

# TECHNOLOGY, INFORMATION, AND THE DECENTRALIZATION OF THE FIRM\*

DARON ACEMOGLU  
PHILIPPE AGHION  
CLAIRE LELARGE  
JOHN VAN REENEN  
FABRIZIO ZILIBOTTI

This paper analyzes the relationship between the diffusion of new technologies and the decentralization of firms. Centralized control relies on the information of the principal, which we equate with publicly available information. Decentralized control, on the other hand, delegates authority to a manager with superior information. However, the manager can use his informational advantage to make choices that are not in the best interest of the principal. As the available public information about the specific technology increases, the tradeoff shifts in favor of centralization. We show that firms closer to the technological frontier, firms in more heterogeneous environments, and younger firms are more likely to choose decentralization. Using three data sets on French and British firms in the 1990s, we report robust correlations consistent with these predictions.

## I. INTRODUCTION

Recent years have witnessed increasing interest in the determinants of firms' organizational choices. This interest is partly motivated by the belief that new technologies are inducing firms to become less hierarchical and more decentralized. Despite this interest, there is limited work on the determinants of the decentralization decisions of firms. This paper undertakes a theoretical and empirical investigation of how the allocation of authority within firms changes as the information structure in an industry evolves.

We develop a simple model where firms make choices on how to implement new technologies. Different organizational forms are distinguished by the amount of information they use in these decisions. As in Aghion and Tirole (1997), centralized control relies more on the information of the principal, which we equate with publicly available information about past implementations

\* We thank Erik Brynjolfsson, participants at seminars in CREST, CEPR (Paris), CIAR, Harvard-MIT, NBER, Toronto, three anonymous referees, and Lawrence Katz for helpful comments and suggestions. Acemoglu thanks the Toulouse Network on Information Technology for financial support. Van Reenen would like to thank the ESRC for help with financing this research at the Centre for Economic Performance. Zilibotti thanks NCCR FINRISK for financial support.

of similar technologies.<sup>1</sup> Decentralized control delegates authority to a manager, who potentially possesses more information than is available in the public history. Nevertheless, because the interests of the principal and the manager are not perfectly aligned, the manager can use his informational advantage to make choices that are not in the best interest of the principal. This tradeoff between the superior knowledge of the manager and the agency costs of managerial delegation determines the optimal degree of decentralization. The main focus of our analysis is on how learning from the experiences of other firms changes this tradeoff. Typically, the more a principal learns from other firms regarding the implementation of new technologies, the less she needs to delegate control to the manager.

Using this basic framework, we derive three sets of empirical predictions:

1. Firms closer to the technological frontier are more likely to choose decentralization, because they are dealing with new technologies about which there is only limited information in the public history.
2. Firms in more heterogeneous environments are more likely to be decentralized, because greater heterogeneity makes learning from the experiences of others more difficult.
3. Young firms, which have had a limited history in which to learn about their own specific needs, are also more likely to be decentralized than older firms.

The bulk of the paper investigates these predictions using two large data sets of French firms and establishments and one smaller set of British establishments in the 1990s. We document a range of empirical patterns consistent with these predictions: firms closer to the technological frontier of their industry, firms operating in more heterogeneous environments, and younger firms are more likely to choose decentralization.

In addition, since our theoretical approach emphasizes the importance of learning about the implementation of new technologies, we also look separately at high-tech industries (defined as those using information technology intensively). Consistent with our theoretical approach, we find that the relationship between

1. Throughout the paper the principal could be thought of as either the owner or the chief operating officer of the firm.

heterogeneity or distance to frontier and decentralization is significantly stronger in high-tech than in low-tech industries.

Our main measure of decentralization is whether different units of the firm are organized into “profit centers.” We show that our main results are robust to proxying decentralization by the extent of delayering or measures of managerial autonomy over investment and/or employment decisions. The results are also robust to the inclusion of a range of controls, to using various different measures of heterogeneity, and to different estimation strategies.

On the theoretical side, our paper is most closely related to the literature on the costs and benefits of delegation or decentralization in firms. A first strand of this literature, for example, Baron and Besanko (1992) and Melumad, Mookherjee, and Reichelstein (1995), investigates the conditions for delegated contracting to replicate the constrained efficient centralized contracting. As emphasized by Mookherjee (2006), however, the presence of complete contracts in these models implies that delegation can at best replicate the constrained efficient allocation that is also achievable by centralized contracting. A second strand emphasizes information processing and communication costs as determinants of centralization or decentralization in firms.<sup>2</sup> Although we also stress the importance of learning, our focus is different, namely on how public information affects how much autonomy the principal would like to grant to the agent. Closer to our paper are the recent models emphasizing the trade-off between loss of control and better information under decentralization—in particular, Aghion and Tirole (1997), Baker, Gibbons, and Murphy (1999), Rajan and Zingales (2001), Dessein (2002), and Hart and Moore (2005).<sup>3</sup> The main differences between these papers and ours are twofold: first, because there are no incentive effects of the form of the organization, our framework is significantly simpler and allows us to focus on the basic tradeoff between information and loss of control; second,

2. See, among others, Sah and Stiglitz (1986), Geanakoplos and Milgrom (1991), Radner and Van Zandt (1992), Radner (1993), Bolton and Dewatripont (1994), and Garicano (2000).

3. The possibility that the implementation of new technologies could encourage delegation was first raised by Jensen and Meckling (1992). Aghion and Tirole (1997) emphasize the tradeoff between loss of control and the agent's *ex ante* incentives to acquire information under decentralization. Hart and Moore (2005) show how the tradeoff between loss of control and information can explain why in many hierarchies generalists command specialists. Dessein (2002) develops a model in which decentralization to a specialized agent entails a loss of control for the principal but at the same time reduces the agent's incentive to miscommunicate her information to the principal.

we allow the principal to learn from other firms' or from her own firm's past experience, which is the source of all the comparative static results we investigate in the empirical work.<sup>4</sup>

The main contribution of our paper is the empirical evidence we provide on the determinants of decentralization. Previous work in the literature focuses on the general move toward "flatter" organizations.<sup>5</sup> Rajan and Wulf (2006) provide the most systematic statistical description of recent organizational trends, showing a strong movement toward flatter corporations in the United States between 1986 and 1999. Caroli and Van Reenen (2001) and Bresnahan, Brynjolfsson, and Hitt (2002) report a positive association between various measures of decentralization and organizational change on the one hand and information technology (and human capital) on the other. Baker and Hubbard (2003, 2004) document the effect of new technologies (on-board computers) on ownership patterns in the U.S. trucking industry. Other related papers include Colombo and Delmastro (2004), who present empirical models of decentralization in Italian manufacturing plants; Lerner and Merges (1998), who examine the allocation of control rights in biotechnology alliances; and the papers by Ichinowski, Prenushi, and Shaw (1997), Black and Lynch (2001), and Janod and Saint-Martin (2004), which examine the impact of human resource practices and firm reorganization on productivity. None of these papers investigate the relationship between decentralization (or organizational change) and distance to frontier or heterogeneity.

The remaining part of the paper is organized as follows. Section II presents some preliminary data description to motivate the basic theoretical framework, which is developed in Section III. Section IV describes the data and our main econometric specification. Section V presents the empirical results. Section VI concludes. Appendix A, which contains a more detailed exposition of

4. Acemoglu and Zilibotti (1999) present a different model, where endogenous accumulation of information affects the internal organization of firms. In their model, a larger number of firms in the economy enables better relative performance of evaluation and creates a shift from direct to indirect monitoring. The number of firms in the economy is, in turn, determined endogenously as a function of the stage of development and the level of the capital stock. The relationship between distance to the frontier and various aspects of the internal organization of the firm is also investigated in Acemoglu, Aghion and Zilibotti (2003, 2006).

5. This phenomenon is described by different terms in different contexts, including decentralization, delayering, and delegation. In the theory, consistent with the principal-agent literature, we use the term "delegation," while in the empirical analysis, we adopt the terms used in the data sets (e.g., "decentralization" in the COI).

the theory and the proofs from Section III, and Appendix B, which contains additional data description and robustness checks, are available upon request and on the Web.<sup>6</sup>

## II. BASIC PATTERNS

To motivate our focus in the paper, we first present some salient patterns from a database of several thousand French manufacturing firms, the “Changements Organisationnels et Informatisation” (COI). This data set, as well as our two other data sets, is described below. Our key indicator for decentralization from the COI is whether a firm is organized into profit centers or whether it is more centrally controlled, with divisions organized as cost centers (or in some other more centralized manner). A manager of a profit center is concerned with all aspects of the business that contribute to profitability, while managers in charge of cost centers focus only on cost targets. When a firm organizes its divisions into profit centers, it typically delegates substantially more authority to its managers (see the discussion in Section IV).

Figures I–III show the proportion of the 3,570 firms in our baseline COI sample that are decentralized into profit centers broken down by various firm characteristics. Figure I divides firms into deciles depending on the heterogeneity of the firm’s environment. Heterogeneity is measured as the difference between log productivity (value added per hour) growth at the 90th and the 10th percentiles of the relevant four-digit industry. This variable is a natural measure of technological heterogeneity among firms within a four-digit industry; it will be greater in industries where some firms are experiencing much faster productivity growth than others. The construction of this variable is discussed in greater detail in Section IV.

Figure I shows a general increase in the probability of decentralization as we move from the firms in the least heterogeneous industries to those in the most heterogeneous industries; while 24% of the firms are decentralized in the second decile, this number is 41% in the tenth decile. The first decile is somewhat anomalous, but closer investigation shows that there is a disproportionately large number of less productive and older firms in these sectors, aspects that we now turn to.

Figure II plots the fraction of firms decentralized into profit centers against the proximity to the frontier (measured as the

6. [http://econ-www.mit.edu/faculty/index.htm?prof\\_id=acemoglu&type=paper](http://econ-www.mit.edu/faculty/index.htm?prof_id=acemoglu&type=paper).

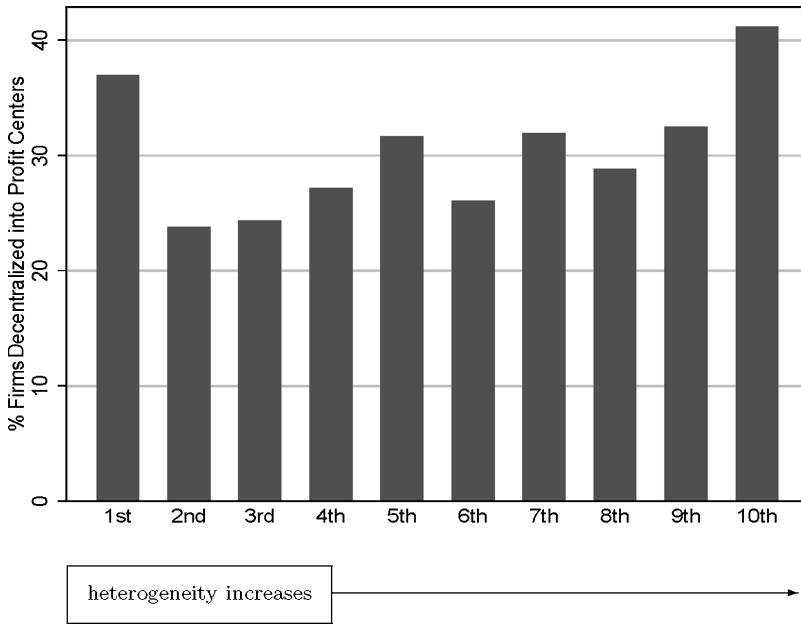


FIGURE I

## Heterogeneity and Decentralization

*Notes.* The X-axis divides all firms into deciles of heterogeneity from the first decile (low heterogeneity) to the tenth decile (high heterogeneity). Heterogeneity is measured by an index of dispersion (the difference of the 90th minus the 10th percentile) of productivity growth between firms in a four-digit industry (see text). The Y-axis indicates the proportion of firms that are decentralized into profit centers in the relevant decile group. The sample is the COI sample (3,570 French firms in 1997).

ratio of the firm's value added per hour to the value added per hour of the firm at the 99th percentile of the distribution in the same four-digit industry). While 27% of the firms in the bottom quintile of the proximity distribution are decentralized, 38% of the firms in the top quintile, which are closer to the technology frontier, are decentralized.

Finally, Figure III shows that younger firms are, on average, more decentralized than older firms: about 45% of the firms under the age of five years are decentralized, compared to 30% for the older firms.

In the rest of the paper, we document that the patterns shown in Figures I–III are robust to a variety of controls, different estimation techniques, and different empirical measures approximating our theoretical concepts. For example, we show that the

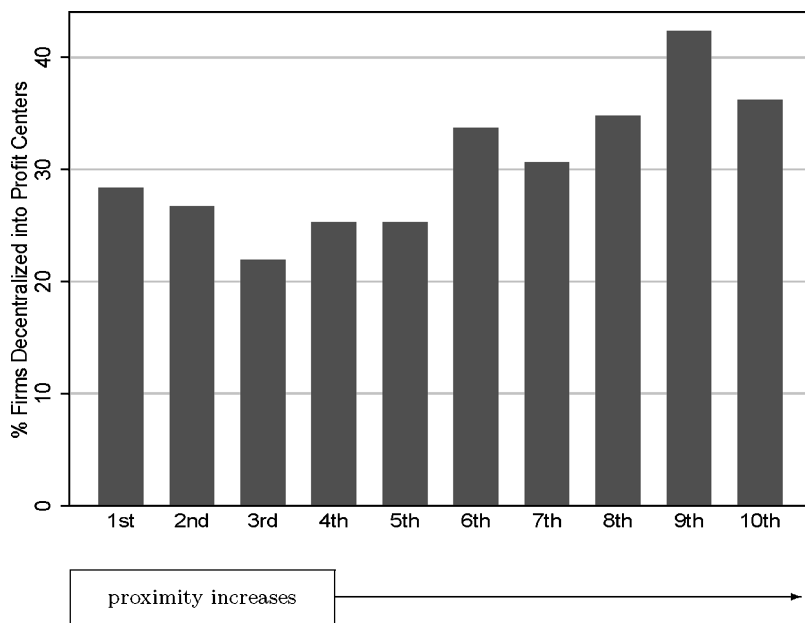


FIGURE II  
Proximity to Frontier and Decentralization

*Notes.* The *X*-axis divides all firms into deciles of proximity to frontier (in terms of value added per hour) from the first decile (low proximity to frontier) to the tenth decile (high proximity to frontier). The *Y*-axis indicates the proportion of firms that are decentralized into profit centers in the relevant decile group. The sample is the COI sample (3,570 French firms in 1997).

same broad patterns apply when we use the variation in productivity levels within four-digit industries (rather than productivity growth) and also a firm-specific index of heterogeneity, measuring the “distance” between the product mix of a firm and those of other firms in the population of French firms. We also show that our main results are robust to using alternative measures of decentralization, including measures of delayering and managerial autonomy over investment and/or employment decisions (the age results are somewhat weaker with some of these alternative measures of decentralization).

Overall, the patterns in Figures I–III, and our more detailed results below, suggest that firms that operate in more heterogeneous environments, that are closer to the technological frontier, and that are younger are more likely to be decentralized. These correlations, especially the relationship between

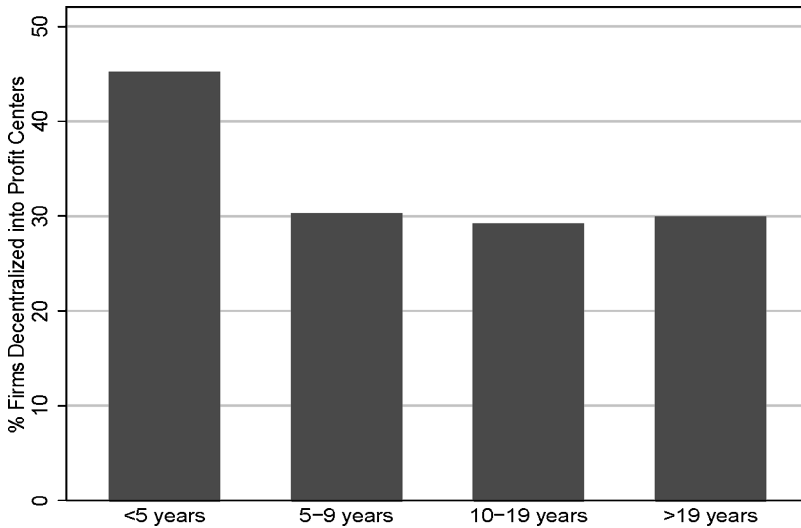


FIGURE III  
Firm Age and Decentralization

*Notes.* Firms are grouped into age bands (dated from the birth of the firm). The Y-axis indicates the proportion of firms that are decentralized into profit centers in the relevant age group. The sample is the COI sample (3,570 French firms in 1997).

decentralization and heterogeneity, indicate that information acquisition and learning may be the important factors in the decentralization decisions of firms. In particular, firms in more heterogeneous environments, those closer to the technology frontier, and younger firms naturally face greater uncertainty regarding their business decisions in general and the optimal implementation of new technologies in particular, compared to firms that are in more homogeneous environments, farther from the frontier, and more experienced. This motivates our theoretical approach emphasizing the relationship between learning and decentralization, which is presented in the next section. Although there may be alternative explanations for some of our findings, we are not aware of other approaches that can explain the evidence as satisfactorily as our theoretical framework.

### III. THEORY

In this section, we describe a theoretical environment linking information and technology choices to decentralization decisions. Our purpose is to highlight a number of implications that will



be investigated in the empirical work below. More details on the theoretical framework, as well as the proofs of all the results stated here, are contained in the working paper version, Acemoglu et al. (2006), as well as in Appendix A.

Suppose that there is a ladder of technologies,  $k = 1, 2, \dots$ . At each point in time,  $t = 1, 2, \dots$ , each firm  $i$  has previously implemented up to some technology, say  $k - 1$ . The next technology in the ladder,  $k$ , becomes available to this firm with probability  $p_i \in (0, 1]$ . The parameter  $p_i$  thus measures the speed at which firm  $i$  climbs the technology ladder. The realizations of technological opportunities are independent across firms and over time. When a new technology becomes available to a firm, it decides how to implement it. In particular, the firm chooses between two actions,  $L$  and  $R$ , that correspond to two different choices in the implementation of the new technology. Dropping the time index, the choice of the firm is denoted by  $x_{i,k} \in \{L, R\}$ . One of these choices,  $x_{i,k}^* \in \{L, R\}$ , leads to successful implementation, while the other leads to an unsuccessful outcome. We will refer to  $x_{i,k}^*$  as the *correct action*. Successful implementation of a technology increases the firm's productivity by a factor  $\gamma > 1$ , while unsuccessful implementation leaves the productivity of the firm unchanged.

We assume that the successful action for firm  $i$  in the implementation of technology  $k$  is given by

$$(1) \quad x_{i,k}^* = \begin{cases} x_k^* & \text{with probability } 1 - \varepsilon \\ \sim x_k^* & \text{with probability } \varepsilon, \end{cases}$$

where  $x_k^* \in \{L, R\}$  is the *reference action* for technology  $k$ ,  $\sim x_k^*$  denotes “not  $x_k^*$ ” (i.e., if  $x_k^* = L$ , then  $\sim x_k^* = R$ ), and  $0 < \varepsilon < 1/2$ . Conditional on  $x_k^*$ , the realizations of  $x_{i,k}^*$  and  $x_{i',k}^*$  for any  $i \neq i'$  are independent.<sup>7</sup> We assume that, for each technology, the prior probability that  $L$  (or  $R$ ) is the reference action is equal to  $1/2$ .

This specification implies that there is a generally correct (“conventional”) way of implementing each technology, given by the reference action, but differences in firms' specific needs and competencies imply that some firms need to take a different action for successful implementation. Equation (1) thus makes it clear that  $\varepsilon$  is a measure of *heterogeneity* among firms: when  $\varepsilon$  is equal to zero, the reference action is the correct action for all

7. This implies that when  $x_k^* = L$ ,  $\{x_{i,k}^*\}_i$  is a Bernoulli sequence with parameter  $1 - \varepsilon$ , and when  $x_k^* = R$ , it is a Bernoulli sequence with parameter  $\varepsilon$ .

firms; when  $\varepsilon$  is equal to  $1/2$ , the correct action is unrelated across firms.

Each firm is owned by a principal who maximizes its value conditional on the public information available. Successful implementation and hence profits depend on the organization of the firm. The two alternative organizational forms available to each firm are *centralization* and *delegation*. With centralization (denoted by  $d_{i,k} = 0$ ), the principal manages the firm and chooses  $x_{i,k}$ ; with delegation ( $d_{i,k} = 1$ ), the choice of  $x_{i,k}$  is delegated to a manager.

The principal in firm  $i$  has no special skills in identifying the right action. Therefore, under centralization she bases her decision on the history of publicly available information relevant for technology  $k$  at the time of her decision, denoted by  $h_k^i$ . In contrast, the manager of firm  $i$  observes the correct action  $x_{i,k}^*$ , so that he knows exactly which action will lead to successful implementation. However, his interests may not be aligned with those of the owner. Following Aghion and Tirole (1997), we model this in a reduced-form way and assume that the preferred action of the manager for technology  $k$  is given by

$$(2) \quad z_{i,k}^* = \begin{cases} x_{i,k}^* & \text{with probability } \delta \\ \sim x_{i,k}^* & \text{with probability } 1 - \delta. \end{cases}$$

This specification implies that  $\delta$  is a measure of *congruence* between the firm's and the manager's objectives. Notice that equation (2) implies that the manager is informed about the right action for this particular firm (not only about the right reference action).

We adopt a number of simplifying assumptions to focus on the main implications of this framework. First, we assume that the relationship between the firm and each manager is short-term. Second, when  $x_{i,k} = z_{i,k}^*$ , the manager obtains a private benefit. We assume that managers are credit-constrained and cannot compensate principals for these private benefits and that these private benefits are sufficiently large so that it is not profitable for the principal to utilize incentive contracts to induce managers to take the right action. These assumptions imply that delegation will lead to the implementation of the action that is preferred by the manager; thus, when there is delegation,  $x_{i,k} = z_{i,k}^*$ .<sup>8</sup>

8. Put differently, in this model the choice between centralization and delegation simply corresponds to whether or not the "advice" of the manager is followed

Finally, we assume that  $\delta \in (1/2, 1 - \varepsilon)$ , which implies that the manager's interests are more likely to be aligned with those of the principal than otherwise ( $\delta > 1/2$ ) and that the conflict of interest between the principal and the manager is sufficiently severe so that a principal who knows the reference action is more likely to make the correct choice if she, rather than the manager, decides ( $\delta < 1 - \varepsilon$ ).

The organizational form and implementation decisions by the principal of firm  $i$  for technology  $k$  depend on the history of public information  $h_k^i$ , which includes the outcomes of all previous attempts with technology  $k$  (in particular, which actions were chosen and whether they led to successful implementation). Since conditional on  $x_k^*$  the success or failure of different firms in the past are independent, all payoff-relevant information can be summarized by  $h_k^i = \{n_k^i, \tilde{n}_k^i\}$ . Here,  $n_k^i$  is the number of firms that have attempted to implement this technology before firm  $i$ , and  $\tilde{n}_k^i \leq n_k^i$  is the number of firms for which  $L$  turned out to be the profitable action.<sup>9</sup> Note also that  $n_k^i$  is a direct measure of *distance to the technology frontier*. If  $n_k^i$  is high, it means that many other firms have implemented technology  $k$  before firm  $i$ . Therefore, comparative statics with respect to  $n_k^i$  will be informative about the impact of the distance to the technology frontier on decentralization decisions.

Let  $\pi(d_{i,k}; h_k^i)$  denote the probability that firm  $i$  chooses the correct action conditional on history  $h_k^i$  and the organizational form  $d_{i,k}$ . It can be shown that profit maximization in this context is equivalent to maximizing  $\pi(d_{i,k}; h_k^i)$  in every period (see Acemoglu et al. [2006]). Hence, the principal will choose  $d_{i,k} = 1$  (delegation) if  $\pi(d_{i,k} = 1; h_k^i) > \pi(d_{i,k} = 0; h_k^i)$ .

The above discussion establishes that when the principal chooses delegation, we have  $\pi(1; h_k^i) = \delta$ . On the other hand, under centralization, that is,  $d_{i,k} = 1$ , the principal makes the

---

by the principal. In particular, all the results would be identical if we considered a somewhat different model in which the manager reported his recommendation and then the principal decided which action to take. In this alternative model, "delegation" would correspond to the principal following the recommendation of the manager. See Acemoglu et al. (2006) and Appendix A for the results in the case where the principal can use incentive contracts.

9. Note that  $\tilde{n}_k^i$  is equal to the number of firms that have adopted technology  $k$  before  $i$ , chose  $x_{i',k} = L$ , and were successful, plus the number of firms that chose  $x_{i',k} = R$  and were unsuccessful. The public information set also includes the organizational forms chosen by firms that have previously adopted technology  $k$ , but equation (2) implies that  $\tilde{n}_k^i$  is a sufficient statistic for this public information.

optimal implementation decision given the publicly available information. Consequently, the probability of success when the principal chooses centralization,  $\pi(0; h_k^i)$ , is a stochastic variable that depends on history  $h_k^i = \{n_k^i, \tilde{n}_k^i\}$ . That is, it depends both on the firm's distance to the frontier,  $n_k^i$ , and on the experiences of firms that have previously implemented the technology,  $\tilde{n}_k^i$ . As the distance to the frontier,  $n_k^i$ , increases, the history available to the principal expands and she learns the reference action,  $x_k^*$ , with greater precision. More specifically, when firm  $i$  is at the technology frontier, so that  $n_k^i = 0$ , the principal has no useful information and  $\pi(0; h_k^i) = 1/2$ . In contrast, as the principal observes the experiences of sufficiently many other firms, the probability that she chooses the correct action under centralization increases. In particular, it can be shown that  $\text{plim}_{n_k^i \rightarrow \infty} \pi(0; h_k^i) = 1 - \varepsilon$ .<sup>10</sup> This implies that when  $n_k^i$  is small,  $\pi(0; h_k^i)$  will be less than  $\pi(1; h_k^i) = \delta > 1/2$ , but as  $n_k^i$  increases, it will approach  $1 - \varepsilon$  and thus exceed  $\pi(1; h_k^i) = \delta$  (since  $\delta < 1 - \varepsilon$ ). This argument establishes that delegation will be chosen by firms closer to the technology frontier, but not by those that are sufficiently behind. Denoting the optimal organizational choice given history  $h_k^i$  by  $d_{i,k}^*(h_k^i)$ , we can therefore establish the following result.

**PROPOSITION 1 (Distance to Frontier).** Consider the adoption decision of technology  $k$  by firm  $i$ , and suppose that  $\delta \in (1/2, 1 - \varepsilon)$ . Then

- (i) For a firm at the technology frontier, that is,  $n_k^i = 0$ , the principal chooses delegation. That is,  $d_{i,k}^*(h_k^i = \{0, 0\}) = 1$ .
- (ii) For a firm sufficiently far from the technology frontier, that is, as  $n_k^i \rightarrow \infty$ , the principal (almost surely) chooses centralization. That is,  $\text{plim}_{n_k^i \rightarrow \infty} d_{i,k}^*(h_k^i = \{n_k^i, \tilde{n}_k^i\}) = 0$ .

In the empirical analysis, we proxy distance to the technology frontier with the gap between the productivity of a particular firm and the highest productivity (or the highest percentile productivity) in the same industry. Firms that are further behind the frontier (i.e., those with higher  $n_k^i$ 's) will be less productive because

10. The statements here and in Proposition 1 show that as  $n_k^i \rightarrow \infty$ ,  $\pi(0; h_k^i)$  will increase toward  $1 - \varepsilon$ . One might also conjecture that  $\pi(0; h_k^i)$  and hence the probability of centralization should be monotonically increasing in  $n_k^i$ . In Acemoglu et al. (2006), we showed that when  $n_k^i$  is low, integer issues may cause  $\pi(0; h_k^i)$  to be nonmonotonic, but it is increasing in  $n_k^i$  "on average," that is, when we average over neighboring values of  $n_k^i$  to smooth out integer issues.

they have been unlucky in the past and have had fewer opportunities to adopt technologies, and also because these are typically the firms with lower  $p_i$ 's, which are slower in climbing the technology ladder. Using this proxy, we test the prediction that centralization increases with the distance to the frontier.<sup>11</sup>

Our next result links the parameter of heterogeneity,  $\varepsilon$ , to firms' decentralization decisions. Let  $\Pr(d_{i,k}^*(h_k^i) = 1)$  be the unconditional probability that firm  $i$  will choose delegation when implementing technology  $k$ .

**PROPOSITION 2 (Heterogeneity).** Consider the adoption decision of technology  $k$  by firm  $i$ . Given the distance to frontier  $n_k^i$ , an increase in heterogeneity,  $\varepsilon$ , makes delegation more likely. That is,  $\partial \Pr(d_{i,k}^*(h_k^i) = 1) / \partial \varepsilon \geq 0$  for all  $h_k^i$ .

Intuitively, when  $\varepsilon$  is small, there is less heterogeneity in the environment, and the performance of firms that have implemented the same technology in the past reveals more information about the reference action. Consequently, when  $\varepsilon$  is small, firms' posterior beliefs are more responsive to public information. In other words, given a history  $h_k^i$ ,  $\partial \pi(0; h_k^i) / \partial \varepsilon \leq 0$ , so that as  $\varepsilon$  increases, delegation becomes more attractive at each history  $h_k^i$ .<sup>12</sup> The complication in the proof comes from the fact that a change in  $\varepsilon$  also affects the likelihood of different histories. Nevertheless, it can be proved that a greater  $\varepsilon$  changes the *ex ante* distribution of different histories in a direction that also increases the probability of delegation.

Proposition 2 provides the most interesting testable implication of our approach; it suggests that there should be more decentralization in industries with greater dispersion of performance across firms and also that decentralization should be more likely for firms that are more dissimilar to others. In the empirical section, we proxy heterogeneity using three different measures. First, we use the dispersion of productivity growth within a four-digit industry. This is a natural measure, since a higher  $\varepsilon$  corresponds to greater variability in the successful implementation of a *given* technology and thus to greater variability in productivity growth.

11. Although in this section we state the results in terms of "distance to the technology frontier," in the empirical work it will be more convenient to use the inverse of this, "proximity to the frontier."

12. Interestingly, this applies to both "correct" and "incorrect" beliefs. For instance, suppose that  $x_k^* = L$ , but  $R$  has been successful more than half of the time; when  $\varepsilon$  is small, the firm will assign higher probability to  $R$  being the correct action.

Second, we check these results using the dispersion in levels of productivity within an industry. Finally, we use a firm-level proxy for heterogeneity, the (IT-weighted) distance between the product mix of a particular firm and those of other firms in the same industry, the idea being that firms with a product mix that is more similar to others should be able to learn more from past experiences of other firms.

In Acemoglu et al. (2006), we extended this framework to derive a relationship between firm age and organizational structure. Firms learn not only from other firms, but also from their own past experiences. The implication of this extension is that younger firms that have accumulated less “firm-specific” information are more likely to choose delegation. Motivated by this observation, in our empirical analysis we also investigate the relationship between firm age and delegation.

#### IV. ECONOMETRIC SPECIFICATION AND DATA

##### IV.A. Empirical Strategy

In our empirical analysis, we will document a number of correlations motivated by the theory presented in the previous section. Recall that the main predictions of our approach are as follows:

1. Delegation should be more common for firms closer to the technological frontier.
2. Delegation should be more prevalent in environments with greater heterogeneity.
3. Young firms should be more likely to choose delegation.

We investigate these predictions by studying the relationship between various explanatory factors and decentralization decisions of several thousand French and British firms. Consider the following econometric model for delegation,

$$(3) \quad d_{ilt}^* = \alpha H_{ilt-1} + \beta PF_{ilt-1} + \gamma age_{ilt-1} + \mathbf{w}'_{ilt-1} \zeta + u_{ilt},$$

where  $i$  denotes firm,  $l$  denotes industry, and  $t$  denotes time. Here,  $d_{ilt}^*$  is a latent variable indicating the propensity to delegate authority to managers,  $H_{ilt-1}$  is a measure of heterogeneity,  $PF_{ilt-1}$  is a measure of “proximity to the frontier” (inverse measure of “distance to the frontier”),  $age_{ilt-1}$  denotes the age of the firm, and  $\mathbf{w}_{ilt-1}$  is a vector of other controls. All right-hand side variables refer to  $t - 1$ , while the dependent variable is for  $t$ , which is an attempt to prevent the most obvious form of reverse causality.

Nevertheless, we do not view estimates from equation (3) as corresponding to causal effects, since there may be other omitted factors simultaneously affecting both the (lagged) right-hand side variables and the delegation decisions. All omitted factors are captured by the error term  $u_{ilt}$ , which we assume to be normally distributed.

In all of our specifications, we observe an indicator of decentralization,  $d_{ilt} \in \{0, 1\}$ , and in our baseline specifications, we assume that

$$(4) \quad d_{ilt} = \begin{cases} 1 & \text{if } d_{ilt}^* > 0 \\ 0 & \text{if } d_{ilt}^* \leq 0, \end{cases}$$

where  $d_{ilt}^*$  is given by (3). Equation (4), combined with the fact that  $u_{it}$  is normally distributed, leads to the standard probit model (Wooldridge 2002). We therefore estimate (3) by maximum likelihood probit. We check the robustness of our results by using logit and linear probability specifications.

#### IV.B. Data and Measurement

We use two French and one UK data set. The use of multiple data sets is an important cross-validation of the robustness of our results. Our first and main data set, “Changements Organisationnels et Informatisation” (COI), covers just over 4,000 manufacturing firms.<sup>13</sup> Using unique identifiers, firms in this data set are matched to the data set FUTE, which contains the entire population of French firms with more than 20 employees.<sup>14</sup> Many of our right-hand-side variables are constructed from the FUTE and thus refer to this entire population. Since the COI contains some firms with less than 20 employees, the match leaves us with a total of 3,570 firms for our basic analysis.

Using the COI, we build a measure of decentralization based on the organization of a firm’s business units into profit centers (see Appendix B for a more detailed description). In practice, once

13. For previous uses of this data set, see Greenan and Mairesse (1999), Janod (2002), Crépon, Heckel, and Riedinger (2004), Janod and Saint-Martin (2004), and Aubert, Caroli, and Roger (2006).

14. FUTE also contains the population of nonmanufacturing firms with more than 10 employees, which we use in some of the later tables. These data are not published in the French national accounts, so we worked directly with the underlying micro data located in the French statistical agencies. Similarly, the information on the demographic structure of each firm (e.g., skills, age, gender of employees, and hours of work) had to be built up from the employee-level data sources aggregated to the firm level. See Appendix B for details.

a firm grows beyond a certain size, it faces the choice of retaining centralized control or allowing some decentralization. Firms are generally organized into business units, with different degrees of responsibility delegated to the managers of these units. While some firms retain complete command and control at the center, most create some form of “responsibility centers” for business unit managers.<sup>15</sup> These responsibility centers (from the most to the least decentralized) are profit centers, cost centers, and revenue centers. Our key indicator for decentralization is whether the firm is organized primarily into profit centers. When a firm organizes into profit centers, the manager keeps track of both revenues and costs with the aim of maximizing profits; he is given considerable autonomy in the purchase of assets, the hiring of personnel, the management of inventories, and the determination of bonuses and promotions.<sup>16</sup> In contrast, a cost (revenue) center manager is responsible only for costs (revenue). Milgrom and Roberts (1992, pp. 229–230) contrast cost and profit centers managers as follows: “Managers who are given responsibility for profits, for example, are commonly given broader decision authority than those responsible just for costs or sales.” Overall about 30% of French firms in our sample are organized into profit centers.

Our second data set, the “Enquête Reponse” (ER), is a survey of just under 3,000 French establishments, covering all sectors of the economy, conducted in 1998. This data set is also matched with the FUTE to construct the right-hand side variables, which leaves us with a data set of around 2,200 establishments. In this data set, delegation can be measured in two ways. First, there is a direct question asked to plant managers regarding the degree of autonomy they enjoy from headquarters in their investment decisions. Since this question only makes sense for firms that are part of a larger group, the analysis is restricted to this subsample

15. For the meaning of the terms “responsibility centers” and “profit centers” in the business literature and in management, see, for example, <http://smccd.net/accounts/nurre/online/chtr12a.htm>. In addition, <http://www.aloa.co.uk/members/downloads/PDF%20Output/costcentres.pdf> provides a standard discussion of autonomy of profit centers. Janod (2002) and Janod and Saint-Martin (2004) have previously used these data on profit centers as a measure of decentralization.

16. Merchant’s (1989, p. 10) book on profit centers explains: “The profit center managers frequently know their business better than top management does because they can devote much more of their time to following up developments in their specialized areas. Hence, top level managers usually do not have detailed knowledge of the actions they want particular profit center managers to take, and even direct monitoring of the actions taken, if it were feasible, would not ensure profit center managers were acting appropriately.”



(of 1,258 establishments). Second, this data set also includes a question on delayering—in particular, on whether there was any reduction in the number of hierarchical layers between 1996 and 1998. Although, a priori, delayering may be associated with more or less delegation (for example, because it may make the chief executive more informed about lower layers), existing evidence shows that delayering tends to involve delegating more power to lower layers of the managerial hierarchy (see Caroli and Van Reenen [2001] and Rajan and Wulf [2006]).

Finally, we draw on a British data set, the 1998 Workplace Employee Relations Survey (WERS), which is similar in structure to ER. WERS does not have a question on plant managers' autonomy with respect to investment decisions but contains a question on their autonomy from headquarters in making employment decisions. We use this question to measure the degree of decentralization. Unlike the French data, for confidentiality reasons WERS cannot be matched with productivity at the firm level, though we can match productivity information at the four-digit-industry level. Details on all three data sets are in Appendix B.

Our indicator of proximity to the frontier is the gap between the log labor productivity of a firm (measured as value added per hour) and the frontier (log) labor productivity in the primary four-digit industry of the firm,  $\ln y_{ilt} - \ln y_{Filt}$ , where  $F$  denotes the frontier, measured in a number of alternative ways. In addition to average labor productivity, we report robustness checks using total factor productivity (TFP). We also construct several alternative indicators of "frontier" productivity. Our main measure is the highest productivity in the firm's primary four-digit industry (defined as the 99th percentile, to mitigate any measurement error from outliers that might have arisen had we used the maximum), again calculated from the FUTE data set. We repeat the same exercise using other percentiles (90th and 95th), and we consider alternative measures based on the firm's productivity *rank* in the four-digit industry.

In addition to our main specification, we also allow  $\ln y_{ilt-1}$  and  $\ln y_{Filt-1}$  to have different coefficients in the regression equation by estimating

$$(5) \quad d_{ilt}^* = \alpha H_{ilt-1} + \beta_1 \ln y_{ilt-1} + \beta_2 \ln y_{Filt-1} + \gamma age_{ilt-1} + \mathbf{w}'_{ilt-1} \zeta + u_{ilt}.$$

This specification allows us to test whether  $\beta_2 < 0$  (that is, whether, as predicted by our theory, delegation is negatively correlated with lagged frontier productivity) and also whether  $\beta_1 = -\beta_2$ . This robustness check is particularly important, since a positive correlation between distance to frontier and decentralization may reflect a positive effect of decentralization on the firm's own productivity. If this were the case, in equation (5) we would estimate that  $\beta_2 = 0$ .

For heterogeneity,  $H_{il}$ , we use three measures. All three measures are constructed from the FUTE data set for the entire covered population of firms (in the United Kingdom we use the Annual Business Inquiry Census data). Our benchmark measure of heterogeneity,  $H_l^G$ , is the dispersion of firm productivity growth within a four-digit sector. This measure captures the effect of the parameter  $\varepsilon$  in the model of Section III, since high values of  $\varepsilon$  correspond to greater heterogeneity in the performance of firms implementing the same technology and thus to greater variability in productivity growth within a sector. We measure productivity growth by the firm's average annual growth in value added per hour over the period 1994 to 1997, and our main measure of dispersion is the difference in productivity growth rates between the 90th and the 10th percentiles in the four-digit industry, so that

$$(6) \quad H_l^G \equiv (\Delta \ln y_{il})^{90} - (\Delta \ln y_{il})^{10},$$

where  $(\Delta \ln y_{il})^P$  denotes the  $P$ th percentile of the distribution of productivity growth across all firms in industry  $l$ . We also consider several alternatives, such as the difference between the 95th and the 5th percentiles, the standard deviation of firm productivity growth rates, and the standard deviation of the trimmed productivity growth distribution.

We also present results with an alternative measure of heterogeneity,  $H_l^L$ , constructed similarly to  $H_l^G$ , but using productivity levels instead of growth rates (i.e.,  $H_l^L \equiv \ln y_{il}^{90} - \ln y_{il}^{10}$ ). This measure has two empirical disadvantages relative to our benchmark. First, it is likely to be correlated with the distance to the frontier, so the heterogeneity and proximity terms may be hard to identify separately. Second, the growth-based measure,  $H_l^G$ , is likely to be a better proxy for  $\varepsilon$  since it differences out time-invariant omitted variables affecting the level of productivity that are observable to firms but not the econometrician (such as management quality and brand differences).

These measures of heterogeneity do not vary within a four-digit industry. Our third measure,  $H_i^F$ , is a firm-specific index of heterogeneity and quantifies (the inverse of) how many other firms are close “neighbors” of the firm in question in the product space. When there are more similar firms (neighbors), the firm will have greater opportunity to learn from the experiences of others, and this will correspond to a lower value of  $\varepsilon$  in terms of our theoretical model.<sup>17</sup> To calculate this measure, for each firm  $i$  we compute the distribution of production across all four-digit sectors. We define  $s_i \equiv (s_{i1}, \dots, s_{iL})$  as firm  $i$ 's shares of production in each industry  $l = 1, \dots, L$  (by definition  $\sum_{l=1}^L s_{il} = 1$ ). An element of the vector  $s_i$  will be equal to zero if a firm produces nothing in industry  $l$  and will be equal to one if a firm produces all its output in that particular industry. We then calculate the closeness of any two firms,  $i$  and  $i'$  in the FUTE as the uncentered correlation coefficient,

$$c_{ii'} \equiv \frac{\sum_{l=1}^L s_{il} \cdot s_{i'l}}{\left(\sum_{l=1}^L s_{il}^2\right)^{\frac{1}{2}} \cdot \left(\sum_{l=1}^L s_{i'l}^2\right)^{\frac{1}{2}}},$$

which takes greater values when the production profiles of two firms are more similar and is equal to one when the two profiles are identical. Since our theoretical approach emphasizes the importance of similarity in the context of experimenting with new technologies, our preferred measure of firm-specific heterogeneity is constructed with information technology (IT) weights,

$$(7) \quad H_i^F \equiv \log \left( \frac{\sum_{i', i' \neq i} c_{ii'} \cdot IT_{i'}}{\sum_{i', i' \neq i} IT_{i'}} \right)^{-1},$$

where  $IT_{i'}$  is the level of investment in IT by firm  $i'$ . We also check the robustness of our results by looking at an alternative unweighted measure. The “inverse” in equation (7) makes sure that high levels of  $H_i^F$  correspond to high values of  $\varepsilon$  in terms of our theory.

A potential concern with this firm-level heterogeneity measure,  $H_i^F$ , is that it may be related to the level of product market

17. This measure of closeness is inspired by Jaffe's (1986) approach in the context of patent spillovers but uses the proportion of production in a four-digit industry. Jaffe originally used patent technology class, which has the potential disadvantage that many firms do not patent, especially in services.

TABLE I  
DESCRIPTIVE STATISTICS (ENQUÊTE COI, 1994-1997)

Variable	Source	Mean	Median	St dev
Decentralization measures				
Organized into profit centers	COI	0.304	0	0.460
Decentralization of investment decisions	ER	0.484	0	0.500
Delaying	ER	0.436	0	0.496
Heterogeneity measures: Industry-level heterogeneity of labor productivity growth ( $H_I^G$ )				
90th - 10th percentiles	DADS/FUTE	0.275	0.263	0.087
95th - 5th percentiles	DADS/FUTE	0.443	0.406	0.160
Standard deviation	DADS/FUTE	0.177	0.165	0.066
Standard deviation after trimming	DADS/FUTE	0.088	0.082	0.033
Heterogeneity measures: Industry-level heterogeneity of labor productivity level ( $H_I^L$ )				
90th - 10th percentiles	DADS/FUTE	0.897	0.861	0.229
Heterogeneity measure: Firm-level inverse share of close firms in the product space ( $H_I^F$ )				
Share of close (IT-weighted) firms, %	FUTE	0.343	0.138	0.049
ln (firm-specific heterogeneity)		7.111	6.587	2.381
Share of close (unweighted) firms, %	FUTE	0.216	0.096	0.308
Distance to technological frontier				
Firm labor productivity	DADS/FUTE	0.163	0.143	0.089
Sectoral 99th percentile labor productivity	DADS/FUTE	0.508	0.397	0.315
Proximity to frontier	DADS/FUTE	0.358	0.334	0.159
ln (proximity to frontier)		-1.125	-1.096	0.457
Other firm-level variables				
Foreign ownership	LIFI	0.173	0	0.379
Firms belonging to a larger group	LIFI	0.547	1	0.498

TABLE I  
(CONTINUED)

Variable	Source	Mean	Median	St dev
Number of plants	DADS	3.092	1	8.510
Firm age	SIRENE	21.658	18	12.740
Capital stock/value added	FUTE	1.143	0.907	1.036
Number of workers	FUTE	323.463	88.375	677.080
Percentage of workers using computers	COI	59.669	71.846	26.300
Percentage of skilled workers	DADS	72.996	77.371	20.202
Age of workers	DADS	38.870	39.010	3.403
Lerner index	FUTE	0.075	0.068	0.077
Market share (%)	FUTE	1.732	0.404	4.171
Herfindahl index	FUTE	0.049	0.031	0.057
Specialization	FUTE	0.831	0.931	0.203
Other industry-level variables				
Capital stock per worker)	BRN	404.987	289.242	369.064
IT investment (per worker)	EAE/FUTE	0.849	0.600	0.725

Note: These descriptive statistics are based on the COI sample (3,570 observations), except for "Decentralization of investment decisions" and "Delaying" (ER sample; 1,258 observations). The COI data set is a firm-level survey providing information on organization and other firm characteristics in 1997; it covers manufacturing and nonmanufacturing sectors only. The ER data set is an establishment survey containing information about organizational change between 1996 and 1998; it covers both manufacturing and nonmanufacturing sectors. The FUTE files contain the firms' balance sheets and further accounting information; it refers to the entire population of French firms having more than 20 employees in manufacturing industries or more than 10 employees in other industries. The DADS files consist of yearly mandatory employer reports of each worker's hours (and gross earnings subject to payroll taxes); they cover the entire population of French firms. The LIPI files describe the structure of ownership of large French firms; it also includes information about their main interests in other companies. SIRENE is the register of all French firms. Units of currency are thousands of French francs at the 1995 prices. See text for variable definitions.

competition. If there are many other firms “close” to a company in the product market space, then this company may be facing tougher competition.<sup>18</sup> To alleviate this concern, we control for various measures of product market competition, in particular the Lerner index (a proxy for price-cost margins), calculated as gross profits (value added minus labor costs) divided by sales, from the FUTE data set. Moreover, we document below that there is a robust positive relationship between product market competition and delegation,<sup>19</sup> so the possible negative correlation between product market competition and  $H_t^F$  will, if anything, bias the results toward finding a negative effect of heterogeneity on delegation, which is the *opposite* of the prediction in Section III.

In addition, since our theory emphasizes the importance of learning in the context of the implementation of new technologies, we estimate (3) and (5) separately in high-tech and low-tech subsamples (as measured by industry IT intensity). We expect the patterns suggested by our model to be more pronounced for high-tech firms.

We measure age,  $age_{it-1}$ , using four dummies; age less than 5 years, between 5 and 9 years, between 10 and 19 years, and the reference category, greater than or equal to 20 years.

Means, medians, and standard deviations for all the main variables are presented in Table I (these are mainly based on our core French data set, the COI). Appendix B gives greater detail on the data used. The average firm in our data has 323 employees, was born 22 years ago, and has three plants.

## V. RESULTS

### V.A. Decentralization

Table II presents our basic findings using the decentralization measure from COI. Throughout, all regressions are estimated by maximum likelihood (ML) probit and we report marginal effects evaluated at the sample mean. All standard errors are computed using the Huber formula, where we allow for heteroscedasticity

18. See Bloom, Schankerman, and Van Reenen (2004) for a discussion.

19. For evidence of the positive influence of competition on organizational change see Nickell, Nicolitsas, and Patterson (2001) and the McKinsey Global Institute (2002).

TABLE II  
DETERMINANTS OF DECENTRALIZATION (ENQUÊTE COI)

Industries:	Dependent variable: Firm decentralized into profit centers					
	Full sample			High-tech		Low-tech
	(1)	(2)	(3)	(4)	(5)	(6)
Heterogeneity ( $H_i^C$ )	0.211 (0.107)	0.252 (0.102)	0.296 (0.127)	0.251 (0.115)	0.679 (0.189)	-0.062 (0.135)
Frontier, 99th percentile ( $\ln y_{FI}$ )	-0.101 (0.039)	—	0.225 (0.045)	—	—	—
Labor productivity, firm-level ( $\ln y_{iL}$ )	0.182 (0.026)	—	0.141 (0.033)	—	—	—
Proximity to frontier (constrained term $\ln y_{iL} - \ln y_{FI}$ )	—	0.167 (0.024)	—	0.164 (0.028)	0.224 (0.040)	0.103 (0.044)
Firm age < 5 years	0.151 (0.040)	0.151 (0.040)	0.172 (0.041)	0.174 (0.041)	0.215 (0.059)	0.122 (0.055)
5 ≤ firm age < 10 years	0.012 (0.021)	0.012 (0.021)	0.066 (0.022)	0.066 (0.022)	0.069 (0.032)	0.049 (0.029)
10 ≤ firm age < 20 years	-0.007 (0.019)	-0.007 (0.019)	0.039 (0.019)	0.040 (0.019)	-0.008 (0.027)	0.083 (0.028)
Lerner index	—	—	-0.660 (0.144)	-0.733 (0.136)	-0.947 (0.168)	-0.547 (0.218)
$\ln$ (number of plants)	—	—	0.041 (0.015)	0.041 (0.015)	0.027 (0.017)	0.052 (0.017)
$\ln$ (firm size)	—	—	0.110 (0.009)	0.110 (0.009)	0.134 (0.015)	0.098 (0.014)
Percentage of workers using computers	—	—	0.230 (0.034)	0.217 (0.034)	0.238 (0.071)	0.189 (0.034)

TABLE II  
(CONTINUED)

Industries:	Dependent variable: Firm decentralized into profit centers					
	Full sample			High-tech	Low-tech	
	(1)	(2)	(3)	(4)	(5)	(6)
Percentage of skilled workers	—	—	0.169 (0.049)	0.153 (0.048)	0.206 (0.078)	0.090 (0.059)
ln (firm capital/value added)	—	—	0.008 (0.012)	0.009 (0.012)	-0.003 (0.017)	0.022 (0.016)
Foreign ownership	—	—	0.047 (0.025)	0.045 (0.025)	0.064 (0.038)	0.015 (0.032)
Average age of workers in the firm (/10)	—	—	-0.057 (0.025)	-0.060 (0.025)	-0.155 (0.046)	0.008 (0.027)
Firm market share	—	—	-0.577 (0.260)	-0.574 (0.257)	-0.821 (0.382)	-0.520 (0.419)
ln (firm specialization)	—	—	-0.071 (0.030)	-0.070 (0.030)	-0.119 (0.047)	-0.027 (0.039)
ln (Herfindahl index)	—	—	-0.015 (0.017)	-0.011 (0.017)	0.031 (0.027)	-0.024 (0.022)
ln (sector capital stock per worker)	—	—	-0.064 (0.040)	-0.074 (0.040)	-0.115 (0.035)	-0.033 (0.043)
ln (sector IT investment per worker)	—	—	0.116 (0.019)	0.102 (0.019)	0.059 (0.044)	0.111 (0.029)
Industry dummies	yes (73)	yes (73)	yes (73)	yes (73)	yes (52)	yes (42)
Mean of dependent variable	0.304	0.304	0.304	0.304	0.378	0.232
Observations	3,570	3,570	3,570	3,570	1,767	1,803

Note. All coefficients are marginal effects from probit maximum likelihood estimation. Robust standard errors corrected for arbitrary variance-covariance matrix at the four-digit industry level in parentheses. Industry variables are defined at the four-digit level (except industry dummies which are at the three-digit level). All right-hand-side variables are lagged and averaged over three years (1994–1997). Labor productivity is the log of value added per hour; frontier is defined as the 99th percentile of the productivity distribution in the firm's four-digit industry. Heterogeneity is defined as the dispersion of productivity growth rate within a four-digit industry (the 90th percentile minus the 10th percentile). The omitted category for firm age is "firm age greater than twenty years." High-tech subsample includes all firms in industries with greater than median IT investment per worker. Low-tech subsample includes all firms in industries with less than median IT investment per worker. See text for variable definitions.



and clustering at the four-digit industry level. All regressions also include a full set of three-digit industry dummies.<sup>20</sup>

The first column of Table II includes only our key variables: heterogeneity (measured by the 90 – 10 of firm productivity growth), frontier productivity (measured as the 99th percentile of the productivity distribution in the firm's primary four-digit industry), own productivity, age dummies, and the three-digit industry dummies. The results are consistent with the predictions in Section III—all key variables take their expected signs and are statistically significant at the 5% level. The marginal effects of heterogeneity and own productivity are positive, whereas the marginal effects of frontier productivity and age are negative.<sup>21</sup> Firms in more heterogeneous environments are significantly more likely to be decentralized (the marginal effect is 0.211, while the standard error is 0.107). The youngest firms (under 5 years old) are 15% more likely to be decentralized than the oldest firms (those over 20 years old), and this difference is significant at the 5% level.<sup>22</sup> In column (2), we combine the frontier productivity and the own productivity terms in a single “proximity to frontier” term, as in equation (3). The marginal effect of proximity to frontier is 0.167 (standard error = 0.024), while the marginal effect of heterogeneity is 0.252 (standard error = 0.102).<sup>23</sup>

The remaining columns in Table II include a range of additional firm-level and industry-level controls to check whether the correlations we report are driven by omitted variables. The

20. Since the frontier productivity term and the heterogeneity measure  $H_f^G$  are defined at the four-digit level, we could not identify their effects if we included four-digit industry dummies. Nevertheless, with a full set of four-digit dummies, we can still identify the marginal effects of age and firm-specific productivity. In regressions including a full set of four-digit dummies, the coefficients on these variables remain correctly signed and statistically significant.

21. When included individually, each variable is also significant. For example, when we drop all other variables except the three-digit industry dummies, the marginal effect of heterogeneity is 0.212 and continues to be significant at the 5% level (see Acemoglu et al. [2006] for details).

22. Note, however, that since our decentralization data are cross-sectional, we cannot separate age effects from cohort effects. Consequently, the positive coefficient on the young firm dummy may reflect that companies founded in more recent years are more likely to adopt “best practice” organizational forms than companies founded in earlier years (see, e.g., Ichinowski, Prenushi, and Shaw [1997]). One might also conjecture that firms in younger industries should be more decentralized than those in older industries. We cannot investigate this question, however, since we do not have a measure of “industry age” (average firm age is not a good measure of “industry age” because of the differential entry and exit patterns across industries).

23. The Wald test rejects the restriction that  $\beta_1 = -\beta_2$  at the 5% level, though when additional covariates are included in columns (3) and (4), this restriction is no longer rejected.

additional firm-level covariates are the Lerner index, log number of plants of the firm, log firm size (employment), fraction of employees working with computers, fraction of highly skilled workers, (log of) capital stock divided by value added, a foreign ownership dummy, average age of workers, firm's market share, and a specialization/inverse diversification index. The additional industry-level covariates are the Herfindahl index, (log of) capital stock divided by employment, and IT expenditures divided by employment. The fixed capital stock and computer use variables are included both as potential controls and also to bring the measure of labor productivity closer to TFP by controlling for the contribution of various components of the capital stock. Firm-level worker characteristics are included since these may affect organizational choices; for example, firms with more skilled workers and/or younger workers might be more likely to decentralize control. The additional controls improve the fit of the model, but the heterogeneity, age, and productivity terms all remain individually significant at the 5% level or less. Also notable is that in the specification of column (3), which includes all the additional covariates, we do not reject the hypothesis that  $\beta_1 = -\beta_2$ , that is, the hypothesis that frontier and own labor productivity terms have equal and opposite-signed coefficients ( $p$ -value  $> .10$ ).

It is also worth noting that the estimated effects of these covariates are consistent with the existing literature. Firms that are more skill-intensive (Caroli and Van Reenen 2001), that employ younger workers (Aubert, Caroli, and Roger 2006), that have more workers using computers, and/or that are more IT-intensive industries (Bresnahan, Brynjolfsson, and Hitt 2002) appear significantly more likely to be decentralized. Furthermore, firms that are large, multiplant, foreign-owned, and/or less specialized (more diversified) are also more likely to be decentralized, possibly because their production processes are more complex. Firm-level capital stock and industry-level capital stock do not appear to have a major effect on decentralization. There is also a robust negative relationship between the Lerner index, our (inverse) proxy for product market competition, and the probability of decentralization, which implies that more competitive environments are associated with greater decentralization (similarly, high-market-share firms are significantly less likely to decentralize). We discuss the association between competition and decentralization further in the concluding section.

Since our theory in Section III relates decentralization decisions to the adoption of new technologies, we expect a stronger relationship between decentralization and heterogeneity in the high-tech sectors than in the low-tech sectors. We define a “high-tech” sample consisting of industries with an average ratio of IT investment per worker greater than the sample median. The “low-tech” sample contains the remaining industries. We reestimate our main regression equation on these two samples separately. Consistent with our expectations, the marginal effects and significance of all the key variables are greater for high-tech sectors than for low-tech sectors. For example, the heterogeneity index,  $H_t^G$ , is positive and significant in the high-tech sample (column (5)), but negative and insignificant in the low-tech sample (column (6)). The marginal effects of proximity to frontier and of the youngest age dummy are twice as large in the high-tech sample as in the low-tech sample. Wald tests show that these differences are significant at the 1% level for heterogeneity and at the 5% level for proximity to frontier (but nonsignificantly different for age).

Overall, the results in Table II suggest that, consistent with our theory and the relationships shown in Figures I–III, firms that operate in more heterogeneous environments, that are closer to the technology frontier, and that are younger are significantly more likely to be decentralized.

### *V.B. Magnitudes*

To gauge the quantitative magnitudes of the estimates in Table II, we look at the impact of doubling each variable starting from its sample mean.

Using the estimate of the marginal effect of heterogeneity in column (4) of Table II, 0.251, we find that doubling the mean value of heterogeneity (the 90 – 10 of firm productivity growth in the industry) from 0.275 to 0.550 increases the predicted probability of a firm being decentralized into profit centers by approximately 7 percentage points ( $0.251 \times 0.275 \approx 0.069$ ) starting from a base of 30%, which is a sizeable effect. Thus, in “elasticity” terms, a doubling of heterogeneity is associated with a 23% increase in the probability of decentralization (a 6.9-percentage-point increase on a base of 30%).<sup>24</sup>

24. A one-standard-deviation increase in heterogeneity (0.087) results in a smaller increase in decentralization probabilities: a 2.2-percentage-point or 7.3% increase.

Again, using the estimate from column (4) of Table II, doubling the proximity measure leads to a substantial increase in the probability of decentralization by about 11 percentage points, which represents a 37% increase on the base of about 30% ( $0.164 \times \ln 2/0.3 \approx 0.37$ ). Also, using the estimates from column (4) of Table II, doubling the age of a firm from 4 years to 8 years reduces the probability of decentralization by a third (12 percentage points on a 30% base). These calculations suggest that the statistical associations documented in Table II appear to be economically as well as statistically significant.

### *V.C. Alternative Measures of Technology*

Table III contrasts our basic measure of heterogeneity ( $H_t^G$ , the interdecile range of firm productivity growth rates in the industry) with several alternative indicators of heterogeneity. The first column of Table III replicates the specification from the fourth column of Table II for comparison. The next three columns, (2)–(4), use alternative measures of heterogeneity, still based on the dispersion of productivity growth rates across firms within the four-digit industry. Column (2) shows a result qualitatively similar to that in column (1), using the difference between the productivity growth rates at the 95th and 5th percentiles (instead of the 90th and 10th percentiles). The marginal effect is 0.142 with a standard error of 0.069. In column (3) we use the standard deviation of the growth rate, which also has a positive marginal effect, but is only significant at the 10% level. This lack of precision may be due to a number of outliers in the firm-level productivity growth distribution. In column (4), we use the standard deviation calculated after trimming the top and bottom 5% of the firm-level productivity growth distribution and obtain a much larger and much more significant marginal effect.

Column (5) includes the heterogeneity term based on firm productivity levels,  $H_t^L$ . The marginal effect of this variable is positive but is not statistically significant. The estimated magnitude is comparable to that in column (1); however, a doubling of  $H_t^L$  is associated with a 27% increase in decentralization (an 8.1 percentage point increase on a base of 30%) compared to 23% for our benchmark measure,  $H_t^G$ . Furthermore, as with our benchmark results in Table II, the level-based measure of heterogeneity,  $H_t^L$ , has a large and statistically significant marginal effect of 0.271 in the high-tech sample (column (6)). In contrast,

TABLE III  
DETERMINANTS OF DECENTRALIZATION: ALTERNATIVE MEASURES OF HETEROGENEITY (ENQUÊTE COI)

Measure of heterogeneity	Dependent variable (mean = 0.304): Firm decentralized into profit centers										
	Heterogeneity: dispersion of productivity growth in four-digit industry ( $H_t^G$ )			Heterogeneity: dispersion of productivity levels in four-digit industry ( $H_t^L$ )			Heterogeneity: ln of the inverse share of "close" firms in the product space ( $1/O_t^f$ )			Unweighted	
Industry	90th - 10th percentiles		95th - 5th percentiles		Std dev after trimming		90th - 10th percentiles			IT-weighted	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Heterogeneity	0.251 (0.115)	0.142 (0.069)	0.231 (0.132)	0.870 (0.316)	0.090 (0.062)	0.271 (0.092)	-0.064 (0.090)	0.063 (0.031)	0.098 (0.048)	0.019 (0.037)	0.055 (0.035)
Proximity to frontier	0.164 (0.028)	0.168 (0.029)	0.152 (0.028)	0.165 (0.028)	0.153 (0.028)	0.222 (0.041)	0.100 (0.044)	0.159 (0.028)	0.208 (0.039)	0.104 (0.043)	0.146 (0.027)
Firm age < 5 years	0.174 (0.041)	0.173 (0.041)	0.171 (0.041)	0.173 (0.041)	0.171 (0.041)	0.211 (0.059)	0.121 (0.056)	0.177 (0.041)	0.214 (0.060)	0.123 (0.056)	0.173 (0.041)
5 ≤ firm age < 10 years	0.066 (0.022)	0.067 (0.022)	0.067 (0.022)	0.066 (0.022)	0.068 (0.022)	0.067 (0.032)	0.049 (0.029)	0.067 (0.022)	0.068 (0.032)	0.049 (0.029)	0.067 (0.022)
10 ≤ firm age < 20 years	0.040 (0.019)	0.041 (0.019)	0.040 (0.019)	0.040 (0.019)	0.039 (0.019)	-0.009 (0.027)	0.083 (0.028)	0.041 (0.019)	-0.005 (0.027)	0.082 (0.028)	0.040 (0.019)
Lerner index	-0.733 (0.136)	-0.750 (0.137)	-0.708 (0.134)	-0.743 (0.136)	-0.725 (0.132)	-0.952 (0.172)	-0.534 (0.217)	-0.721 (0.136)	-0.895 (0.168)	-0.544 (0.218)	-0.697 (0.133)
Industry dummies	yes (73) 3,570	yes (73) 3,570	yes (73) 3,570	yes (73) 3,570	yes (73) 3,570	yes (52) 1,767	yes (42) 1,803	yes (73) 3,570	yes (52) 1,767	yes (42) 1,803	yes (73) 3,570
Observations											

Note: All coefficients are marginal effects from probit maximum likelihood estimation. Robust standard errors corrected for arbitrary variance-covariance matrix at the four-digit industry level in parentheses. In column (1) the measure of heterogeneity is the difference between the productivity growth rate for the firm at the 90th percentile minus the 10th percentile; in column (2) it is the 95th percentile minus the 5th percentile; in column (3) it is the standard deviation of productivity growth rates and in column (4) it is the same as column (2) except that we trim the bottom and top 5% of productivity growth distribution in each four-digit industry. In columns (5)-(7) the measure of heterogeneity is the difference between the productivity level for the firm at the 90th percentile minus the 10th percentile. In columns (8)-(10), the heterogeneity measure is the log of the inverse of the share of IT-weighted "close" firms in the product space, whereas in column (11) these firms are not IT-weighted. Full set of firm and industry level controls included as in Table II column (4); see text for variable definitions.

its marginal effect is nonsignificant (and negative) in the low-tech sample (column (7)) and is also significantly different from the estimate in the high-tech sample ( $p$ -value = .009).

Columns (8)–(11) report results using the firm-level measure of heterogeneity,  $H_i^F$ .<sup>25</sup> Recall that this index measure is the (inverse) IT-weighted distance of a firm to all other firms. This is an entirely different source of variation in heterogeneity and thus constitutes a useful cross-validation of the main results. In column (8) of Table III,  $H_i^F$  has a marginal effect of 0.063 and a standard error of 0.031. The next two columns show that, as with the other measures, the effect of heterogeneity is stronger in the high-tech sample than in the low-tech sample (0.098 with a standard error of 0.048 versus 0.019 with a standard error of 0.037). Finally, in column (11) we look at the simpler unweighted measure of the firm-level heterogeneity measure. This is useful as another check to see whether the measure  $H_i^F$  is capturing some competition-related factors. If that were the case, we would expect the unweighted measure to be stronger. The unweighted measure also has a positive effect, but with a smaller coefficient that is only statistically significant at the 10% level. This suggests that, consistent with our theoretical approach, the IT weights increase the explanatory power of the firm-level heterogeneity index.<sup>26</sup>

Overall, the results in this table show that there is a robust positive association between heterogeneity and decentralization, particularly in high-tech industries.<sup>27</sup>

#### *V.D. Further Robustness Checks*

In addition, we conducted a large number of robustness checks (see Acemoglu et al. [2006] and Appendix B for details). These checks show that our main results do not depend on the

25. All of the results in Table II are similar if we use this measure. For example, the most parsimonious specification in column (1) of Table II gives a marginal effect of  $H_i^F$  of 0.111 with a standard error of 0.034.

26. If we include both the weighted and the unweighted measures together with all the covariates, the weighted measure is positive and significant at the 5% level (marginal effect = 0.184, standard error = 0.096), while the unweighted measure is negative and insignificant (marginal effect = -0.142, standard error = 0.109).

27. One concern with any measure of heterogeneity is that, since it is correlated with uncertainty in firm's environment, it may affect the extent of the moral hazard problem between the firm and the manager (an issue we have abstracted from in the model). Nevertheless, everything else equal, this effect would bias the results against finding a positive association between heterogeneity and decentralization, since greater uncertainty should increase "agency costs," making decentralization less attractive.

precise functional form, the control variables, or the exact sample. Here we give a brief summary of these robustness checks.

First, estimating by OLS or logit gave marginal effects very similar to the probit estimates of column (3) in Table II.

Second, alternative measures of productivity and distance to the frontier also gave similar results. For example, results using total factor productivity were very close to those using labor productivity. We also experimented with alternative definitions of the distance to the frontier using an ordinal measure (the rank of the firm's labor productivity in the four-digit industry) or the productivity distribution relative to lower percentiles than the 99th percentile in order to measure the frontier (e.g., the 95th and the 90th). Again, the results were qualitatively similar, but the marginal effects of the frontier became progressively weaker as we used the 95th and the 90th percentiles. This pattern is not surprising, since we expect the 95th and 90th percentiles to be poorer proxies for the technology frontier than the 99th percentile.

Third, although a single firm can be organized into divisions, with each division being decentralized as a profit center, the measure of profit centers may be more natural for firms that are part of larger groups. To investigate this issue and also to exclude potentially owner-managed firms, which may be different for a variety of reasons, we reestimated our basic specification on the subsample of 1,793 firms that are part of a larger corporate group. Reassuringly, the effects of heterogeneity and proximity to the frontier are considerably larger and more significant in this subsample (0.461 with a standard error of 0.140 for heterogeneity and  $-0.303$  with a standard error of 0.056 for the frontier).

Another concern is that we have allocated a single "frontier" productivity to each firm, whereas firms that operate across multiple industries will have multiple "frontiers." To address this concern, we limited the sample to firms that have at least 80% of their sales in their primary four-digit industry, since the multiple industry issue should not be a serious concern for these firms. In this limited sample of 2,555 firms, both heterogeneity and the frontier terms remain highly significant, but the marginal effect of the frontier term is somewhat smaller;  $-0.179$  instead of  $-0.225$  in the baseline specification.

We also estimated instrumental-variable models to address the issue of endogeneity of our main right-hand side variables. Our strategy was to use the UK counterparts of our key variables as instruments. Although this approach does not solve all possible

endogeneity problems, it is a useful check against reverse causality concerns. We constructed heterogeneity variables identical to  $H_t^G$  based on the dispersion of productivity growth among British firms for the same time period to instrument French industry-level heterogeneity. We also constructed the 99th percentile of the productivity distribution in each four-digit British industry as a potential instrument for the French proximity to frontier. The details are provided in Acemoglu et al. (2006). Briefly, these instruments are highly significant in the first stages. Using instrumental-variables probit (see Lee [1981]), we estimated positive and significant effects of both heterogeneity and proximity to the frontier in the second stage. The marginal effects in this case were 1.572 for heterogeneity and 0.456 for proximity to the frontier (compared to 0.230 and 0.167 when these variables are treated as exogenous). These instrumental-variable results therefore suggest that, if anything, treating heterogeneity and proximity as exogenous may be causing some attenuation due to measurement error and making us underestimate the impact of heterogeneity and proximity to the frontier on decentralization.

#### *V.E. Alternative Measures of Decentralization*

Two alternative measures of decentralization are control over investment decisions and delayering. Whether an establishment's senior managers can make investment decisions without consulting headquarters is directly related to delegation of authority. In addition, case studies and econometric evidence suggest that reducing the layers of the managerial hierarchy tends to be associated with decentralized decision-making.<sup>28</sup> There are questions on delayering and the autonomy of investment decision-making in our second French data set, the *Enquête Reponse (ER)*.<sup>29</sup> Delayering is defined as the removal of one or more layers of the managerial hierarchy between 1996 and 1998. Our indicator of investment autonomy/decentralization is equal to one if the plant manager has "full" or "important" authority in making investment decisions independently of central headquarters and to zero if he

28. See, for example, Caroli and Van Reenen (2001) and Rajan and Wulf (2006).

29. In the COI data set there is an indicator of the number of hierarchical levels, but as discussed in Appendix B, a better data source to measure delayering is the ER. This is because the ER question on delayering refers explicitly to changes in management as in our theory, while the COI question refers to the number of "hierarchical levels" and is thus likely to be more informative on hierarchies involving nonmanagerial workers.



has “limited” or “no” autonomy in making such decisions. In this case, we also limit the sample to firms that are part of a larger group, because the question on delegation of investment decisions from headquarters is only relevant for these firms.

Table IV shows the results of estimating equation (5) for these alternative measures both for the full sample and also separately for the high-tech and the low-tech samples (constructed using industry IT intensity as in Table II). In columns (1)–(3) the dependent variable is an indicator of whether the firm grants autonomy over investment decisions to its plant managers. In columns (4)–(9), the dependent variable is an indicator for whether there was a reduction in the number of layers in the managerial hierarchy between 1996 and 1998.

In column (1) of Table IV, frontier productivity is negatively and significantly related to the probability of allowing managers to make investment decisions without consulting headquarters (decentralization). Heterogeneity is positively related to decentralization but (like the firm’s own productivity) is insignificant. When we distinguish between high-tech (column (2)) and low-tech samples (column (3)), however, the results are stronger. The marginal effect of heterogeneity for high-tech sectors is positive and significant at the 5% level, whereas in the low-tech sample, heterogeneity is nonsignificant. Similarly, the marginal effect of the productivity frontier is negatively and significantly related to decentralization in the high-tech sample, but is positive and nonsignificant in the low-tech sample. Own productivity and age are nonsignificant in both samples.

The next six columns use the measure of delaying as the dependent variable. In column (4) the productivity terms are both correctly signed and significant, suggesting that the closer a firm is to the technology frontier, the more likely it is to choose delaying. Younger firms are also significantly more likely to delay than older firms.<sup>30</sup> The heterogeneity term is positive and significant at the 10% level. When we split the sample into high-tech (column (5)) and low-tech (column (6)) sectors, the marginal effects of heterogeneity and frontier productivity are again much larger for high-tech sectors than for low-tech sectors, but the standard errors are also much larger in both samples. In contrast, the age

30. Although the ER data are at the establishment level, the regressions in Table IV use firm age to make the results comparable to those in Tables II and III. The young firm dummy remains positive and significant if we also condition on establishment age.

TABLE IV  
DETERMINANTS OF DECENTRALIZATION: ALTERNATIVE MEASURES OF DECENTRALIZATION (ENQUÊTE REPONSE)

Dependent variable	Decentralization of investment decisions, 1998						Some delayering between 1996 and 1998					
	Level			Level			Level			Growth rate		
	Full sample (1)	High-tech (2)	Low-tech (3)	Full sample (4)	High-tech (5)	Low-tech (6)	Full sample (7)	High-tech (8)	Low-tech (9)			
Heterogeneity ( $H_I^G$ )	0.108 (0.165)	0.455 (0.235)	-0.127 (0.415)	0.355 (0.185)	0.398 (0.283)	0.075 (0.301)	0.434 (0.200)	0.396 (0.304)	0.102 (0.294)			
Frontier (99th percentile)	-0.110 (0.054)	-0.249 (0.079)	0.021 (0.103)	-0.115 (0.051)	-0.152 (0.080)	0.011 (0.086)	-0.058 (0.048)	-0.078 (0.064)	-0.043 (0.067)			
Labor productivity (firm)	0.072 (0.052)	0.064 (0.077)	0.104 (0.075)	0.126 (0.056)	0.118 (0.072)	0.066 (0.081)	-0.056 (0.101)	0.164 (0.157)	-0.137 (0.109)			
Firm age < 5 years	-0.036 (0.056)	-0.016 (0.080)	-0.027 (0.092)	0.183 (0.088)	0.099 (0.113)	0.275 (0.129)	0.054 (0.107)	0.102 (0.171)	0.017 (0.114)			
5 ≤ firm age < 10 years	-0.007 (0.048)	-0.044 (0.074)	0.022 (0.061)	0.047 (0.056)	-0.007 (0.064)	0.076 (0.084)	0.034 (0.059)	-0.031 (0.068)	0.095 (0.090)			
10 ≤ firm age < 20 years	0.004 (0.040)	-0.015 (0.059)	0.026 (0.054)	0.069 (0.039)	0.059 (0.054)	0.068 (0.055)	0.072 (0.040)	0.056 (0.053)	0.099 (0.054)			
Lerner index	-0.034 (0.009)	-0.046 (0.024)	-0.029 (0.114)	-0.934 (0.288)	-0.166 (0.416)	-0.981 (0.402)	-0.666 (0.257)	0.048 (0.358)	-0.977 (0.359)			
Industry dummies	yes (81)	yes (49)	yes (31)	yes (70)	yes (47)	yes (43)	yes (69)	yes (47)	yes (42)			
Mean of dependent variable	0.484	0.475	0.493	0.440	0.553	0.325	0.436	0.553	0.320			
Observations	1,258	648	610	1,049	526	523	1,011	505	501			

Note. All coefficients are marginal effects from probit maximum likelihood estimation. Robust standard errors corrected for arbitrary variance-covariance matrix at the four-digit industry level in parentheses. All establishments are part of a large (French or foreign) group but are not headquarters. Heterogeneity is defined as the dispersion of productivity growth rates within a four-digit industry (the 90th percentile minus the 10th percentile). Full set of firm- and industry-level controls included as in Table II, column (4); see text for variable definitions.

effects are larger in the low-tech sample, which is the opposite of the prediction of our theory.

Since the delayering variable measures organizational change (rather than the level of decentralization, as in our previous dependent variable), we also considered regressions where the productivity terms are in differences rather than in levels. Since we do not have reliable time-series information on the heterogeneity term and some of the other covariates, they are still included in levels. The results, presented in columns (7)–(9), are similar to the benchmark estimates but somewhat weaker. The frontier growth term is correctly signed but no longer significant, and the own productivity term is also nonsignificant.<sup>31</sup> The heterogeneity measure remains positive and significant in the full sample. With the sample split, however, heterogeneity is no longer significant in either sample (presumably because of the smaller number of observations), though, as expected, the marginal effect is substantially larger in the high-tech sample.

In summary, the results from using delayering and autonomy over investment decisions as alternative indicators of decentralization broadly support our earlier conclusions. Decentralization appears to be more likely when the environment is more heterogeneous and when firms are closer to the technology frontier, particularly in the high-tech sample, though the age results appear to be somewhat less robust.

#### *V.F. Decentralization in Britain*

We complement our evidence from the French micro data sets with an analysis of the British Workplace Employee Relations Survey (WERS98). The French Enquête Reponse was modeled on the WERS, and we use the 1998 wave to match the year used in the ER. The WERS cross section does not have a question on autonomy over investment decisions, but there is a similar question on the establishment manager's autonomy over employment decisions. Senior managers were asked whether they were able to

31. The weakness of the frontier growth term in this case is related to the higher correlation between productivity growth and heterogeneity variables (recall that heterogeneity is defined here as the inter-decile range of productivity growth rates in the firm's four-digit industry). In column (7), if we drop the heterogeneity and firm productivity terms, the marginal effect of frontier productivity growth increases to  $-0.061$  and becomes significant at the 5% level. If we use the full specification of column (7), but just include two-digit (instead of the usual three-digit) industry dummies, the marginal effect of frontier growth becomes  $-0.074$ , with a standard error of 0.038.

make decisions on staff recruiting without consulting company headquarters. Our WERS sample is further restricted because we are only able to match manufacturing establishments to industry-level information (since census information on nonmanufacturing is not available over this time period). Finally, we are unable to condition on the rich set of firm-level covariates as in the French data, because confidentiality restrictions limit the data that can be matched at the firm-level (such as firm-level output, capital or age).

The results are presented in Table V.<sup>32</sup> Column (1) includes the first measure of heterogeneity (the difference between the 95th percentile and the 5th percentile of the productivity growth rates in the four-digit industry) with only a full set of three-digit industry dummies as extra controls. Heterogeneity is positively and significantly associated with decentralization at the 5% level. The next column performs the same exercise for the 90 – 10, the relationship is still positive and significant at the 10% level. Column (3) includes the frontier growth term, which is negatively signed, as we would expect from the theory, but nonsignificant. The fourth column includes the age dummies. These are nonsignificant and show no clear pattern (possibly because in this data set we only have establishment age rather than firm age).

The fifth and sixth columns include all the covariates. There appears to be some evidence that firms facing less competition are significantly less likely to decentralize. More importantly, the heterogeneity terms measured either as the 95 – 5 (column (5)) or the 90 – 10 (column (6)) percentile differences remain positive and significant. The frontier term is negative and significant at the 5% level in both columns. These findings are consistent with our theory and with the results from the French data sets, even though they use a different data set from a different country.

## VI. CONCLUSIONS

Despite considerable academic and popular interest in changes in the internal organization of the firm, we are far from a theoretical or empirical consensus on the determinants of the organizational decisions of firms and on the reasons that there has recently been a significant move toward greater decentralization.

32. Because the sample size is smaller with WERS, we estimate liner probability models instead of probit. The results with probit are broadly similar.

TABLE V  
DETERMINANTS OF DECENTRALIZATION IN BRITAIN (BRITISH WERS98)

Dependent variable (mean = 0.805)	Decentralization of employment decisions					
	(1)	(2)	(3)	(4)	(5)	(6)
Heterogeneity ( $H^G$ ) (95th – 5th percentiles)	0.273 (0.130)	—	—	—	0.316 (0.129)	—
Heterogeneity ( $H^G$ ) (90th – 10th percentiles)	—	0.540 (0.325)	—	—	—	0.659 (0.312)
Frontier (99th percentile)	—	—	-0.051 (0.073)	—	-0.204 (0.073)	-0.156 (0.073)
Establishment age < 5 years	—	—	—	-0.076 (0.115)	-0.099 (0.116)	-0.123 (0.114)
5 ≤ est. age < 10 years	—	—	—	0.086 (0.081)	0.055 (0.089)	0.049 (0.089)
10 ≤ est. age < 20 years	—	—	—	-0.127 (0.077)	-0.164 (0.076)	-0.173 (0.075)
Many competitors	—	—	—	—	0.127 (0.082)	0.150 (0.078)
Few competitors	—	—	—	—	0.210 (0.070)	0.228 (0.065)
No competitors	—	—	—	—	ref	ref
Other reestablishment controls	no	no	no	no	yes	yes
Industry dummies	yes (64)	yes (64)	yes (64)	yes (64)	yes (64)	yes (64)
Observations	236	236	236	236	236	236

*Note.* All coefficients are marginal effects from linear probability models. Robust standard errors corrected for arbitrary variance-covariance matrix at the four-digit industry level in parentheses. Data are from the 1998 British Workplace Employee Relations Survey (WERS); they include manufacturing establishments only. Dependent variable is a dummy variable indicating whether “Establishment’s manager is able to make decisions on which staff to recruit without consulting Head Office.” Heterogeneity and frontier are averaged between 1994 and 1997. All regressions include a control for employment size (current, lagged one year, and lagged five years). Other establishment controls include the proportion of young workers (under 20 years old), the proportion of older workers (aged over 50 years old), the proportion of unskilled manual workers, and the proportion of part-time workers. See text for variable definitions.

In this paper we presented a simple model of the relationship between technology, information, and decentralization and empirically investigated the main predictions of this model using three microlevel data sets. In our model, firms delegate authority to managers, that is, “decentralize,” in order to use the manager’s superior information about the implementation of new technologies. Because the interests of the manager and the principal are not perfectly aligned, such delegation entails a costly loss of control for the principal. The model predicts that as the amount of publicly available information about the optimal implementation of new technologies increases, firms should become less likely to decentralize, whereas firms dealing with new (frontier) technologies should be more likely to decentralize. We also showed that firms in more heterogeneous environments and young firms are more likely to choose decentralization. These are intuitive, but quite novel, predictions and have, to the best of our knowledge, never been investigated empirically.

We documented that in all three data sets the correlations are broadly consistent with the predictions of our model. Firms in more heterogeneous environments and those that are closer to the frontier of their industry are more likely to choose decentralization. Moreover, consistent with the predictions of the theory, these results are stronger for firms in high-tech sectors. The results are robust to using a variety of alternative measures of decentralization and heterogeneity. We also found that younger firms tended to be more likely to decentralize, though this result was less robust when we looked at alternative measures of decentralization. These results suggest that the recent move toward more decentralized organizations may be driven, in part, by the rapid diffusion of new technologies and the increase in the number of young firms.

The theory and empirical results, taken together, suggest that learning and information accumulation may have important effects on the internal organization of firms and may be especially important for decentralization decisions. Our analysis also highlights a number of avenues for future research. First, it would be useful to study decentralization and vertical integration decisions jointly, since the same forces pushing toward decentralization may also encourage spinoffs and reduce the incentives for vertical integration.

Second, our empirical results showed a robust positive association of competition and decentralization. An interesting question

is to investigate the channels through which competition may affect decentralization. One possibility is that competition may increase the value of information because falling behind competitors may be costly to firms, thus encouraging delegation to the manager, who has superior information. Yet another effect of a more competitive environment may be through disciplining the manager; faced with greater competition, managers may be forced to take profit-maximizing decisions more often, thus reducing the conflict of interest between the principal and the manager. This would naturally increase delegation, since delegation becomes more attractive to the principal.

Another interesting area for future research would be to investigate whether the statistical associations between proximity to frontier or heterogeneity and decentralization correspond to the causal effects of these variables on the internal organization of the firm, for example, by estimating a more structural model.

Finally, our approach suggests that cross-country differences in the internal organization of firms constitute a promising area for future research, since there may be less decentralization in developing countries, where most firms use well-established (rather than frontier) technologies.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
 HARVARD UNIVERSITY  
 INSEE-CREST PARIS  
 LONDON SCHOOL OF ECONOMICS AND CENTRE FOR ECONOMIC PERFORMANCE  
 UNIVERSITY OF ZÜRICH

#### REFERENCES

- Acemoglu, Daron, Philippe Aghion, Claire Lelarge, John Van Reenen, and Fabrizio Zilibotti, "Technology, Information and the Decentralization of the Firm" NBER Working Paper 12206, 2006.
- Acemoglu, Daron, Philippe Aghion, and Fabrizio Zilibotti, "Distance to Frontier and Vertical Integration," *Journal of the European Economic Association Papers and Proceedings*, 1 (2003), 630–638.
- , "Distance to Frontier, Selection, and Economic Growth," *Journal of the European Economic Association*, 4 (2006), 37–74.
- Acemoglu, Daron, and Fabrizio Zilibotti, "Information Accumulation in Development," *Journal of Economic Growth*, 4 (1999), 5–38.
- Aghion, Philippe, and Jean Tirole, "Formal and Real Authority in Organizations," *Journal of Political Economy*, 105 (1997), 1–29.
- Aubert, Patrick, Eve Caroli, and Muriel Roger, "New Technologies, Workplace Organization and the Structure of the Workforce: Firm-Level Evidence," *Economic Journal*, 116 (2006), 73–93.
- Baker, George, Robert Gibbons, and Kevin Murphy, "Informal Authority in Organizations," *Journal of Law, Economics, and Organization*, 15 (1999), 56–73.
- Baker, George, and Thomas Hubbard, "Make Versus Buy in Trucking: Asset Ownership, Job Design and Information," *American Economic Review*, 93 (2003), 551–572.

- , “Contractibility and Asset Ownership: On Board Computers and Governance in U.S. Trucking,” *Quarterly Journal of Economics*, 119 (2004), 1443–1479.
- Baron, David, and David Besanko, “Information, Control, and Organizational Structure,” *Journal of Economics and Management Strategy*, 1 (1992), 237–275.
- Black, Sandra, and Lisa Lynch, “How to Compete: The Impact of Workplace Practices and Information Technology on Productivity,” *Review of Economics and Statistics*, 58 (2001), 434–445.
- Bloom, Nicholas, Mark Schankerman, and John Van Reenen, “Technological Spillovers and Product Market Rivalry,” Centre for Economic Performance Discussion Paper 675, 2004.
- Bolton, Patrick, and Mathias Dewatripont, “The Firm as a Communication Network,” *Quarterly Journal of Economics*, 109 (1994), 809–839.
- Bresnahan, Timothy, Erik Brynjolfsson, and Lorin Hitt, “Information Technology, Workplace Organization and the Demand for Skilled Labor: Firm-Level Evidence,” *Quarterly Journal of Economics*, 117 (2002), 339–376.
- Caroli, Eve, and John Van Reenen, “Skill Biased Organizational Change,” *Quarterly Journal of Economics*, 116 (2001), 1448–1492.
- Colombo, Massimo, and Marco Delmastro, “Delegation of Authority in Business Organizations: An Empirical Test,” *Journal of Industrial Economics*, 52 (2004), 53–80.
- Crépon, Bruno, Thomas Heckel, and Nicolas Riedinger, “Computerization, Organizational Change and Productivity: Microeconomic Evidence for France,” mimeo, INSEE, 2004.
- Dessein, Wouter, “Authority and Communication in Organizations,” *Review of Economic Studies*, 69 (2002), 811–838.
- Garicano, Luis, “Hierarchies and the Organization of Knowledge in Production,” *Journal of Political Economy*, 108 (2000), 874–904.
- Geanakoplos, John, and Paul Milgrom, “A Theory of Hierarchies Based on Limited Managerial Attention,” *Journal of the Japanese and International Economies*, 5 (1991), 205–225.
- Greenan, Nathalie, and Jacques Mairesse, “Organizational Change in French Manufacturing: What Do We Learn from Firm Representatives and from Their Employees?” NBER Working Paper 7285, 1999.
- Hart, Oliver, and John Moore, “On the Design of Hierarchies: Coordination versus Specialization,” *Journal of Political Economy*, 113 (2005), 675–702.
- Ichinowski, Casey, Giovanna Prenushi, and Kathryn Shaw, “The Effects of Human Resource Management: A Study of Steel Finishing Lines,” *American Economic Review*, 87 (1997), 291–313.
- Jaffe, Adam, “Technological Opportunity and Spillovers from Firms’ Patents, Profit, and Market Value,” *American Economic Review*, 76 (1986), 984–1001.
- Janod, Véronique, “Changements Organisationnel, Qualification et Croissance,” Ph.D. Dissertation, Université Paris 1 Panthéon-Sorbonne, 2002.
- Janod, Véronique, and Anne Saint-Martin, “Measuring Work Reorganization and Its Impact on Firm Performance: An Estimate on French Manufacturing Firms over 1995–1999,” *Labor Economics*, 11 (2004), 785–798.
- Jensen, Michael, and William Meckling, “Specific and General Knowledge, and Organizational Structure,” in *Contract Economics*, Werin Lars and Hans Wijkander, eds. (Oxford: Blackwell, 1992).
- Lee, Lung-Fei, “Simultaneous Equation Models with Discrete and Censored Dependent Variables,” in *Structural Analysis of Discrete Data and Econometric Applications*, Charles Manski, and Daniel McFadden, eds. (Cambridge, MA: MIT Press, 1981).
- Lerner, Josh, and Robert Merges, “The Control of Biotechnological Alliances: An Empirical Examination of the Biotechnology Industry,” *Journal of Industrial Economics*, 46 (1998), 125–156.
- McKinsey Global Institute, “Reaching Higher Productivity Growth in France and Germany,” *MGI Reports* (<http://www.mckinsey.com/knowledge/mgi/europe/index.asp>), 2002.
- Melumad, Nahum, Dilip Mookherjee, and Stefan Reichelstein, “Hierarchical Decentralization of Incentive Contracts,” *Rand Journal of Economics*, 26 (1995), 654–672.



- Merchant, Kenneth, *Rewarding Results: Motivating Profit Center Managers* (Cambridge, MA: Harvard Business School Series in Accounting and Control, 1989).
- Milgrom, Paul, and John Roberts, *Economics, Organization and Management* (Englewood Cliffs, NJ: Prentice Hall, 1992).
- Mookherjee, Dilip, "Decentralization, Hierarchies and Incentives: A Mechanism Design Approach," *Journal of Economic Literature*, 64 (2006), 367–390.
- Nickell, Stephen, Daphne Nicolitsas, and Malcolm Patterson, "Does Doing Badly Encourage Managerial Innovation?" *Oxford Bulletin of Economics and Statistics*, 3 (2001), 5–28.
- Radner, Roy, "The Organization of Decentralized Information Processing," *Econometrica*, 61 (1993), 1109–1146.
- Radner, Roy, and Timothy Van Zandt, "Information Processing in Firms and Returns to Scale," *Annales d'Economie et de Statistique*, 25/26 (1992), 265–298.
- Rajan, Raghuram, and Julie Wulf, "The Flattening Firm: Evidence from Panel Data on the Changing Nature of Corporate Hierarchies," *Review of Economics and Statistics*, 88 (2006), 759–773.
- Rajan, Raghuram, and Luigi Zingales, "The Firm as a Dedicated Hierarchy: A Theory of the Origin and Growth of Firms," *Quarterly Journal of Economics*, 116 (2001), 805–851.
- Sah, Raaj, and Joseph Stiglitz, "The Architecture of Economic Systems: Hierarchies and Polyarchies," *American Economic Review*, 76 (1986), 716–727.
- Wooldridge, Jeffrey, *Econometric Analysis of Cross Section and Panel Data* (Cambridge, MA: MIT Press, 2002).