but is a non-linear process involving several threshold levels. The move from one to another stage is not guaranteed and requires a new set of technical, financial, and organisational preconditions. Also, past successes are usually a source of weakness since it is necessary to pursue a dual strategy to move between stages. For example, success in the technology stage is based on low cost manufacturing capabilities and the capacity to imitate the technology leaders when introducing new products. The network on which this capability relies is not sufficient for the next hierarchical stage, which requires more differentiated knowledge networks and much larger investments in R&D-based developments and marketing. Finally, reliance on GVCs is the key to success in the initial production and technology capability stages. However, GVCs can become a source of vulnerability since technology leadership requires more autonomous development, strong local demand for technology and a variety of specialised services and knowledge providers.

3.3. *Breadth of technology upgrading: structural change, infrastructure, and firm structure (scope)*

Technology upgrading is more than intensity or scale of technological activities. It includes the breadth or scope of structural factors that affect the intensity of technology upgrading. There are three structural factors: the structural change itself, the infrastructure (human, physical, and organisational), and the firm structure.

3.3.1. *Structural change*

There is no general theory of *structural change*, although there is a variety of theoretical approaches that use different methodologies that claim to explain structural shifts between three broad sectors, and among the industries within these sectors (Krüger 2008). There is a common understanding that technological change affects structural change in relation to how industries with relatively low rates of productivity growth tend to shrink in terms of market shares while those with higher rates of productivity growth expand. Thus, structural change promotes aggregate productivity growth even if within industries, productivity growth is stagnant. However, the empirical evidence on the role of structural change in aggregate productivity growth differs widely across time periods, countries, and regions. Structural change often is dominated by the inter or intra-sectoral effects of productivity growth. Peneder (2003) concludes that structural change generates positive as well as negative contributions to aggregate productivity growth. However, since many of these effects net out, structural change appears to have only a weak impact on average. However, Sandven, Smith, and Kaloudis (2005) show that structural change in the manufacturing industries of the OECD countries is not a key feature of the growth process. Growth is based primarily on internal transformations in the low and medium tech sectors, rather than the creation of new sectors. For instance, the incorporation of information and communication technology (ICT) in medium or low-tech products is only one element of innovation in these sectors.

The issue is complicated by the level at which structural change is observed. Jorgenson and Timmer (2011) show that splitting the economy into agriculture, industry, and services is no longer relevant. There is substantial heterogeneity within the services sector, while the use of ICT and skilled labour is increasing in all sectors, and especially in services. The linkages among industries and innovation, including generic technologies such as ICT, are permeating structural change. The empirical results do not support the idea that growth is correlated with the share of the high tech sectors (Sandven et al. 2005). Instead, we are observing a change in the nature of industries and services, and their convergence. This is exemplified by knowledge intensive business services (KIBS), which are especially prominent in these developments.[3] The importance of KIBS as sources of innovation, technologies, and inputs has increased steadily over time resulting in the linkages between KIBS and the manufacturing industries in different countries strengthening over time.

Another structural change is the increasing importance of knowledge in all economic activities, which is being captured by knowledge intensive activities (KIA) defined as economic sectors

Table 3: Components of structural factors of technology upgrading.

Structural changes which promote technology upgrading	ICT as generic technology: proxy of structural change Knowledge intensive business services (KIBS) Knowledge intensive activities (KIA) Technology diversification
Infrastructural upgrading	An important element or externality of technology upgrading. Inefficiencies in infrastructure can hinder otherwise competitive firms to upgrade Infrastructure upgrading (Ozawa 2009) Human capital
Firms' structure	Share of large firms Share of SMEs

in which more than 33% of the employed labour force have completed an academic tertiary education (i.e. ISCED 5 and 6 levels; ECR 2011).

Imbs and Wacziarg (2003) find that sectoral concentration in relation to per capita income follows a U-shape. Thus, increased sectoral specialisation applies only to high-income economies. Countries diversify over most of their development path (Imbs and Wacziarg 2003, p. 64), which is in line with Lee's (2013) findings on growth and structural change which show that technology diversification is an important and robust feature of the transition from middle to (upper) high incomes.

In summary, despite recognition of the importance of structural change we can say little about the importance of different sectors and industries related to economic growth. The essence of structural change driven by technology is that it changes both the boundaries to and the nature of industries. Hence, using high tech to proxy for structural change is misleading since many high-tech elements permeate many low-tech sectors. Also, catching-up countries are involved increasingly in high-tech industries, but in low value-added segments. So, instead of focusing on structural change at the industry level, we investigate more reliable trends related to technological change. By this we refer primarily to the increasing importance of ICT in all economic sectors and activities; the increasing importance of the convergence between manufacturing and services captured by KIBS; the increasing knowledge intensity of all sectors of the economy captured by the KIA indicator; and increasing technology diversification as countries upgrade technologically (see Table 3).

3.3.2. *Infrastructural upgrading*

Technology upgrading takes place primarily in firms, but is not just a firm-level issue. The accumulation of technology capability in firms must be accompanied by an organisational and institutional *infrastructure* that supports the acquisition of such capabilities. Choung et al. (2014) show that the transition from adoption (catching-up) to creation (post-catch-up) depends on the range of infrastructure to support a country's innovation activity, and the strategies and resources of individual companies. We consider infrastructure to be an important dimension of structural change.

Infrastructure is one component of an economy's endowments, which generates large externalities for other firms in relation to transaction costs. It is both a public good and an input to the production of other intermediate inputs. Access to infrastructure services is strongly correlated with a country's average income. Infrastructure matters, but the evidence does not provide an unequivocal argument in favour of more or less infrastructure investment (Prud'homme 2005). However, despite the obvious problems related to estimating the direction of causation between infrastructure investment and growth, the evidence suggests that infrastructure causes growth, which, in turn, causes greater demand for (and supply of) infrastructure. As countries reach a certain stage of economic development, the extent to which infrastructure represents a binding constraint on development, changes.

Human capital is an important driver of growth (Glaeser, La Porta, Lopez-de-Silanes, and Shleifer 2004). The technology embodied in new machinery and equipment will not by itself lead to increased productivity without the human capabilities to use it effectively. Human capital based on education is an infrastructural precondition for or input into technology upgrading. In addition to school attainment, and years of schooling, differences in learning achievements matter even more for explaining cross-country differences in productivity growth (Hanushek and Wößmann 2007). Long run growth is closely related to the level of cognitive skills in the population (Hanushek 2013). In short, evidence on the 'quantity' and quality of human capital supports its inclusion as an important structural component.

However, in order to be effective, human skills need to be part of a specific organisational and economic process that rewards dexterity, learning, and innovation. Human skills need to be converted into firm specific skills to achieve technology upgrading. Eastern Europe is good example of a region whose labour force post-1989 had relatively high education levels, but low firm specific skills. Post-1989, this high level of education was considered an advantage and, in a few cases led to domestic innovations, but with meagre economic results. A good example is Estonia's ICT industry (see Hogselius 2005) which generated several innovations in IT services. However, a careful examination of this case shows that individual competencies without firm specific organisational capabilities were not sufficient. Inherited competencies are strongest at the level of individuals which is not enough to develop a dynamic innovation system, which requires organisational capabilities to harness individual competencies. Estonia's ICT sector has developed customised innovations, which, by definition, are not directly transferable to other contexts. These product innovations are either easy to imitate or apply to services rather than a unique, firm-specific-accumulated technological competence. Estonia's weak organisational capabilities were further reinforced by barriers to exporting. Another example is inherited skills in electronics in 10 socialist era electronics conglomerates. In only one case were these skills preserved due largely to organisational capabilities and the strategies of top management (see Radosevic and Yoruk 2004). In all other cases, these labour force skills were not employed in a productive context enabling the development of new organisational capabilities within which this human capital could be successfully deployed.

Another, perhaps better known case, is the Indian software sector whose success is usually attributed to individuals. Indeed, competition from MNEs in labour markets (not product markets) has induced productive efficiency among domestic firms. However, the key to India's exploitation of human capital was the organisational capabilities of Indian software firms, which were based on imitation and deployed the productive skills of its labour force (Athreye 2005). This leads to the next important structural factor: firm structure.

3.3.3. *Firm structure*

Schumpeterian economics emphasises firm heterogeneity as an essential feature of industry dynamics (Nelson and Winter 1985). One aspect of heterogeneity is size differences or the role of large versus small firms in technology upgrading. Views on the role of large versus small firms are quite divided. Chandler (1994) is best known account of the importance of big business in economic growth. With the advent of 'third industrial revolution' and globalisation, a view emerged that 'the Chandlerian firm is under siege from a panoply of decentralised and market-like forms that often resemble some of the "inferior" nineteenth-century structures the managerial enterprise replaced' (Langlois 2003, p. 355). On the hand, there is increasing evidence that globalisation has reinforced the importance of big business. Despite the new institutional framework, which gives prominence to markets and networks, global enterprises have remained the major players in global markets. It is true that the new paradigm has significantly influenced both the firm boundaries and the patterns of inter-organisational division of labour, but the 'visible hand' of organisations, and the relative competitive advantage of size persist (Dosi, Gambardella, Grazzi, and Orsenigo 2008). Lee, Kim, Park, and Sanidas (2013) provides the most grounded confirmation of a significant and robust relationship between the number or sales of large firms, such as Fortune 500 firms, and national economic growth, after controlling for country size and endogeneity. Lee et al. show that among latecomer economies, China and Korea, have more large firms than their country size would predict, whereas some middle-income countries have fewer large firms than their size would predict and many high-income countries have many more such companies. This is in line with IFC (2013) survey data that shows that the share of large firms in employment is larger in high income and upper middle-income economies compared to lower income countries. Evidence on the role of small and medium-sized enterprises (SMEs) is also weaker. When not controlling for endogeneity, Beck, Demirguc-Kunt, and Levine (2005) find a positive, but weak correlation between SME growth and per capita income, and no significance when controlling for endogeneity.

Since, by definition, organisational capabilities are more complex and more developed in large firms, firm structure is an important factor in technology upgrading. Based on the above evidence we formulate our working hypothesis that the share of large firms is conducive to technology upgrading other things being equal.

3.4. *Interaction with global economy for technology upgrading*

Successful technology upgrading is never an entirely autonomous process, and is always linked to the inflow of foreign knowledge skills coupled with intensive domestic technology efforts (Radosevic 1999). There is a large body of literature on this topic; a few examples will suffice to emphasise this robust, but often forgotten stylised fact (Mowery and Oxley 1997, Kim 1997, Amsden 2001). The focus is usually on one of two elements of catching up – domestic technology accumulation or inflows of foreign knowledge through trade, FDI and a generally open economic regime.

The FDI and technology upgrading or knowledge spillovers literature is quite extensive. A meta-review of this literature by Bruno and Campos (2013) shows that the effect of FDI on economic performance and growth is conditional. Firms, sectors, or countries that are below certain 'thresholds' (in terms of human capital, financial development, or institutional quality) are less likely to benefit from FDI. Overall, the benefits are significantly greater in low income than in lower and upper middle-income countries (at both the micro and macro levels). The available data provide strong support for the differentiating effect of FDI on growth across levels of development rather than geographic regions.

The effect at the macro level depends on whether the recipient countries have achieved a minimum level of human capital, financial, and institutional development. The effects of FDI based on firm-level data tend to show that the (micro-) effect is conditional upon the type of linkage (with backward linkages, that is, links between the firm and its suppliers, dominating horizontal, or forward linkages).

FDI is a potential source of technology upgrading. Integration into the global economy, and FDI can be important catalysts for change, while on its own FDI does not drive technology upgrading. The literature suggests that its effects on upgrading are highly differentiated and dependent on indigenous technology efforts. The fact that countries are globally integrated in

R&D networks does not mean that they are linked to the domestic manufacturing value chain, which can lead to what Ernst (2014) describes in an example based on Indian electronics, as 'truncation of FDI based learning'. He explains this as due to the fragmented Indian national innovation system, in which local electronics manufacturing remains disconnected from India's chip-design capabilities which are integrated into global innovation and production networks.

FDI indicators are of limited value for detecting the true knowledge acquired through international industry networks. Research on GVCs is useful in that respect, although difficult to generalise. Various contributions show the positive and significant effects of learning through value chains, related to process, product, and functional upgrading up to the ODM level. Yoruk (2013) shows the major importance of both knowledge and production networks for firms' upgrading, but shows also that it is misleading to reduce the learning opportunities for upgrading to interactions with global buyers within GVCs. Her research in the case of Eastern Europe shows that learning by doing and learning by exporting do not have a statistically significant effect on functional upgrading. She shows that opportunities offered by GVCs are of little use unless firms have the ability to internalise this external knowledge through their human resources, and through training and research within the firm. Yoruk shows also that managerial upgrading is important for technology upgrading, but global buyers do not support this. Again, the importance of organisational capabilities or firm structure is highlighted as discussed in relation to the structural dimensions of technology upgrading.

Globalisation of technology exploitation and collaboration, and also technology generation through the globalisation of the R&D process, further increases the importance of international linkages for industrial upgrading (UNCTAD 2005). An example of the importance of integration into GVCs and its growth benefits is the German–Central European Supply Chain Cluster (GCESC) (IMF 2013a,b). The increase in foreign value added in four major country locations of the GCESC (Czech Republic, Slovakia, Poland, and Hungary/CE4) appear to have led to increases in domestic value added through productivity increases and creation of demand for ancillary products and services in the host economies. It seems that participation in the GCESC has led to valuable technology transfer to the CE4 countries, although there is no clear consensus on its magnitude due to the heterogeneity among firms in terms of skills.

The weakness of many technology upgrading metrics is that they focus on explicit domestic technology efforts or the import of knowledge via licences, and neglect knowledge inflows in embodied forms via imported inputs and equipment. In countries behind the technology frontier growth is driven mainly by the diffusion and absorption of technologies that are new to the firm or the country, but not new to the world. Domestic knowledge generation in the business enterprise sector through R&D or non–R&D technical activities, and the accumulation of knowledge in the public R&D system is not yet the major driver of growth compared to indirect knowledge and R&D embodied in imported inputs and machinery. R&D activity in other industries has a significant effect on productivity growth. Own-R&D activity accounts for about one-half of total R&D in countries at the technological frontier, and for between one-quarter and one-half of total R&D in countries below the frontier (Knell 2008).

Finally, mobility of people is an effective channel of knowledge transfer and technology upgrading. It is crucial for transferring tacit knowledge and initiating learning.

Of the three dimensions of technology upgrading, interaction with the global economy is probably the most difficult to capture since technology transfer happens through capital equipment imports, is embedded in FD, networks and subcontracting, or is disembodied (in the form of licences). However, modes of technology transfer cannot be used as proxies for real knowledge transfer (Radosevic 1999). Thus, we consider the distinction between technology (embodied) imports, knowledge imports (licences), and knowledge cooperation (R&D

cooperation) as components of the interaction with the global economy dimension, which are distinctive, but can be captured in data.

4. Technology upgrading in the context of catch-up and post-catch-up

As highlighted in introduction, our point of departure is the assumption that it is unrealistic to search for universal and simple metrics of technology upgrading. We argued also that current metrics are particularly inappropriate for countries behind the technology frontier. Hence, we focus most; on a 'broad' middle-income group, which is the largest country grouping and one where technology-upgrading issues play a key role in the catching-up process. Accordingly, our conceptual framework is best suited to depicting the transition from the 'broad' middle to the (upper) high-income group.

The papers in this issue of *AJTI* address the issue of transition from catch-up to post-catch up. In terms of the different income groupings discussed in Section 1, this is a transition from the lower high income to the upper high-income group, or shift from \$12,745–\$30 K per capita to over \$30 K per capita.[4] A 'broad' middle-income group perspective should include the upper middle-income group (\$4126–\$12,745pc). This has been actually done not so much through the country level analyses (cf. paper on Brazil as upper middle-income economy) but much more through analytical focus on technology accumulation issues of 'broad' middle-income group (east Asia and Latin America).

In terms of technology upgrading, the transition from catch-up to post-catch up represents a shift from technology diversification activities to technology frontier activities. However, as we have pointed out, each income group practices a variety of modes of technology upgrading, that is, a mix of technology imitation, diversification, and world frontier activities. However, the composition of these activities differs especially regarding the drivers of this technology accumulation. So, achieving the post-catch-up stage does not imply that all activities are at the technology frontier, but rather that technology frontier activities gradually are becoming those that drive technology accumulation. For example, in the post-catch-up stage, production capabilities are less important than technology capabilities, but remain an important part of the technology spectrum as demonstrated by recent attempts by the US to return manufacturing from Asia (Berger 2013). Also, as countries transform from the catch-up to the post-catch-up stage, R&D and science in general becomes more important in relation to its world knowledge frontier generation function than in terms of absorption capabilities (see Radosevic and Yoruk 2014). The importance of the knowledge infrastructure increases compared to the physical infrastructure. The role of large firms' organisational capabilities, but also their interaction with technology active small firms and extra-mural research organisations, becomes especially important. Also, the nature of the knowledge trade changes from decreasing importance of foreign acquisition of national patents, towards co-inventions and national acquisition of foreign patents (see Jindra, Lacasa, and Radosevic 2015). Conversely, the catch-up stage does not mean that the country does not include pockets of world frontier technology activities, but these are not the main drivers of technology accumulation in the economy. Due to modernisation efforts, the infrastructure in middle-income economies may be better developed that might be expected given their income level. However, other dimensions of technology upgrading may be lagging behind, thus, reducing potential complementarities and increasing returns. For example, a high level of technology openness may be accompanied by weak intensity of own technology activities in production, R&D or technology areas. Also, imbalances may be concentrated in specific dimensions of technology upgrading. For example, a well-developed R&D and innovation infrastructure may be neither firm nor technology specific due to the absence of sophisticated large or medium sized firms to articulate demand for R&D and innovation services.

In summary, the intensity and weight of different types of technology activities changes as countries move from catch-up to post-catch up. This process can be unbalanced or harmonious with different dimensions of technology upgrading reinforcing each other. We believe that our three pronged conceptual framework allows us to model the strengths and weaknesses of different dimensions of technology upgrading and would be useful to policy-makers.

If catch-up countries adopt the metrics of the technology leaders they will lack important insights into their position in the transition to post-catch-up. We see major value in alternative metrics for understanding differences in the accumulation of innovation capabilities as reflected in the different dimensions of technology upgrading rather than summary country rankings. Approaches and metrics that go beyond the science and technology dimensions of technology upgrading, and recognise its multidimensional nature can provide new insights into innovation activities that allow latecomer countries to establish new technological trajectories for innovation (Choung et al. 2014).

5. Conclusions

We argued in this paper that we need a theory and metrics of technology upgrading for several reasons. First, aggregate theories of growth are not useful and represent a kind of ‘holy grail’ of growth theory. Second, current metrics of technology upgrading are either atheoretical or are not useful for countries behind technology frontier. Third, such metrics lead to confusing or irrelevant policies. Hence, there is a need to generate a theoretically relevant, but empirically grounded middle level conceptual and statistical framework to model the type of challenges relevant to a large number of economies at different income levels.

We reviewed the relevant literature and derived a conceptual framework which we consider provides a useful approach to a theory and metrics of technology upgrading. In a nutshell, we conceptualise technology upgrading as a three-dimensional process that includes intensity and types of technology upgrading through various types of innovation and technology activities; a broadening of technology upgrading through different forms of technology and knowledge diversification; and interaction with the global economy through different forms of knowledge import, adoption, and exchange. We discussed each of these dimensions in some detail pointing to their major components and justifying their importance for an understanding of the three dimensions of technology upgrading. We consider this to be a necessary first step towards a theory and metrics of technology upgrading, and the generation of a relevant composite indicator of technology upgrading in countries at different levels of income. Finally, we consider this approach to be of relevance to understanding the transformation from catch-up to post catch-up. Although the aim is to reach the post-catch up stage, we argue that it would be misleading to apply the metrics of the technology leaders to measure this progress.

Finally, we would highlight two limitations of this analysis. First, we focus on a new conceptual approach to the measurement of technology upgrading. For reasons of both space and complexity we do not discuss specific measures and indicators. However, our work in progress is aimed at combining a new conceptual framework with the existing data, which as might be suspected is far from satisfactory (see Radosevic and Yoruk 2015 for preliminary results). There is a need to generate new data related specifically to non-R&D activities, the technology content of trade and FDI, and the technological features of structural change.

The existing metrics are excessively biased towards science and technology modes of learning and greatly underestimate ‘doing-using-interaction’ modes of learning (see Jensen, Johnson, Lorenz, and Lundvall 2007[5]). As our in depth case study suggests, ‘the dominant aggregated

S&T indicators are of little, if any, relevance for understanding the process of innovativeness, knowledge formation and technical change in industry' (Laestadius 1998, p. 393) except in 'modern' academic-based industries such as IT and pharmaceuticals (Laestadius 1998). However, diffusion of science based generic technologies into traditional and natural resource based activities will further increase these biases and, thus, provide an unrealistic basis for decision-making. The only solution is to generate new data which should provide a more realistic understanding of the innovation activities and different dimensions of technology upgrading.

We also made it clear in the introduction to this paper that the institutional context is also important to explain different growth performance, but our primary concern is with technology upgrading as an accumulation of technology capabilities issue, at different levels. In this respect, we see great value in measurement approaches aimed at depicting the accumulation of capabilities, rather than their being confused with specific institutional variables such as types of labour markets, financial systems, etc. However, we are aware that different capabilities and institutional arrangements are required as catch-up economies transit from catch-up. Finally, the contributions in this Special Issue show the changing institutional requirements for the transformation from catch-up to post catch-up. We consider our analytical approach as complementing not competing with perspectives that explore and measure the interaction between technological characteristics and the institutional setting.

Acknowledgements

We are grateful to an anonymous reviewer for comprehensive and grounded comments on an earlier version of this paper. All remaining errors are our responsibility.

Notes

1. In what follows, the middle income group includes lower middle, upper middle income, and lower high-income countries, and constitutes a 'broad' middle income group, which we describe simply as 'middle income' economies. In the analysis we refer to three specific sub-groups within the broad middle-income category (lower middle, upper middle, and lower high income), and confine the high-income group to the 'upper high income group'.
2. We are aware that technology upgrading emerges through interactions between demand and supply factors. However, we consider that including demand upgrading would introduce another layer of complexity and would make our conceptual framework unmanageable.
3. KIBS are defined according to the NACE classification, NACE REV 1.1. as including the categories computer and related activities (NACE 72), research and development (NACE 73), and other business activities (NACE 74).
4. GNI per capita Atlas method, data for 2013.
5. We are in full agreement with Jensen et al. (2007, p. 685) who argue that the absence of DUI type indicators reflects 'political priorities and decision-making rather than any inevitable state of affairs'.

Funding

This work was supported by the European Commission (GRINCOH project Nr. 290657).

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References

Abernathy, W.J., and Utterback, J.M. (1978), 'Patterns of industrial innovation', *Technology Review*, 8(7), 40–47.

Acemoglu, D., Zilibotti, F., and Aghion, P. (2006), 'Distance to frontier, selection, and economic growth', *Journal of the European Economic Association*, 4(1), 37–74.

Aghion, P., Akcigit, U., and Howitt, P. (2013), *What Do We Learn From Schumpeterian Growth Theory?* NBER Working Paper Series No 18824, February.

Akamatsu, K. (1962), 'A historical pattern of economic growth in developing countries', *The Developing Economies*, 1(1), 3–25.

Amsden, A.H. (2001), *The Rise of "'The Rest"'. Challenges to the West from Late-industrializing Economies*, Oxford: Oxford University Press.

Amsden, A.H., and Tschang, F. T. (2003), 'A new approach to assessing the technological complexity of different categories of R&D (with examples from Singapore)', *Research Policy*, 32, 553–572.

Archibugi, D., and Coco, A. (2005), 'Measuring technological capabilities at the country level: a survey and a menu for choice', *Research Policy*, 34(2005), 175–194.

Archibugi, D., Denni, M., and Filippetti, A. (2009), 'The technological capabilities of nations: the state of the art of synthetic indicators', *Technological Forecasting and Social Change*, 76(7), 917–931.

Athreye, S. (2005), 'The Indian software industry and its evolving service capability', *Industrial and Corporate Change*, 14(3), 393–418.

Beck, T., Demirguc-Kunt, A., and Levine, R. (2005), 'SMEs, growth and poverty: cross-country evidence', *Journal of Economic Growth*, 10(3), 199–229.

Bell, M., and Pavitt, K. (1993), 'Technological accumulation and industrial growth: contrasts between developed and developing countries', *Industrial and Corporate Change*, 2(2), 157–210.

Berend, I.T., and Ránki, G. (1982), *The European Periphery and Industrialization, 1780–1914*, New York: Cambridge University Press.

Berger, S. (2013), *Making in America: From Innovation to Market*, (August 2013) with the MIT Task Force on Production in the Innovation Economy, Cambridge, MA: The MIT Press.

Bruno, R.L., and Campos, N.F. (2013), *Reexamining the Conditional Effect of Foreign Direct Investment*, IZA Discussion Paper No. 7458, June 2013. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2287068.

Bruno, R., Douarin, E., Korosteleva, J., and Radosevic, S. (2015), 'Technology choices and growth: testing new structural economics in transition economies', *Journal of Economic Policy Reform*, 18(2), 131–152.

Chandler, A.D. Jr (1994), *Scale and Scope. The Dynamics of Industrial Capitalism*, Cambridge, MA: Harvard University Press.

Chenery, H., and Syrquin, M. (1975), *Patterns of Development, 1950-1970, (World Bank)*, Oxford: Oxford University Press.

Choung, J.-Y., Hwang, H. R., and Song, W. (2014), 'Transitions of innovation activities in latecomer countries: an exploratory case study of South Korea', *World Development*, 54, 156–167.

Crépon, B., Duguet, E., and Mairesse, J. (1998), 'Research and development, innovation and productivity: an econometric analysis at the firm level', *Economics of Innovation and New Technology*, 7(2), 115–158.

Dahlman, C., Ross-Larson, B., and Westphal, L.E. (1987), 'Managing technological development: lessons from the newly industrializing countries', *World Development*, 15(6), 759–775.

Dosi, G., Gambardella, A., Grazzi, M., and Orsenigo, L. (2008), 'Technological revolutions and the evolution of industrial structures: assessing the impact of new technologies upon the size and boundaries of firms', *Capitalism and Society*, 3(1), 1–47, Article 6.

Dutrenit, G. (2000), *Learning and Knowledge Management in the Firm: From Knowledge Accumulation to Strategic Capabilities*, Aldershot: Edward Elgar.

Easterly, W. (2001), *The Elusive Quest for Growth. Economists' Adventures and Misadventures in the Tropics*, Cambridge, MA: MIT Press.

Ernst, D. (1997), *From Partial to Systemic Globalization: International Production Networks in the Electronics Industry*, BRIE Working Paper 98.

Ernst, D. (1998), 'Catching-up crisis and industrial upgrading: evolutionary aspects of technological learning in Korea's electronics industry', *Asia Pacific Journal of Management*, 15(2), 247–283.

Ernst, D. (2001), Global Production Networks and Industrial Upgrading – A Knowledge Centred Approach, East-West Center Working Papers, Economics Series, No. 25.

Ernst, D. (2008a), 'Asia's "upgrading through innovation" strategies and global innovation networks: an extension of Sanjaya Lall's research agenda', *Transnational Corporations*, 17(3), 22–44. December 2008.

Ernst, D. (2008b), *Can Chinese IT Firms Develop Innovative Capabilities within Global Knowledge Networks?* East-West Center Working Papers, Economics Series, 94.

Ernst, D. (2013), *Industrial Upgrading through Low-Cost and Fast Innovation—Taiwan's Experience*, East-West Center working paper, Honolulu, Economics Series, No. 133, September 2013.

Ernst, D. (2014), *Upgrading India's Electronics Manufacturing Industry: Regulatory Reform and Industrial Policy*, Honolulu: East West Centre.

Ernst, D., and Kim, L. (2002), 'Global production networks, knowledge diffusion and local capability formation', *Research Policy*, 31, 1417–1429.

European Competitiveness Report (2011), *Chapter 2 'Convergence of Knowledge Intensive Sectors and the EU's External Competitiveness'*, Brussels: EC.

Foray, D. (2015), *Smart Specialization. Opportunities and Challenges for Regional Innovation Policy*, London: Routledge.

Freeman, C. (2002), 'Continental, national and sub-national innovation systems—complementarity and economic growth', *Research Policy*, 31, 191–211.

Freeman, C., and Louçã, F. (2001), *As Time Goes by From the Industrial Revolutions to the Information Revolution*, Oxford: Oxford University Press.

Furman, J.L., and Hayes, R. (2004), 'Catching up or standing still? National innovative productivity among 'follower' countries, 1978–1999', *Research Policy*, 33(2004), 1329–1354.

Gereffi, G. (1999), 'International trade and industrial upgrading in the apparel commodity chain', *Journal of International Economics*, 48(1), 37–70.

Glaeser, E.L., La Porta, R., Lopez-de-Silanes, F., and Shleifer, A. (2004), 'Do institutions cause growth?', *Journal of Economic Growth*, 9, 271–303.

Gort, M., and Klepper, S. (1982), 'Time paths in the diffusion of product innovations', *The Economic Journal*, 92(367), 630–653.

Hanushek, E. (2013), 'Economic growth in developing countries: the role of human capital', *Economics of Education Review*, 37, 204–212. doi:10.1016/j.econedurev.2013.04.005.

Hanushek, E.A., and Wößmann, L. (2007), *Education Quality and Economic Growth*, Washington, DC: World Bank.

Hausmann, R., Hwang, J., and Rodrik, D. (2007), 'What you export matters', *Journal of Economic Growth*, 12, 1–25.

Hausmann, R., and Klinger, B. (2006), *Structural Transformation and Patterns of Comparative Advantage*, CID Working Paper No. 128. Cambridge, MA: Center for International Development, Harvard University.

Hidalgo, C., and Hausmann, R. (2009), 'The building blocks of economic complexity', *Proceedings of the National Academy of Sciences*, 106(26), 10570–10575.

Hidalgo, C., Klinger, B., Barabasi, A.L., and Hausmann, R. (2007), 'The product space conditions the development of nations', *Science*, 317, 482–487.

Hobday, M. (1995), 'East Asian latecomer firms: learning the technology of electronics', *World Development*, 23(7), 1171–1193.

Hobday, M., Rush, H., and Bessant, J. (2004), 'Approaching the innovation frontier in Korea: the transition phase to leadership', *Research Policy*, 33, 1433–1457.

Hogselius, P.T. (2005), *Dynamics of Innovation in Eastern Europe: Lessons from Estonia*, Cheltenham: Edward Elgar.

Humphrey, J., and Schmitz, H. (2004), 'Governance in global value chains', in *Local Enterprises in the Global Economy. Issues of Governance and Upgrading*, ed. H. Schmitz, Cheltenham: Edward Elgar, pp. 95–109.

IFC. (2013), *IFC Jobs Study. Assessing Private Sector Contributions to Job Creation and Poverty Reduction*, Washington: International Financial Corporation.

Imbs, J., and Wacziarg, R. (2003), 'Stages of diversification', *American Economic Review*, 93(1), 63–86.

IMF. (2013a), *German-central European Supply Chain-cluster Report*, IMF Country Report 13/263, August 20th, 2013.

IMF. (2013b), *Trade Linkages, Balance Sheets, and Spillovers: The Germany-central European Supply Chain*, Prepared by Selim Elekdag and Dirk Muir, IMF Working Paper, European Department, October 2013.

Jensen, M.B., Johnson, B., Lorenz, E., and Lundvall, B.A. (2007), 'Forms of knowledge and modes of innovation', *Research Policy*, 36, 680–693.
Jindra, B., Lacasa, I.D., and Radosevic, S. (2015), *Dynamics of Technology Upgrading of the Central and East European Countries in a Comparative Perspective: Analysis Based on Patent Data*, Economics and Business Working Paper No.135, February, UCL Centre for Comparative Economics.
Jorgenson, D.W., and Timmer, M.P. (2011), 'Structural change in advanced nations: a new set of stylised facts', *Scandinavian Journal of Economics*, 113(1), 1–29.
Kim, L. (1980), 'Stages of development of industrial technology in a developing country: a model', *Research Policy*, 9(3), 254–277.
Kim, L. (1997), *Imitation to Innovation: The Dynamics of Korea's Technological Learning*, Boston, MA: Harvard Business School Press.
Klepper, S. (1997), 'Industry life cycles', *Industrial and Corporate Change*, 6(1), 145–182.
Klepper, S., and Graddy, E. (1990), 'The evolution of new industries and the determinants of market structure', *The RAND Journal of Economics*, 21, 27–44.
Knell, M. (2008), Product-Embodied Technological Diffusion and Intersectoral Linkages in Europe, 28 April, Innovation Watch – SYSTEMATIC, NIFUSTEP.
Kravtsova, V., and Radosevic, S. (2011), 'Are systems of innovation in Eastern Europe efficient?', *Economic Systems*, 36, 109–126. doi:10.1016/j.ecosys.2011.04.005.
Krüger, J.J. (2008), 'Productivity and structural change: a review of the literature', *Journal of Economic Surveys*, 22(2), 330–363.
Kuznets, S. (1930), *Secular Movements in Production and Prices: Their Nature and Their Bearing upon Cyclical Fluctuations*, Boston, MA: Houghton Mifflin, New York, repr. Kelley, New York, 1967.
Laestadius, S. (1998), 'The relevance of science and technology indicators: the case of pulp and paper', *Research Policy*, 27, 385–395.
Lall, S. (1992), 'Technological capabilities and industrialization', *Research Policy*, 20(2), 165–186.
Langlois, R.N. (2003), 'Chandler in a larger frame: markets, transaction costs, and organizational form in history', *Business and Economic History*, 1(3), 355–375.
Lee, K. (2013), *Schumpeterian Analysis of Economic Catch-up, Knowledge, Path-creation and the Middle-Income Trap*, Cambridge: Cambridge University Press.
Lee, K., Kim, B.-Y., Park, Y.Y., and Sanidas, E. (2013), 'Big businesses and economic growth: identifying a binding constraint for growth with country panel analysis', *Journal of Comparative Economics*, 41(2), 561–582.
Lin, J.Y. (2011), *From Flying Geese to Leading Dragons New Opportunities and Strategies for Structural Transformation in Developing Countries*, Policy Research Working Paper 5702, World Bank.
Lin, J.Y. (2012a), 'From flying geese to leading dragons: new opportunities and strategies for structural transformation in developing countries', *Global Policy*, 3(4), 397–409.
Lin, J.Y. (2012b), *New Structural Economics. A Framework for Rethinking Development and Policy*, Washington, DC: The World Bank.
Lin, J.Y., and Rosenblatt, D. (2012), 'Shifting patterns of economic growth and rethinking development', *Journal of Economic Policy Reform*, 15(3), 171–194.
Majcen, B., Radosevic, S., and Rojec, M. (2009), 'Nature and determinants of productivity growth of foreign subsidiaries in central and East European countries', *Economic Systems*, 33, 168–184.
Malerba, F., and Orsenigo, L. (1994), *The Dynamics and Evolution of Industries*, Working Paper WP-94-120, November 1994, The International Institute for Applied Systems Analysis.
Marshall, A. (1890), *Principles of Economics* (Vol. 1, 9th ed.), ed. C.W. Guillebaud, London: Macmillan/Royal Economic Society, 1961.
Mowery, D.C., and Oxley, J. (1997), 'Inward technology transfer and competitiveness: the role of national innovation systems', in *Technology, Globalisation and Economic Performance*, eds. D. Archibugi and J. Michie, Cambridge: Cambridge University Press, pp. 138–171.
Nelson, R.R., and Winter, S.G. (1985), *An Evolutionary Theory of Economic Change*, Cambridge, MA: Belknap Press.
Ozawa, T. (2009), *The Rise of Asia, the 'Flying Geese' Theory of Tandem Growth and Regional Agglomeration*, Cheltenham: Edward Elgar.
Peneder, M. (2003), 'Industrial structure and aggregate growth', *Structural Change and Economic Dynamics*, 14(2003), 427–448.
Perez, C. (2010), 'Technological revolutions and techno-economic paradigms', *Cambridge Journal of Economics*, 34, 185–202.

Prud'homme, R. (2005), 'Infrastructure and development', in *Lessons of Experience (Proceedings of the 2004 Annual Bank Conference on Development Economics)*, eds. F. Bourguignon and B. Pleskovic, Washington, DC: The World Bank and Oxford University Press, pp. 153–181.

Radelet, S., and Sachs, J. (1997), *Asia's Re-emergence*, Foreign Affairs, November/December.

Radosevic, S. (1999), *International Technology Transfer and Catch-up in Economic Development*, Cheltenham: Edward Elgar.

Radosevic, S., and Kaderabkova, A. (eds.) (2011), *Challenges for European Innovation Policy: Cohesion and Excellence from a Schumpeterian Perspective*, Cheltenham: Edward Elgar.

Radosevic, S., and Yoruk, D.E. (2004), 'The growth of enterprise through entrepreneurship and network alignment', in *International Industrial Networks and Industrial Restructuring in Central Europe, Russia and Ukraine*, eds. S. Radosevic and B. Sadowski, Dordrecht: Kluwer, pp. 109–130.

Radosevic, S., and Yoruk, E. (2014), 'Are there global shifts in world science base? Analysis of catching up and falling behind of world regions', *Scientometrics*, 101, 1897–1924. doi:10.1007/s11192-014-1344-1.

Radosevic, S., and Yoruk, E. (2015), A New Metrics of Technology Upgrading: The Central And East European Countries in a Comparative Perspective, Working Paper, No. 3.04, Available at http://www.grincoh.eu/.

Rostow, W.W. (1960), *The Stages of Economic Growth: A Non-Communist Manifest* (2nd enlarged edn., 1971), Cambridge: Cambridge University Press.

Sandven, T., Smith, K., and Kaloudis, A. (2005), 'Structural change, growth and innovation: the roles of medium and low tech industries, 1980-2000', in *Low-Tech Innovation in the Knowledge Economy*, eds. H. Hirsch-Kreinsen, D. Jacobson, S. Laestadius, and K. Smith, Frankfurt: P. Lane, pp. 31–63.

Seong, J., Kim, J., and Cho, Y. (2014), *Korea's Post Catch-up Policy Experiment: Focusing on the Transition towards a Sustainable Socio-technical System*, Paper prepared for thematic issue of AJTI.

Spence, M. (2011), *The Next Convergence: The Future of Economic Growth in a Multispeed World*, New York, NY: FSG Books.

Suarez, F., and Utterback, J. (1995), 'Dominant designs and the survival of firms', *Strategic Management Journal*, 16, 415–430.

Yoruk, D.E. (2013), 'Firm-level upgrading in low- and medium-technology industries in emerging markets: the role of learning networks', Ph.D. thesis, University of Sussex, December, SPRU.

UNCTAD. (2005), *World Investment Report*, Geneva: UN.

Von Tunzelmann, G.N. (1995), *Technology and Industrial Progress: The Foundations of Economic Growth*, Aldershot: Edward Elgar.

Appendix

Table A1: World Bank and our classification of countries based on income per capita, 2014.

	World Bank 2014 classification	Our classification	
LOW INCOME	Low income (less than $1045)	–	
MIDDLE INCOME	Lower middle income ($1046–$4125)	Lower middle income ($1046–$4125)	'BROAD' MIDDLE INCOME
	Upper middle income ($4126–$12,745)	Upper middle income ($4126–$12,745)	
HIGH INCOME	High income ($12,746+)	Lower high income ($12,746–$30,000)	
		Upper high income ($30,000+)	HIGH INCOME

Table A2: Grouping by GNI per capita 2013_atlas method, selected countries.

Lower middle income (GNI pc atlas method $1046–$4125)	Upper middle income (GNI pc atlas method $4126–$12,745)	Lower high income (GNI pc atlas method $12,176–$30,000)	Upper high income (GNI pc atlas method $30,001–)
Ghana	Albania	Chile	Austria
India	Argentina	Czech Republic	Belgium
Indonesia	Belarus	Estonia	Germany
Moldova	Brazil	Greece	Ireland
Morocco	Bulgaria	Korea	Italy
Philippines	China	Poland	Japan
Ukraine	Hungary	Portugal	Norway
Vietnam	Jordan	Russia	Sweden
	Kazakhstan	Slovenia	UK
	Malaysia	Spain	USA
	Mexico		
	Peru		
	Romania		
	South Africa		
	Thailand		
	Turkey		