MANAGEMENT SCIENCE
Vol. 60, No. 12, December 2014, pp. 2859–2885
ISSN 0025-1909 (print) | ISSN 1526-5501 (online)

http://dx.doi.org/10.1287/mnsc.2014.2013

The Distinct Effects of Information Technology and Communication Technology on Firm Organization

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Guided by theories of "management by exception," we study the impact of information and communication technology on worker and plant manager autonomy and span of control. The theory suggests that information technology is a decentralizing force, whereas communication technology is a centralizing force. Using a new data set of American and European manufacturing firms, we find indeed that better information technologies (enterprise resource planning (ERP) for plant managers and computer-assisted design/computer-assisted manufacturing for production workers) are associated with more autonomy and a wider span of control, whereas technologies that improve communication (like data intranets) decrease autonomy for workers and plant managers. Using instrumental variables (distance from ERP's place of origin and heterogeneous telecommunication costs arising from regulation) strengthens our results.

Data, as supplemental material, are available at http://dx.doi.org/10.1287/mnsc.2014.2013.

Keywords: organization; delegation; information technology; communication technology; the theory of the firm
History: Received June 25, 2013; accepted January 14, 2014, by John List, behavioral economics. Published online in *Articles in Advance* November 5, 2014.

1. Introduction

A century ago, an ambassador to a distant nation operated as a "viceroy." Given the difficulty of communicating with the home nation, he was empowered to make decisions up to matters of war and peace. Falls in communication costs have arguably turned this powerful job into the equivalent of a glorified salesman. Ambassadors attend many events but rarely make major decisions. In the apt words of Wikipedia, "[Ambassadors] have since been reduced to spokespeople for their foreign offices."[1] On the other hand, the same information and communication technology (ICT) revolution that de-skilled the occupation of the ambassador has been a godsend for nurses. These days a nurse can diagnose a vast number of complaints that previously required a highly skilled physician. Nurses can treat a wide variety of ailments without the patient ever seeing the doctor. How can the same technology that emasculates one job empower another? Are we talking about the same technologies? If ICT empowers individuals such as nurses why does it eliminate the ambassador's ability to make decisions?

Although most economic studies of the effect of ICT on firm organization, inequality, and productivity treat ICT as an aggregate capital stock, in this paper we argue that these technologies have at least two distinct components, information technology (IT) and communications technology (CT). First, through the spread of cheap storage and processing of data, information is becoming cheaper to access (IT). Second, through the

[1] The full phrase in the "Ambassador" entry (http://en.wikipedia.org/wiki/Ambassador, accessed October 11, 2013) of Wikipedia states, "Before the development of modern communications, ambassadors were entrusted with extensive powers; they have since been reduced to spokespeople for their foreign offices."

spread of cheap wired and wireless communications (CT), agents find it easier to communicate with each other (e.g., through email and mobile devices).

We expect these two changes to have very different impacts on firm organization. Cheaper information access acts as a decentralizing or "empowering" force, allowing agents (like the nurses in our example) to autonomously handle more problems. By contrast, cheaper communication technology acts as a centralizing force, substituting the knowledge and decisions of the frontline agents for those at headquarters, so that, like the ambassador in our example, they ultimately perform a more limited variety of tasks. This difference matters not just for how organizations assign decisions and divide labor, but also for productivity and for labor market outcomes, including wages.[2]

To address this empirically, we utilize a new international firm-level data set with directly measured indicators of organization and technologies to study whether ICTs have these distinct effects. Our theoretical starting point is the analysis in Garicano (2000) on the hierarchical organization of expertise. Taking decisions requires solving problems and thus acquiring the relevant knowledge for the decision. When matching problems with solutions is cheap, expertise is organized horizontally: one goes to an electrician for electrical problems. However, when matching problems and solutions is expensive, the organization of knowledge is hierarchical: those "below" deal with the routine problems, and those "above" deal with the exceptions. For example, in a law firm, low-level lawyers handle the document making, and partners add the expert knowledge. Similarly, in the shop floor, lower-level production supervisors deal with routine issues, and the exceptions are handled by plant-level managers.

In determining at what hierarchical level decisions should be made, firms face a trade-off between *information acquisition costs* and *communication costs*. Making decisions at lower levels implies increasing the cognitive burden of agents at those levels. For example, decentralizing the decision whether to invest in new equipment from the corporate headquarters (CHQ) to plant managers requires training plant managers to better understand financial decision making, cash flows, risk, and so on. To the extent that acquiring this knowledge is expensive, the knowledge of the plant manager can be substituted for by the knowledge of those at corporate headquarters. Relying more on the direction of corporate headquarters reduces the cognitive burden on the plant manager and so lowers the total information acquisition costs but increases communication costs. Decentralized decision making thus implies incurring higher costs of information acquisition to economize on communication costs (trading off knowing versus asking for directions).

The level at which decisions are taken thus responds to the cost of acquiring and communicating information. For the ambassador, reductions in the cost of communication allow for a reduction in knowledge acquisition costs through the increasing use of "management by exception"; e.g., local managers rely more on corporate managers for decision making. The ambassador takes his directions from the ministers back home. Reductions in the cost of information access, on the other hand, reduce the cognitive burden imposed by decentralized decision making and make more decentralization efficient, as in our nurse example. Consequently, information and communication technologies affect differently the hierarchical level at which different decisions are taken. Improvements in information technology should push decisions "down," leading to decentralization, whereas improvements in communication technology should push decisions "up," leading to centralization.

In this paper, we study this cognitive view of hierarchy by testing for the differential impact on the organization of firms of these two types of technology (information versus communication). We apply this framework in a world with two types of decisions, production and nonproduction ones.

First, we consider *nonproduction decisions*. These decisions can either be taken at the corporate headquarters or delegated to a business unit (in our case, the plant manager). The specific decisions that we study are capital investment, hiring new employees, new product introductions, and sales and marketing decisions. A key piece of information technology is, as we discuss in §3, enterprise resource planning (ERP). ERP is the generic name for software systems that integrate several data sources and processes of an organization into a unified system. These applications are used to store, retrieve, and share information on any aspect of the sales and firm organizational process in real time. This includes standard metrics like production, deliveries, machine failures, orders, and stocks, but also broader metrics on human resources and finance. ERP systems increase dramatically the availability of information to decision makers in the company.[3] It follows that they should increase the autonomy of the plant manager.

Second, we consider factory floor *production decisions*, such as which tasks to undertake and how to pace them, that can either be taken by production workers themselves or by those higher up in the plant hierarchy.

[2] Information access and communication technology changes can be expected to affect the wage distribution in opposite directions, as Garicano and Rossi-Hansberg (2006) show theoretically.

[3] We present survey evidence consistent with our discussions with technology experts that ERP primarily reduces information acquisition costs rather than reducing communication costs (see the online appendix).

Here, a key technological change in the manufacturing sectors is the introduction of computer-assisted design/computer-assisted manufacturing (CAD/CAM). Again, the impact of information technology here is that it allows workers to solve a wide range of production problems, so that they need less access to their superiors to inform their decisions. Thus, this technology should increase worker autonomy and, by reducing the amount of help that workers need from plant managers, increase the span of control of plant managers. In summary, we expect "information technologies" (ERP and CAD/CAM) to decentralize decision making, respectively, in nonproduction decisions (from CHQ to plant managers) and in production decisions (from plant managers toward production workers).

On the other hand, as we argued above, we expect *communication technologies* to increase centralized decision making. This will be true for both types of decision discussed above, so that these technologies will centralize decisions previously taken by production workers (so that plant managers will take more of their decisions) and by plant managers (so that the corporate headquarters will take more of their decisions). A key technological innovation affecting communication is the growth of intranets. We test whether the availability of intranets reduced the decision-making autonomy in production decisions of workers and in nonproduction decisions of managers.

We utilize a new data set that combines manufacturing plant-level measures of organization and ICT across the United States and Europe. The organizational questions were collected as part of our own management survey work (see Bloom and Van Reenen 2007) and were asked to be directly applicable to the theories we investigate. The technology data set is from a private sector data source (Harte-Hanks Ci Technology Database, http://www.europe.hartehanksmi.com/citdb_europe.htm) that has been used mainly to measure hardware utilization in large publicly listed firms (e.g., Bresnahan et al. 2002). We use computer hardware as a control, but we focus on the less-used software components of the survey, where clearer distinctions can be made between information technologies and communication technologies.

In terms of identification, we are guided by the theory to focus on the conditional correlations between the different ICT measures and three dimensions of firm organization: (i) decentralization from headquarters to plant manager, (ii) decentralization from plant manager to workers, and (iii) the plant manager's span of control. However, we also consider two instrumental variable strategies to take into account the possible "endogeneity" of investments in ICT. First, we use the distance from Walldorf, Germany, where the SAP company originated and which remains the location of its headquarters, as an instrument for ERP presence. *SAP* was the first major ERP vendor and is still the market leader. This draws on the general observation, which is true in our data, that the diffusion of an innovation has a strong geographical dimension.[4] Second, we utilize the fact that the differential regulation of the telecommunication industry across countries generates exogenous differences in the effective prices of intranets. We show that industries that exogenously rely more on intranets are at a greater disadvantage in countries with high communication costs, and we use this to identify the effect of communication costs on decentralization. Our instrumental variable (IV) results support a causal interpretation of the effect of ICT on firm organization.

In short, the evidence is supportive of the theory. Technologies that lead to falling information costs for nonproduction decisions (like ERP) tend to empower plant managers (relative to the headquarters), and technologies that lead to falling information costs for production decisions (like CAD/CAM) tend to empower workers relative to plant managers. Information technologies also widen the plant manager's span of control. By contrast, technologies that reduce communication costs (like intranets) lead to more centralization and have ambiguous effects on the span of control both in the theory and in the data.

Much previous empirical work on this topic has tended to aggregate all ICT together because of data constraints, often simply measured by computers per person or "ICT capital." As noted above, this is problematic since hardware will simultaneously reduce information and communication costs, and we show that these should have very different effects on firm organization. One strand of the literature also looks for complementarities between ICT and organizational aspects of the firm but typically takes organization as exogenous.[5] A second branch of the literature treats organizational form as an endogenous outcome, but

[4] Examples of how geographical proximity is important for diffusion include Skinner and Staiger (2007), Griffith et al. (2011), Holmes (2011), and (for a survey) Foster and Rosenzweig (2010). Becker and Woessmann (2009) use distance from Wittenberg as an instrument for the spread of Protestantism in Germany, which they show fosters human capital. Note that in our regressions we control for human capital, so this cannot be driving the results.

[5] For example, research in the information systems field suggests that ICT (in aggregate) should be associated with increased centralization because of its impact on coordination costs (Malone et al. 1987, McElheran 2014), informational economies of scale (Brynjolfsson 1994), and increased speed and quality of decision making (Gurbaxani and Whang 1991). However, others suggest that ICT may complement decentralization thanks to its effects on monitoring and performance measurement ability (Gurbaxani and Whang 1991), or when there is a need for local agility and adaptation (Sambamurthy and Zmud 2000, McElheran 2014), and when specific knowledge resides at the edges of the organization (Hitt and Brynjolfsson 1997). Overall, this literature suggests that firms might require a hybrid of both

does not discriminate between types of ICT.[6] A third branch, which we are perhaps closest to, looks more closely at the effects of ICT on organization but does so in the context of a single industry in a single country.[7] What is unique about our study is the disaggregation of types of ICT and organization across a number of industries and countries.

An alternative to our cognitive perspective is that hierarchies may be a solution to incentive problems (e.g., Jensen and Meckling 1992, Aghion and Tirole 1997, Dessein 2002), linked to automation (Autor et al. 2003), or result from coordination issues (Crémer et al. 2007, Alonso et al. 2008). Although we do not reject the potential importance of other mechanisms, we think our information perspective is first order and provide some empirical support for this in a range of robustness tests.[8]

We proceed as follows. In §2 we discuss a basic theoretical framework that allows us to study the impact of information and communication technologies. We then discuss our data (§3) and map the model to the data by focusing on some key factors that affect information and communication costs. Finally, we discuss possible alternative mechanisms driving the relationship between the technological variables and the organizational outcomes that we consider (§4) and present our results (§5). The final section (§6) offers some concluding comments.

2. Theory: The Race Between Communication and Information Technology

Garicano (2000) proposes a theory of a hierarchy as a cognitive device. In the model the role of hierarchy is to facilitate the acquisition of knowledge by increasing its utilization rate. Here we present a simplified version of that theory to help frame the empirical analysis.

Assumption 1 (Production Requires Time and Knowledge). *Each production worker draws a unit mass of problems (or tasks or decisions) in* $[0, 1]$ *per unit of time. Production only takes place if all the problems are dealt with by someone in the organization. We normalize to* 1 *the output per agent and per unit of time once problems are solved. Some problems occur more often than others: problems are distributed according to a density function* $f(z)$. *Agents can only deal with a problem or task if they have the relevant knowledge.*

Assumption 2 (Knowledge Acquisition Is Costly). *The cost incurred by an agent* i *to acquire the knowledge necessary to deal with problems in* $[0, z]$ *is proportional to the length of the interval of problems* $a_i z$. *The information acquisition cost parameter* a_i, *which is individual specific, may depend on the technology available to different agents and their skill. Thus an agent who acquires the information required to perform all the tasks in* $[0, 1]$ *incurs a cost* a_i *and produces net output* $1 - a_i$.[9]

Assumption 3 (Knowledge Can Be Communicated). *Managers can be used to provide directions and thus economize on the knowledge that must be acquired by production workers. Specifically, the cost of training agents can be reduced through a hierarchy in which production agents deal with only a fraction of problems—i.e., those in* $(0, z_p)$*—and ask for help on the rest from an agent* m *(for manager) who is specialized in problem solving. A communication or helping cost* h *is incurred by managers whenever their help is sought; i.e.,* h *is incurred per question posed. Clearly, communication is minimized if workers learn the most common problems and ask for help on the rest; thus, without loss of generality, we reorder problems so that* $f'(z) < 0$; *i.e., more common problems have a lower index and are performed by workers. In other words, "management by exception" is optimal, so that workers do routine tasks and managers deal with the exceptions.*[10] *Figure* 1 *illustrates this task allocation.*

The value of problem solvers or managers is that, by reducing lower-level workers' decision range, the cost of acquiring information is reduced. The cost of hierarchy is the time wasted in communication, since problem solvers do not produce output but instead use their time to help others to solve their problems.

Suppose a team must deal with N problems per unit of time. The team needs N production workers

centralization and decentralization (Sambamurthy and Zmud 2000) to obtain the maximum benefit from ICT (Gu et al. 2008). Examples in personnel economics include Black and Lynch (2001), Bresnahan et al. (2002), Bartel et al. (2007), and Bloom et al. (2012a). See also the survey in Draca et al. (2007).

[6] For example, see Acemoglu et al. (2007), Caroli and Van Reenen (2001), Colombo and Delmastro (2004), and Aubert et al. (2006). To explain the evidence for trend delayering described in Rajan and Wulf (2006), Guadalupe and Wulf (2008) emphasise competition rather than ICT.

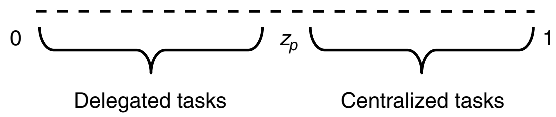
[7] See, for example, Baker and Hubbard (2004), Garicano and Heaton (2010), or the case studies in Blanchard (2004).

[8] Our work also relates to the wider theoretical literature on firm delegation. For example, see Baron and Besanko (1992), Melumad et al. (1995), Baker et al. (1999), Radner (1993), and Hart and Moore (2005).

[9] The cost of information acquisition was denoted "c" in earlier versions to be consistent with Garicano (2000). The change in notation here was made to avoid confusion with communication, or helping, cost "h." We assume that the cost of learning is linear so that learning z problems costs az. This is without loss, because we can redefine problems of tasks so that $f(z)$ is the frequency of a renormalized (equal-cost) problem.

[10] See Garicano (2000) for a formal proof. In that paper, there are potentially many layers of problem solvers, and organizations can decide which problems to do and which ones not to deal with at all, whereas here all problems must be solved. It is shown that the organization set up in the model (characterized by "management by exception") is optimal. Intuitively, if those lower in the hierarchy learned exceptions (rather than routine tasks), the tasks could be swapped, reducing communication costs. Here, in our basic model, there are only two layers and all problems are (eventually) solved; the only choice is who learns the solution. The model with two types of problems in §3.2 extends the framework in Garicano (2000).

Figure 1 Delegation of Tasks in the Basic Model



Note. $z \in [0, z_p]$, tasks performed by lower-level agents; $z \in (Z_p, 1]$, passed on to the higher level.

in layer 0 and n_m managers or problem solvers. The profits generated by this hierarchy, with N production workers each receiving a wage w_p, and n_m managers specialized in "problem solving" or "helping" each receiving a wage w_m, is as follows:[11]

$$\pi = N - N(a_p z_p + w_p) - n_m(a_m z_m + w_m); \qquad (1)$$

that is, when the N production workers deal with problems in $[0, z_p]$ they must learn the z_p most common problems. We further assume (although it is unnecessary for the results) that the learning technology is such that managers know all the tasks that workers also know, and more, so that knowledge overlaps.[12] Thus, since all tasks must be dealt with, $z_m = 1$. A production agent can deal with a fraction $F(z_p)$ of the tasks and asks for help with probability $(1 - F(z_p))$. Thus, a manager spends time $h(1 - F(z_p))$ helping each production worker. Since there are N agents, the needed number of managers or problem solvers is $Nh(1 - F(z_p)) = n_m$, resulting in a span or ratio of workers per manager of $s = N/n_m$. This time constraint determines a trade-off between what the agents below can do and how many managers are needed. The more knowledge is acquired by lower-level agents, the fewer managers are needed. Figure 2 provides an overview of the model.

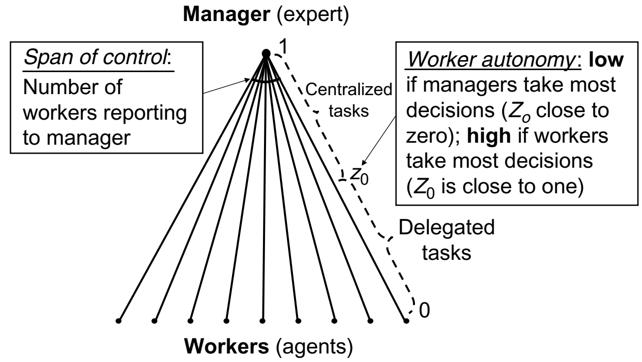
The problem of the firm is to decide the size or span of the hierarchy (s) and the degree of worker autonomy (z_p) so as to maximize profits per problem. Substituting for n_m in Equation (1), we obtain

$$\pi^* = \max_{z_p} [N(1 - (a_p z_p + w_p) - h(1 - F(z_p))(a_m + w_m))].$$

The comparative statics below follow immediately.

Proposition 1 (Cheaper Communication Centralizes; Cheaper Information Access Decentralizes). 1. *A drop in communication (or helping) costs (h) reduces worker autonomy (z_p) and has an ambiguous impact*

Figure 2 Management Span and Autonomy



on span of control $s = N/n_m$ (i.e., more questions are asked, but each one takes less time).

2. *A reduction in the cost of acquiring information of all agents ($a = a_m = a_p$), or one affecting only lower-level agents (a_p), increases lower-level autonomy (z_p) and increases managerial span of control, s (i.e., fewer questions are asked).*

The formal proof of the above is straightforward. Note first that $f'(z) < 0$ implies that the second-order condition for optimization is met, $\partial^2\pi/\partial z_p^2 < 0$. Then the first result follows from the fact that $\partial^2\pi/(\partial z_p \partial h) > 0$. Second, letting $a_p = a_m = a$, we have that at the optimum (using the first-order conditions) $\partial^2\pi/(\partial z_p \partial a) < 0$. Similarly, $\partial^2\pi/(\partial z_p \partial a_p) < 0$; i.e., if workers can learn cheaper they do more. The changes in span follow straightforwardly from $s = N/n_m = 1/(h(1 - F(z_p)))$.

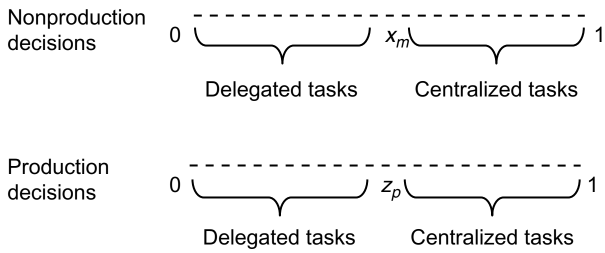
The intuition for these results is as follows. (1) Cheaper communication cost lowers the value of additional worker knowledge, since that economizes on communication. (2) Cheaper information acquisition costs for all agents lowers the value of asking questions for workers, since the role of asking questions is to economize on expensive information acquisition. In summary, although communication cost reductions facilitate the reliance on specialist problem solvers and decrease what each worker can do (centralize knowledge/information), reductions in the cost of acquiring information make learning cheaper and reduce the need to rely on specialized problem solvers for help with solutions (decentralize knowledge/information).

In a working paper version of this paper (Bloom et al. 2013), we extend this model to a setting with different types of decisions: production and nonproduction decisions. We show that the same comparative statics that govern the allocation of production decisions between production workers and managers also hold for the allocation of nonproduction decisions between the plant manager and the company head. That is, we can equivalently interpret the theoretical result in the proposition above by simply relabeling the workers and managers as, respectively, middle managers and corporate headquarters.

[11] We are solving throughout for the partial equilibrium effects (taking wages as given) as is common in the literature (see, e.g., Milgrom and Roberts 1990). For a general equilibrium analysis with heterogeneous workers (i.e., where wages are adjusting), see Garicano and Rossi-Hansberg (2006).

[12] This overlapping knowledge assumption is used because it seems more reasonable in the empirical context, but it is irrelevant for the comparative statics in the propositions here, as can be seen by replacing $h(1 - F(z_p))(a_m + w_m)$ with $h(1 - F(z_p))(a_m(1 - z_p) + w_m)$. Overlapping knowledge could result from learning that takes place on the job or because the process of learning involves learning the "easy" tasks first.

Figure 3 Delegation of Tasks in the Extended Model



Notes. This figure generalizes Figure 1, where we allow for nonproduction decisions and production decisions. Nonproduction decisions below x_m are performed by plant managers, the rest by corporate headquarters. Production decisions below z_p are performed by production workers, the rest by plant managers.

The crucial insight in either case is that a technology that lowers information costs increases the autonomy of the lower-level agent (a worker in the production case, a plant manager in the nonproduction case), whereas a technology that lowers communication costs reduces this autonomy. Figures 3 and 4 graphically show this link.

Table 1 summarizes the comparative statics that our model predicts concerning the impact of the relevant information costs and communication costs on the autonomy of workers and plant managers. We have thus six predictions to take to the data for the impact of either communication or information costs on worker and plant manager autonomy and plant manager span.

3. Data

We use a new international micro data set combining novel sources from the United States and several European countries to test the empirical relevance of the model presented in §2. Our two main sources of data are the CEP management and organization survey and the Harte-Hanks ICT panel. We also match in information from various external data sources such as firm-level accounting data and industry and macroeconomic data. The full data set plus all Stata do files are available at http://dx.doi.org/10.1287/mnsc.2014.2013 (also at http://www.stanford.edu/~nbloom/bsgv.zip).

3.1. The CEP Management and Organization Survey

3.1.1. Overview. In the summer of 2006, a team of 51 interviewers ran a management and organizational practices survey from the CEP at the London School of Economics covering over 4,000 firms across Europe, the United States, and Asia. In this paper we use data on approximately 1,000 firms from the United States, France, Germany, Italy, Poland, Portugal, Sweden, and the United Kingdom, for which we were able to match the organization data with ICT data from Harte-Hanks (which only has data on a subsample of our countries). The online appendix (available at http://dx.doi.org/10.1287/mnsc.2014.2013) provides detailed information on our sources, but we summarize relevant details here.

The CEP survey uses a double-blind technique developed in Bloom and Van Reenen (2007) to try to obtain unbiased accurate responses to the survey questions. One part of this double-blind methodology is that managers are not told they were being scored in any way during the telephone survey. The other part of the double-blind methodology is that the interviewers know nothing about the performance of the firm

Figure 4 Information and Communication

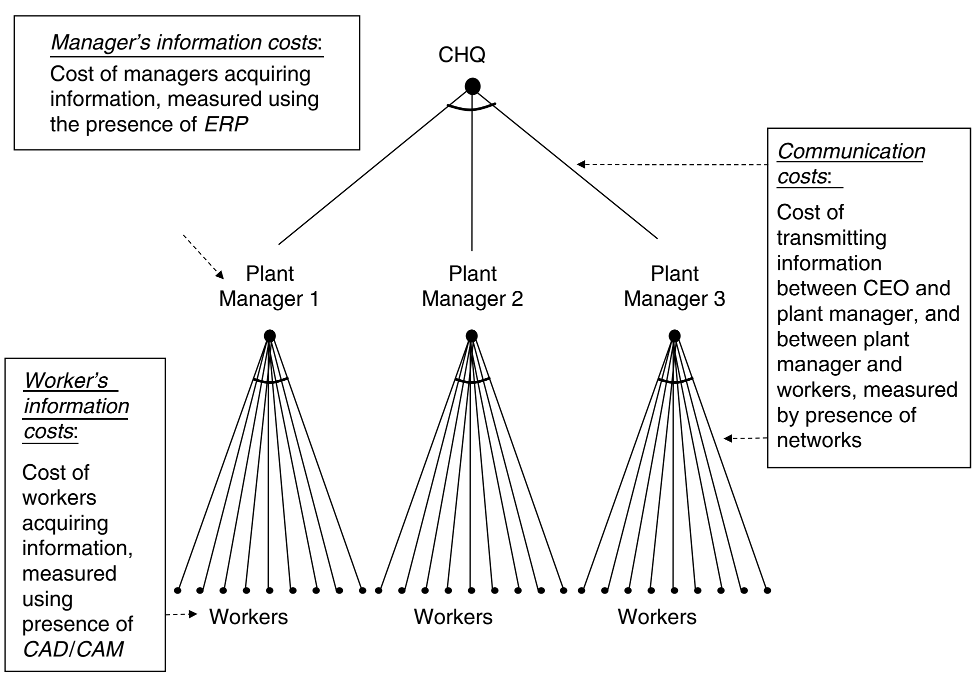


Table 1 Summary of Main Theoretical Predictions That We Empirically Test

	(1) Plant manager autonomy (Table 3)	(2) Worker autonomy (Table 4)	(3) Plant manager span of control (Table 5)
Reduction in communication costs (*h*)			
Technology indicator	*INTRANET*	*INTRANET*	*INTRANET*
Theoretical prediction	−	−	?
Empirical finding	−	− (insig.)	− (insig.)
Reduction in information acquisition costs (*a*)			
Technology indicator	*ERP*	*CAD/CAM*	*CAD/CAM*
Theoretical prediction	+	+	+
Empirical finding	+	+	+

Notes. This table presents the theoretical predictions and the empirical findings. Column (1) refers to plant manager autonomy, column (2) refers to worker autonomy, and column (3) refers to span of control (for plant manager). *INTRANET* denotes the presence of an intranet (leased line/frame relay), *ERP* denotes the presence of enterprise resource planning, and *CAD/CAM* denotes the presence of computer-assisted design/computer-assisted manufacturing. A "+" denotes an increase, a "−" denotes a decrease and "?" denotes an ambiguous sign. All empirical coefficients are statistically significant at the 5% level except those marked ("insig.").

because they are not given any information except the name of the company and a telephone number. Since these firms are medium sized, there will be effectively no large household names.

The survey is targeted at plant managers in firms randomly drawn from the population of all publicly listed and private firms in the manufacturing sector with between 50 and 5,000 employees. We had a response rate of 45% that was uncorrelated with firm profitability or productivity overall and is the sample we focus on in this paper. The interviews took an average of 45 minutes with the interviewers running an average of 78 interviews each, over a median of three countries, allowing us to remove interviewer fixed effects. We also collected detailed information on the interview process, including the interview duration, date, time of day, day of the week, and analyst-assessed reliability score, plus information on the interviewees' tenure in the company, tenure in the post, seniority, and gender. We generally include these variables plus interviewer fixed effects as "noise controls" to mitigate measurement error.

3.1.2. Measuring Plant Manager Autonomy. As part of this survey we asked four questions on plant manager autonomy. First, we asked how much capital investment a plant manager could undertake without prior authorization from the corporate headquarters. This is a continuous variable enumerated in national currency (which we convert into U.S. dollars using purchasing power parity). We also asked where decisions were effectively made in three other dimensions: (a) the hiring of a new full-time permanent shop floor employee, (b) the introduction of a new product, and (c) sales and marketing decisions. These more qualitative variables were scaled from a score of one, defined as all decisions taken at the corporate headquarters, to five, defined as complete power ("real authority") of the plant manager, and intermediate scores were defined as varying degrees of joint decision making. In Table A.2 in the appendix, we detail the individual questions (D1–D4) and scoring grids in the same order as they appeared in the survey.

Since the scaling may vary across all of these questions, we converted the scores from the four decentralization questions to z-scores by normalizing each score to have a mean of zero and standard deviation of one. In our main econometric specifications, we take the unweighted average across all four z-scores as our primary measure of overall decentralization.[13] These results are robust to other weighting schemes and when the questions are disaggregated into their component parts.

3.1.3. Measuring Worker Autonomy. During the survey we also asked two questions about worker autonomy over production decisions regarding the pace of work and the allocation of production tasks. These questions were taken directly from Bresnahan et al. (2002) and are reported in Table A.2 (questions D6 and D7). These questions are scored on a scale of one to five, with a one denoting that managers have full control, and a five denoting that workers have full control over the pace of work and allocation of tasks. Our measure of workers' autonomy is a dummy taking a value of one whenever decisions on both pace of work and allocation of production tasks are mostly taken by workers (i.e., both variables take values higher than three[14]). Again, we experiment with other functional forms.

3.1.4. Measuring Span of Control. We also asked about the plant manager's span of control in terms of the number of people he directly manages, as reported in Table A.2 (question D8). The interviewers were explicitly trained to probe the number of people that

[13] The resulting decentralization variable is itself normalized to mean of zero and standard deviation of one.

[14] Decisions on the pace of work are taken mostly by workers 11% of the time. Similarly, decisions on the allocation of production tasks are taken mostly by workers 12% of the time.

Table 2 Summary Statistics

Variable	Mean	Median	Standard deviation	Firms
Employment (*firm*)	962	350	3,256	945
Employment (*plant*)	250	153	276	912
Plant manager autonomy	0.255	0	0.982	950
Worker autonomy	0.076	0	0.265	937
ln(*Plant manager span*)	1.891	2	0.523	875
CEO span (multiplant dummy)	0.640	1	0.480	950
Computers per employee	0.496	0	0.358	937
ERP	0.340	0	0.390	950
CAD/CAM	0.030	0	0.154	614
INTRANET	0.358	0	0.396	950
LAN/WAN	0.475	0	0.456	930
Foreign multinational	0.349	0	0.477	950
Domestic multinational	0.286	0	0.452	950
%College	15.882	10	17.041	870
Bonus as a % of salary	0.112	0	0.151	863
% Salary increase on promotion	0.214	0	0.189	611
Leased line price (PPP 2006 USD)	4,985	5,260	1,438	950
ln(*Distance from Walldorf*)	6.862	7	1.150	950

Notes. These are descriptive statistics from the sample in Table 3 (except for *CAD/CAM*, which is from the sample in Table 4). The mean of plant manager autonomy is not zero because it was z-scored over the (larger) CEP sample.

directly report to him rather than the total number in the hierarchy below him. Unfortunately, we do not have such a direct measure of CHQ span (since we did not interview the CEO). However, we try to get a sense of senior management's (CHQ) span of control by asking about whether the firm was a single or multiplant firm, with the idea that multiplant firms lead to larger spans at the senior management level.

3.1.5. Other Data. In addition to the organizational variables, the CEP survey also provides a wide variety of other variables such as human capital, demographics, and management practices. Also, since the CEP survey used accounting databases as sampling frames from the Bureau van Dijk (BvD) (Amadeus in Europe and Icarus in the United States), we have the usual accounting information for most firms, such as employment, sales, industry, location, etc. Table 2 contains some descriptive statistics of the data we use. In the largest sample, we have 950 plants with mean employment of 250 employees (153 at the median).

3.2. ICT Data

We use a plant-level ICT panel database produced by the information company Harte-Hanks (HH). HH is a multinational firm that collects detailed hardware and software information to sell to large ICT firms, like IBM and Cisco, to use for marketing. This exerts a strong market discipline on the data quality, because major discrepancies in the data are likely to be rapidly picked up by HH customers. For this reason, HH conducts extensive internal random quality checks on its own data, ensuring a high level of accuracy.

The HH data have been collected annually for over 160,000 plants across Europe since the late 1990s. They target plants in firms with 100 or more employees, obtaining a 37% response rate. We use the data for the plants we were able to match to the firms in the management survey. Since this matching procedure sometimes leads to multiple plants sampled in HH per firm, we aggregate ICT plant-level data pooled across 2000–2006 (i.e., prior to the CEP organization survey) to the firm level, using plant employment weights. A number of papers, such as Bresnahan et al. (2002), Brynjolfsson and Hitt (2003), Beaudry et al. (2010), and Forman et al. (2011), have previously used the U.S. HH hardware data, but few papers have used the software data. Certainly no one has combined the software data with information on organizational form in a single country, let alone internationally as we do here.

The prior literature has typically used information on firms' aggregate ICT capital stock covering PCs, servers, and infrastructure, but since these simultaneously reduce information and communication costs we do not expect a clear result. Our approach consists instead in considering the presence of three specific technologies that differentially affect the cost of information access and the cost of communication within the organization. Concerning communication (or helping) costs, we focus on the introduction of intranets. Concerning information access costs, we focus on the widespread adoption of CAD/CAM technologies and the introduction of large, real-time, connected databases, most notably in the form of enterprise resource planning (ERP) systems.

The reason we focus on these three technologies is that they are major advances in the manufacturing sector that we study, as well as other sectors like retail, wholesale, and banking.[15] We also believe that they map clearly into reductions in communication costs (INTRANET) and reductions in information acquisition costs in production (CAD/CAM) and management (ERP), as we discuss in detail in the appendix. In summary, our hypotheses concerning these variables, given the model presented in §2, are as follows.

- Falling information acquisition costs for nonproduction decisions (with ERP as proxy) are predicted to raise autonomy for plant managers.
- Falls in information acquisition costs for production decisions (proxied by CAD/CAM) are predicted to increase both worker autonomy and plant manager's span (i.e., they can manage more workers if these workers are making more of their own decisions).
- Finally, falling communication costs (with INTRANET as proxy) have negative effects on autonomy and ambiguous effects on spans (i.e., each worker does more but will ask more questions).

[15] This is based on reviewing the literature; U.S., UK, China, and India factory visits; and discussions with engineers and consultants at Sun Microsystems, EDS, Hewlett-Packard, McKinsey, and Accenture.

This is depicted in relation to the models in Figures 2 and 4.

In practice, the presence of any of these technologies at the plant level is codified by using binary variables, and plant-level employment weights are used to generate firm-level indicators.[16] The technologies are measured as follows.

- HH distinguishes up to 17 distinct types of ERPs: the market leader is SAP, but Oracle, IBM, and many others all offer products in this space. HH tries to record only ERP systems in operation (rather than those pending the go-live decision), which Aral et al. (2012) highlight as important.
- HH defines under "workstation applications" the presence of CAD/CAM, software tools that assist production workers, engineers, and machinists.
- HH measures the presence of leased lines or frame relays (INTRANET), which are technologies used by businesses to connect offices or production sites.[17] We have, in some years, direct information on local area networks (LAN) and wide area networks (WAN) and find these both to be highly correlated with our INTRANET variable. In the robustness tests, we show the similarity of results when using this as an alternative proxy for intranets.

In terms of other technologies, we condition on computers per worker, but note its theoretical ambiguity.

4. Alternative Theoretical Channels

Before moving to the empirical results, we present a brief discussion of alternative channels through which ICT could affect the allocation of decisions and span and how we might distinguish them from the information approach we emphasize in this paper. We first investigate their impact on coordination costs absent incentive considerations; in the next subsection we discuss the possible impact on delegation through the reduction in informational asymmetries.

[16] The resulting variables have mass points at zero or one. We present robustness tests using just the discrete versions of these technology indicators.

[17] A leased line is a symmetric telecommunications line connecting two locations. It is sometimes known as a "private circuit" or "data line." Unlike traditional public switched telephone network lines, a leased line does not have a telephone number, because each side of the line is permanently connected to the other. Leased lines can be used for telephone, data, or Internet services. Frame relay is a data transmission technique used to send digital information (data and voice) cheaply and quickly, which is often used in local and wide area networks. These systems are predominantly used to manage internal communication systems. They are not specifically about production or nonproduction decisions but affect communication through out the firm.

4.1. Coordination

ICTs could affect centralization by reducing coordination costs.[18] This is more likely to be true of both ERP and INTRANET, but probably less so of CAD/CAM. By unifying multiple previously unrelated databases, ERP facilitates coordination between independently operated business units. In fact, by creating a common language, ERP may facilitate the substitution of "horizontal" or peer-to-peer communication for "hierarchical/vertical" communication, as Crémer et al. (2007) have noted. As a result, if coordination across units becomes easier and less hierarchical, we could also expect (similar to the effect we predict in our theory) that ERP results in "empowerment" and decentralization as managers of business units coordinate with their colleagues without going through central management.

A communication technology such as INTRANET would have a similar effect: it would also allow local managers to more easily coordinate with one another without the intervention of corporate headquarters. In this case, the effect is however *opposite* to what we expect in our theory: more centralization when communication, rather than information, technology improves. Thus, our empirical analysis does allow us directly to separate the two hypotheses, since they have opposite predictions for decentralization.

In other words, the coordination perspective does not result in a sharp distinction between technologies that reduce information costs (like ERP and CAD/CAM) and those that reduce communication costs (INTRANET). Both reduce coordination costs and thus predict the same impact on decentralization (increased). The data will allow us to differentiate the coordination costs perspective from ours, since we expect changes in information and communication costs to have different impacts on organizational outcomes.

We shall also provide several direct tests of the coordination hypothesis (reported in Table A.3 in the appendix and discussed in §5.2.2). Our tests rely on the observation that, if technology is affecting centralization through its impact on coordination, its impact must be higher where coordination needs are particularly relevant, as Hart and Moore (2005) have argued. We study three environments in which we have a priori reasons to expect coordination to matter more: (i) when the firm is a multinational, (ii) when the firm operates in multiple industries, and (iii) when the headquarters and the plant are located separately. We do not find that our results are any different across these three environments.

[18] A large literature focuses on the importance of coordination in organizations, including Hart and Moore (2005), Dessein and Santos (2006), and Crémer et al. (2007).

4.2. Agency and Incentives

Information and communication technologies could also affect the allocation of decisions by reducing informational asymmetries. As Jensen and Meckling (1992) have argued, delegation allows decisions to be taken by those with better information but at the cost that their preferences differ from those of the top management.[19] Centralization trades off less-biased decisions against worse information. If ICT broadly improves the information available at the center then it should make centralization more preferred.

Again, delegation theory's predictions differ clearly from ours in that they do not allow us to make a distinction between information and communication technology. If both reduce informational asymmetries, they both should produce the same effect: more centralization.

More subtly, technologies such as ERP may affect either (or both) output or input monitoring. As Prendergast (2002) showed, a technology that results in better measures of output will increase delegation, because incentives can be used to align decision making. On the other hand, a technology that facilitates monitoring of inputs will reduce delegation. Specific technologies, and specific instances of the technology, may have stronger impact on inputs or on outputs. For example, Baker and Hubbard (2004) have argued that a specific piece of ICT, the on-board computers used in trucks, decreases the cost of monitoring a trucker's level of care in driving (an input). As a result, these on-board computers induced an increase in vertical integration (fewer incentives and less delegation).

We do not have clear prior indications on whether our technologies affect monitoring of inputs or of outputs. Since the CEP survey also includes information on the percentage of plant manager salary that is linked to individual, team, or firm performance, we can explicitly test whether this effect is driving our results by controlling in our regressions for the impact of ICT on delegation holding incentive pay constant.

4.3. Automation

Autor et al. (2003) have argued that the key way ICT impacts the division of labor is through automation. Essentially, their argument is that the routine tasks of both low human capital workers (like assembly line workers) and higher human capital workers (like bank clerks) have been replaced by computerization and do not have to be either learned or undertaken by workers or managers. In a bank, for example, information technology allows for automatic sorting of checks.

We can extend our model to deal with this type of mechanism. Specifically, suppose that a worker is in charge of tasks z_0, the machine is in charge of tasks m, and the manager of tasks $1 - z_0 - m$. The impact of automation is to increase the number of tasks m undertaken by the machine. Straightforward comparative statics show that the number of tasks undertaken by a worker is reduced as the machine does the more routine tasks. Thus, a worker does $z_0 - m$ tasks compared to z_0 tasks before, while in this simple setting the manager continues to do $1 - z_0$ tasks, thereby reducing the share of tasks carried out by worker. The reason is that the marginal value of learning an additional task does not get increased by the machine doing the most routine task, so z_0 stays constant.

Our data allow testing for the impact of this channel since, if any of our ICT measures is having an impact through automation, this will reduce the number of tasks done by lower-level agents, reducing their autonomy. By contrast, our perspective predicts increases in the number of tasks done by lower-level agents in response to falls in information acquisition costs. Another distinguishing feature of our theory is that we obtain specific predictions on the impact of intranets, on which the automation perspective is largely silent.

5. Empirical Results

5.1. Econometric Model

We wish to estimate the following equation,

$$O_{ijk} = a_{ijk} + h_{ijk} + x'_{ijk}\gamma + u_{ijk}, \tag{2}$$

where the dependent variable is O_{ijk}, which denotes the organizational form of firm i in industry j in country k. Our theory offers predictions over three types of organizational outcomes for which we have data: the autonomy of the worker ($O = \text{AW}$), the autonomy of the plant manager ($O = \text{AP}$), and the span of control of the plant manager ($O = \text{SP}$). As in the theory, a denotes information access costs and h denotes communication (helping) costs. The term x_{ijk} denotes other control variables, and u_{ijk} is a stochastic error term—we will discuss these in more detail later.

As discussed in the data section, we have direct measures of workers' autonomy, plant manager's autonomy, and plant manager's span of control from our survey. The management autonomy questions investigate the extent of "nonproduction" autonomy that the plant manager has from the corporate headquarters (e.g., how much investment could be made without corporate headquarters' approval). The worker autonomy questions relate to decisions the worker could have control over compared to the plant manager (e.g., setting the pace of work).

The information costs and communication costs facing the firm are not directly observable, but we

[19] Dessein (2002) and Alonso et al. (2008) formalize this analysis and also allow for communication between the boss and his subordinates.

substitute the relevant indicator from HH (INTRANET lowers h, and ERP and CAD/CAM lower a). To be more explicit, the three regressions we will estimate are as follows:

autonomy of the plant manager (AP),

$$AP_{ijk} = \alpha^{AP} ERP_{ijk} + \beta^{AP} INTRANET_{ijk} + x'_{ijk}\gamma^{AP} + u^{AP}_{ijk}; \quad (3)$$

autonomy of the worker (AW),

$$AW_{ijk} = \alpha^{AW}(CAD/CAM)_{ijk} + \beta^{AW}_{ijk} INTRANET_{ijk} + x'_{ijk}\gamma^{AW} + u^{AW}_{ijk}; \quad (4)$$

span of control of the plant manager (SP),

$$\ln(SP_{ijk}) = \alpha^{SP}(CAD/CAM)_{ijk} + \beta^{SP}_{ijk} INTRANET_{ijk} + x'_{ijk}\gamma^{SP} + u^{SP}_{ijk}. \quad (5)$$

Recall that Table 1 contains the main theoretical predictions of the model that we have sketched together with the technologies we are using. Falls in information acquisition costs are associated with greater plant manager autonomy and worker autonomy and larger spans of control. By contrast, falls in communication costs are associated with decreases in autonomy and ambiguous effects on spans.

In the empirical implementation of these equations, we are *not* assuming that each of the three observable technologies affects *only* information costs or *only* communication costs. Rather, we are merely assuming that each technology has a *relatively* larger effect on a or on h. For example, following the discussion in the previous section, we claim that ERP has a stronger effect on reducing information access costs than reducing communication costs. Hence, consider a simplified managerial autonomy equation $AP = -a + h$ with the parameterization $a = -\eta_1 ERP - (1-\eta_1)NETWORK$ and $h = -(1-\eta_2)ERP - \eta_2 NETWORK$ with weights $1 \geq \eta_1,\ \eta_2 > \frac{1}{2}$. Substituting these into Equation (2) implies that in Equation (3), $\alpha^{AP} = \eta_1 + \eta_2 - 1 > 0$ and $\beta^{AP} = 1 - \eta_1 - \eta_2 < 0$. These are the qualitative predictions we test.

We have a rich set of controls to draw on (x_{ijk}), although we are careful about conditioning on factors that are also directly influenced by technology. Consequently we consider specifications with very basic controls as well as those with a more extensive vector of covariates. Since there is measurement error in the organizational variables, we generally condition on noise controls that include interviewer fixed effects and interviewee controls (e.g., tenure of manager) and interview controls (e.g., time of day). Other controls include a full set of three-digit industry and country dummies, plant age, skills (share of college-educated workers), firm and plant size, and multinational status. We also perform robustness checks with many other variables suggested in the literature that may potentially confound our key results.

5.2. Basic Results

Tables 3–5 present the main results. Each table has a different dependent variable and corresponds to Equations (3)–(5).

5.2.1. Plant Manager Autonomy. Table 3 contains the empirical results for plant manager autonomy. All columns control for size (the number of employees in the firm and in the plant), multinational status (foreign and domestic multinational with the omitted base as a purely domestic firm), whether the CEO is located on the same site as the plant manager,[20] noise controls (e.g., interviewer dummies) as discussed above, and a full set of country and three-digit industry dummies. Column (1) uses the presence of enterprise resource planning (ERP) as a measure of information acquisition over nonproduction decisions. As the theory predicts, ERP is associated with greater autonomy of plant managers (relative to the corporate headquarters) because the plant manager is allowed greater flexibility in making decisions over investment, hiring, marketing, and product introduction.[21] In our model this is because ERP enables the plant manager to access information more easily and solve more problems without referring them upward. In terms of the other covariates, we find that larger and more complex enterprises (as indicated by size and multinational status) are more likely to decentralize decision making to the plant manager. Column (2) includes firm-level skills, as measured by the proportion of employees with college degrees. The variable takes a positive and significant coefficient, indicating that more skilled workplaces tend to be more decentralized (consistent with Caroli and Van Reenen 2001). This column also includes the computer intensity of a plant, whose coefficient enters with a negative and insignificant sign. The ambiguity of the IT hardware variable is unsurprising because greater computer intensity simultaneously lowers information costs and communication costs, which have opposite effects on autonomy, according to our theoretical model. Despite

[20] All results are robust to dropping size, multinational status, and CEO on-site location controls (results available at http://www.stanford.edu/~nbloom/bsgv.zip). Note that firms wherein the CEO was the same individual as the plant manager are dropped.

[21] We investigate the endogenous quality of the technology variables in depth in Table 6. One initial check on whether the OLS results are upward-biased is to implement a propensity score matching technique. We found that matching strengthened the results. For example in the specification of column (2) of Table 3, the average treatment effect on the treated was 0.194 with a standard error of 0.102. This used nearest-neighbors matching with three neighbors.

Table 3 Plant Manager Autonomy

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:			*Plant manager autonomy*			
ERP	0.150*	0.169*			0.181**	0.192**
	(0.085)	(0.087)			(0.085)	(0.087)
INTRANET			−0.177**	−0.163*	−0.208**	−0.188**
			(0.090)	(0.090)	(0.091)	(0.090)
ln(*Percentage college*)		0.107***		0.104***		0.104***
		(0.033)		(0.033)		(0.033)
ln(*Computers/employee*)		−0.059		−0.025		−0.043
		(0.045)		(0.045)		(0.045)
ln(*Firm employment*)	0.069*	0.058	0.076*	0.068	0.075*	0.065
	(0.042)	(0.043)	(0.041)	(0.043)	(0.041)	(0.043)
Plant employment	0.133***	0.126***	0.133***	0.132***	0.129***	0.125***
	(0.047)	(0.048)	(0.047)	(0.048)	(0.047)	(0.048)
Foreign multinational	0.151*	0.160*	0.193**	0.190**	0.182**	0.184**
	(0.082)	(0.083)	(0.082)	(0.083)	(0.083)	(0.084)
Domestic multinational	0.146*	0.141	0.170**	0.157*	0.165*	0.156*
	(0.086)	(0.087)	(0.087)	(0.088)	(0.086)	(0.087)
Number of observations	1,000	1,000	1,000	1,000	1,000	1,000
Number of firms	950	950	950	950	950	950

Notes. The dependent variable is the *z*-score of plant manager autonomy (mean equals zero and standard deviation equals one) across four questions relating to plant manager's control over hiring, investment, product introduction, and marketing (see text). All columns are estimated by ordinary least squares (OLS) with standard errors in parentheses (clustered by firm). The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the United Kingdom, and the United States (country dummies included). All columns include a full set of three-digit industry dummies, noise controls (interviewer fixed effects, the interviewee's seniority and tenure in company, the day of the week the interview was conducted, and interview duration and reliability), and a variable summarizing the number of Harte-Hanks cross sections over which the technology variables have been computed. Ln(*Percentage college*) is the log of the fraction of plant employees with a college degree. *Foreign* (*Domestic*) *multinational* is a dummy denoting plants belonging to a foriegn (domestic) multinational. *Plant employment* is the ratio of plant employment to firm employment. *ERP* denotes enterprise resource planning, and *INTRANET* denotes that the firm has an internal intranet (leased lines or frame relays). All columns exclude firms where the plant manager is the CEO and include a dummy equal to unity if the CEO is on site. There are more observations than firms because some firms were interviewed more than once across different plants.

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

the extra controls, the coefficient on ERP remains positive and significant at the 10% level.

Column (3) of Table 3 reports the same specification as column (1), but instead of ERP we use an indicator for the presence of intranets, which indicates lower communication costs. There is a negative and significant coefficient on the intranet variable, and our theory suggests that this reflects the fact that lower communication costs imply that corporate headquarters make more decisions than the plant manager because it is now easier to pass on solutions. This result is robust to including skills and computer intensity in column (4). Columns (5) and (6) include both information and communications technologies in the same specification. Since these are positively correlated, the results are stronger with both variables significant and correctly signed.[22] Overall, Table 3 is consistent with the theoretical model sketched earlier: falling information costs are associated with decentralization, whereas falling communication costs are associated with centralization.

[22] The results are robust to clustering at a higher level, such as by industry–country cell. For example, if we cluster the standard errors at this level in the final column of Table 3, the coefficients (standard errors) on ERP and INTRANET are, respectively, 0.192 (0.085) and −0.188 (0.096).

5.2.2. Coordination Costs. As discussed in §4.1, an alternative way in which ICT may affect firm organization is by reducing coordination costs. To the extent that both ERP and INTRANET reduce coordination costs we would expect them to increase the degree of plant manager autonomy. This means that, although coordination is an alternative explanation for the positive ERP coefficient in Table 3, it will make it harder for us to find a negative coefficient on INTRANET. This is contrary to our results that show that ERP tends to result in decentralization (a positive coefficient in Table 3), whereas INTRANETs tend to centralize (a negative coefficient).

Nevertheless, to examine coordination in more depth we consider several indicators of environments where we would expect a priori that coordination costs are more important: (i) when firms operate in multiple countries, (ii) when firms operate across multiple industries, and (iii) when the headquarters and plant are not colocated. We examine this in Table A.3 and do not find much evidence in favor of the idea that coordination costs drive our results. Column (1) reproduces the baseline results, and columns (2)–(4) examine the multinational indicator. Column (2) looks at the subsample of domestic firms, and column (3) looks at multinational firms. The results for domestic firms look like those

Table 4 Worker Autonomy

Dependent variable:	(1)	(2)	(3) Worker autonomy	(4)	(5)	(6)
CAD/CAM	0.930**	0.893**			0.947**	0.915**
	(0.420)	(0.418)			(0.414)	(0.411)
	[0.116]	[0.104]			[0.117]	[0.104]
INTRANET			−0.269	−0.352	−0.285	−0.367
			(0.214)	(0.224)	(0.216)	(0.225)
			[−0.034]	[−0.041]	[−0.035]	[−0.042]
ln(*Percentage college*)		0.290***		0.295***		0.289***
		(0.095)		(0.094)		(0.095)
		[0.034]		[0.034]		[0.033]
ln(*Computers/employee*)		0.138		0.176		0.181
		(0.123)		(0.125)		(0.126)
		[0.016]		[0.020]		[0.021]
ln(*Firm employment*)	0.035	0.032	0.053	0.053	0.041	0.043
	(0.096)	(0.096)	(0.095)	(0.096)	(0.096)	(0.096)
	[0.004]	[0.004]	[0.007]	[0.006]	[0.005]	[0.005]
Plant employment	−0.043	−0.026	−0.027	−0.007	−0.047	−0.023
	(0.122)	(0.127)	(0.123)	(0.127)	(0.123)	(0.127)
	[−0.005]	[−0.003]	[−0.003]	[−0.001]	[−0.006]	[−0.003]
Foreign multinational	0.385*	0.317	0.431**	0.361	0.407*	0.337
	(0.204)	(0.217)	(0.209)	(0.221)	(0.209)	(0.221)
	[0.052]	[0.039]	[0.060]	[0.045]	[0.055]	[0.041]
Domestic multinational	0.206	0.179	0.252	0.229	0.230	0.211
	(0.204)	(0.211)	(0.205)	(0.214)	(0.205)	(0.213)
	[0.027]	[0.022]	[0.034]	[0.028]	[0.030]	[0.026]
Number of observations	649	649	649	649	649	649
Number of firms	614	614	614	614	614	614

Notes. The dependent variable in all columns is a dummy equal to unity if the plant manager reports that task allocation and pace of work are determined mostly by workers (instead of managers). All columns are estimated by probit maximum likelihood (ML) with standard errors in parentheses (clustered by firm). Marginal effects (evaluated at the mean) are reported in square brackets. All columns exclude firms where the plant manager is the CEO and include a dummy equal to unity if the CEO is on site. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the United Kingdom, and the United States (country dummies included). All columns include a full set of three-digit industry dummies, noise controls (interviewer fixed effects, the interviewee's seniority and tenure in company, the day of the week the interview was conducted, and interview duration and reliability), and a variable summarizing the number of Harte-Hanks cross sections over which the technology variables have been computed. Ln(*Percentage college*) is the log of the fraction of plant employees with a college degree. *Foreign* (*Domestic*) *multinational* is a dummy denoting plants belonging to a foriegn (domestic) multinational. *Plant employment* is the ratio of plant employment to firm employment. *CAD/CAM* denotes computer-assisted design/computer-assisted manufacturing, and *INTRANET* denotes that the firm has an internal intranet (leased lines or frame relays). There are more observations than firms because some firms were interviewed more than once across different plants.

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

in the overall sample in column (1). The results in column (3) are actually weaker for ERP, which goes against a coordination story, whereas they are similar for INTRANET. In column (4) we pool the sample and introduce an interaction of the multinational status with ERP and INTRANET and find both are insignificant. Hence, overall there is no evidence that coordination is explaining the impacts of our ICT variables on plant manager autonomy. In columns (5)–(7) of Table A.3, we repeat the same exercise for firms who operate in multiple industries compared to a single industry. Again, the results looks similar across the two subsamples, and neither ERP or INTRANET have a significant interaction with the industry terms. Finally, columns (8)–(10) use an indicator of whether the plant we interviewed is colocated with the headquarters, and again find no evidence of differential.

Overall, then, it does not seem that the pattern of coefficients from ERP and INTRANET is easily accounted for by the coordination costs mechanism. This does not, of course, rule out the importance of coordination issues for Firms, which are generally likely to be important. It simply means that coordination is unlikely to be responsible for generating the covariance patterns between plant manager autonomy and the ICT we examine here.

5.2.3. Worker Autonomy and Managerial Span of Control. Tables 4 and 5 analyze the relationship between information and communication technologies with worker autonomy and plant manager span of control (this follows exactly the order in Table 3).[23] Table 4 is a probit model of workers' autonomy where our indicator of information acquisition over production decisions is CAD/CAM. In columns (1) and (2), the coefficient on CAD/CAM is positive and significant, indicating that such technologies are associated with worker empowerment. In columns (3) and (4), by contrast, the presence of INTRANET has a negative

[23] The number of observations is smaller than that in Table 3 because of missing values for the worker autonomy question.

Table 5 Plant Manager Span of Control

Dependent variable:	(1)	(2)	(3)	(4)	(5)	(6)
	Plant manager span of control					
CAD/CAM	0.253**	0.244**			0.253**	0.244**
	(0.117)	(0.120)			(0.117)	(0.120)
INTRANET			−0.012	−0.016	−0.013	−0.016
			(0.057)	(0.058)	(0.056)	(0.058)
ln(*Percentage college*)		0.042*		0.044*		0.042*
		(0.023)		(0.023)		(0.023)
ln(*Computers/employee*)		0.004		0.006		0.006
		(0.030)		(0.030)		(0.030)
ln(*Firm employment*)	0.062**	0.059**	0.066**	0.063**	0.062**	0.060**
	(0.026)	(0.026)	(0.026)	(0.027)	(0.026)	(0.027)
Plant employment	0.048	0.052	0.052	0.056*	0.047	0.052
	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)
Foreign multinational	0.034	0.025	0.032	0.023	0.036	0.027
	(0.055)	(0.056)	(0.056)	(0.057)	(0.056)	(0.057)
Domestic multinational	0.071	0.066	0.067	0.062	0.072	0.067
	(0.057)	(0.057)	(0.057)	(0.057)	(0.057)	(0.057)
Number of observations	902	902	902	902	902	902
Number of firms	859	859	859	859	859	859

Notes. The dependent variable in all columns is the log of the number of employees reporting directly to the plant manager. All columns are estimated by OLS with standard errors in parentheses (clustered by firm). All columns exclude firms where the plant manager is the CEO and include a dummy equal to unity if the CEO is on site. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the United Kingdom, and the United States (country dummies included). All columns include a full set of three-digit industry dummies, noise controls (interviewer fixed effects, the interviewee's seniority and tenure in company, the day of the week the interview was conducted, and interview duration and reliability), and a variable summarizing the number of Harte-Hanks cross sections over which the technology variables have been computed. Ln(*Percentage college*) is the log of the fraction of plant employees with a college degree. *Foreign* (*Domestic*) *multinational* is a dummy denoting plants belonging to a foriegn (domestic) multinational. *Plant employment* is the ratio of plant employment to firm employment. *CAD/CAM* denotes computer-assisted design/computer-assisted manufacturing software, and *INTRANET* denotes that the firm has an internal intranet (leased lines or frame relays). There are more observations than firms because some firms were interviewed more than once across different plants.

* and ** indicate significance at the 10% and 5% levels, respectively.

coefficient that is consistent with the theoretical notion that greater communication leads to centralization. Although the coefficient on INTRANET is correctly signed, it is insignificant even when both technologies are included simultaneously (in the final two columns).

Table 5 examines the plant manager's span of control as measured by the number of employees who directly report to him. CAD/CAM is associated with significantly *greater* plant manager span, consistent with the idea that production technologies that facilitate worker information access enable workers to do more tasks, which makes it possible for the plant manager to oversee more production workers (greater span). The coefficient on INTRANET is negative and insignificant (i.e., the theory does not have an unambiguous prediction for this coefficient).

Comparing the empirical results with our expectations in Table 1, we obtain a reasonably close match. All the coefficients are in the same direction as in the theoretical predictions (when they are unambiguous) and all are significant at the 5% level in the most general specifications (with the exception of INTRANET in the worker autonomy equation). The idea that information technologies are associated with increased autonomy and span of control, whereas communications technologies are associated with decreased autonomy, appears to have some empirical content. By contrast, the automation story would predict that information technologies should be associated with centralization (away from lower-level employees), and the coordination theories would predict that communication technologies should be associated with decentralization (see §3.3). Thus, we interpret our evidence on ICT and firm organization as providing some support for the cognitive view of hierarchies discussed in §2.

5.3. Magnitudes

The estimates are statistically significant and broadly consistent with our theory, but are they of economic significance? One way of examining this question is by simulating an increase in the diffusion of our ICT indicators. Given the debate over whether the increasing productivity gap between Europe and the United States in the decade since 1995 was related to ICT (e.g., Bloom et al. 2012a), we simulate increasing the ICT diffusion measures by 60% (the difference in the average level of the ICT capital stock per hour worked between the European Union and the United States in 2000–2004).[24]

An increase in the penetration of ERP of 60% over the sample average of 34% is approximately 20 percentage points. Using column (6) of Table 3, this is associated with a 0.038 standard deviation increase in plant manager autonomy. This is equivalent in effect to an increase in the proportion of college graduates of

[24] This is based on the EU KLEMS data. See Table 5 in Timmer et al. (2003) for a similar figure for 2001 and a description of the data.

38% (when using the coefficients in the plant manger autonomy regression), which is one-third higher than the increase in education achieved by the United States between 1990 and 2000 of approximately 24%. So we regard this as a substantial effect. Similar calculations show that increasing the penetration of INTRANET by 60% (21 percentage points at the mean) is associated with a decrease in plant manager autonomy by approximately 0.040 standard deviations, equivalent to reducing the college share by 38%. This same increase in INTRANET is associated with a decrease in worker autonomy of 0.80% (equivalent to a 27% fall in the college share when using the coefficients in the worker autonomy regression). Finally, consider a 60% increase in CAD/CAM. This is associated with a 0.40% increase in plant manager span (equivalent to a 10% rise in the college share) and a 1.60% increase in worker autonomy (equivalent to a 5.70% increase in the college share). This is lower because the mean of CAD/CAM is lower than the other technologies.

Although benchmarking magnitudes is difficult for the theoretical concepts (and should be a priority for future work), these back-of-the-envelope calculations imply that technical changes in ICT appear to be important for firm organization (benchmarked against equivalent increases in skills), especially ERP on plant manager autonomy and INTRANET on all three organizational dimensions.

5.4. Extensions and Robustness

5.4.1. Endogeneity. Tables 3–5 present conditional correlations that seem to be broadly consistent with the theory. The theoretical model suggests that the endogenous outcomes should covary in systematic ways in equilibrium, which is what we examine in the data. We are of course concerned about endogeneity bias. For example, there may be an unobservable variable that is correlated with the organizational outcomes and our measures of information and communication costs (especially because these are all measured at the firm level). Although these ICT indicators are positively correlated in the data,[25] we take some reassurance in the fact that their predicted effects on the same organizational variable can take opposite signs. For example, in the plant manager autonomy equation the coefficient on information acquisition technologies (with ERP as proxy) is opposite in sign to communication technologies (INTRANET) both theoretically and empirically. For endogeneity to generate these results, the hypothetical unobservable variable positively correlated with decentralization would have to mimic the pattern of having a negative covariance with INTRANET and a positive covariance with ERP. This is always a theoretical possibility, but it is not obvious what would generate these covariance patterns.

Nevertheless, we are still concerned with endogeneity, so in this subsection we consider instrumental variable strategies for ERP and INTRANET.[26] SAP is the market leader in ERP and was founded by five IBM engineers who formed their start-up in Walldorf, a suburb of the German city of Heidelberg, in 1972 (e.g., Hagiu et al. 2007). SAP's headquarters remain in Walldorf. Studies of diffusion suggest that geography plays an important role because when there is uncertainty and tacit knowledge, being geographically close to the innovator promotes the adoption of the new technology (e.g., Baptista 2000). Studies of the diffusion of ERP (e.g., Armbruster et al. 2005) suggest that firms closer to SAP's headquarters were more likely to be early adopters, all else being equal. Since our firms are medium-sized enterprises that could also learn from these earlier adopters (ERP is more common among very large enterprises), we use closeness to Walldorf as an exogenous factor that shifts the probability of adopting ERP. We focus on continental Europe, because the United States and United Kingdom are separated by sea from Germany, making "distance" harder to define, and we drop subsidiaries of multinational firms because there is no obvious distance measure for such global corporations.

We regress the presence of ERP in the plant on the ln(*Distance to Walldorf*) (in kilometers) in column (1) of Table 6. To be conservative we cluster the standard errors by region because we are using a distance instrument and shocks may be spatially correlated. Consistent with our priors, a firm twice as far as another from Walldorf is significantly less likely (approximately 24%) to adopt an ERP system. When entered instead of ERP in the plant manager autonomy equation (the "reduced form" of column (2) of Table 6), the coefficient on distance is again negative and (weakly) significant. Column (3) of Table 6 presents the instrumental variable results, showing that ERP has a large and positive causal effect on decentralization. We also ran these regressions on the larger sample that includes multinationals with similar results.[27] In the subsample in Table 6, 45% of firms use ERP, of which 30% use SAP and 70% use a variety of other ERP offered by vendors like Oracle, Sage, and Microsoft. Since our instrumental variable should be most powerful for

[25] For example, the pair-wise correlation between the *ERP* and the *INTRANET* variables is 0.168, significant at the 1% level.

[26] We do not have an obvious instrumental variable for *CAD/CAM*, so we can only reestimate Table 3 by using this alternative identification strategy.

[27] As expected, the first stage was weaker, with a coefficient (standard error) on distance of −0.087 (0.052). Nevertheless, the second stage remained significant with a coefficient (standard error) on *ERP* of 1.906 (1.101).

Table 6 Plant Manager Autonomy, Instrumental Variable Estimates

Dependent variable:	(1) *ERP*	(2) *Plant manager autonomy*	(3) *Plant manager autonomy*	(4) *INTRANET*	(5) *Plant manager autonomy*	(6) *Plant manager autonomy*	(7) *Plant manager autonomy*
Regression	First stage	Reduced form	Second stage	First stage	Reduced form	Second stage	Second stage
ERP			1.876** (0.780)				1.540* (0.799)
INTRANET						−2.771* (1.517)	−3.198 (2.248)
ln(*Distance to Walldorf*)	−0.237** (0.104)	−0.445* (0.242)					
ln(*INTRANET price*) ∗ (*Industry INTRANET intensity*)				−1.439* (0.779)	3.988** (1.928)		
Number of observations	165	165	165	956	956	956	165
Number of firms	161	161	161	908	908	908	161

Notes. The dependent variable is the z-score of plant manager autonomy. Standard errors are clustered at the regional level in all columns (54 regions). All columns exclude firms where the plant manager is the CEO and include a dummy equal to unity if the CEO is on site. The sample includes firms based in France, Germany, Italy, Portugal, Poland, and Sweden (country dummies included). All multinational subsidiaries are dropped in columns (1)–(3) and (7). All columns include noise controls, firm controls, and industry dummies as in previous tables. The instrument for ERP is the distance (in km) from Walldorf, Germany (the headquarters and founding place of SAP). The instrument for INTRANET is the cost of communications interacted with industry-level intranet intensity. industry INTRANET intensity represents the fraction of workers with access to an internal intranet (leased lines or frame relays) in the three-digit industry across all countries. INTRANET price is the cost of an annual subscription to a leased line contract at 2006 purchasing power parity (PPP) USD (taken from OECD 2007). Regressions are weighted by the plant's share of firm employment. There are more observations than firms because some firms were interviewed more than once across different plants.

* and ** indicates significance at the 10% and 5% levels, respectively.

SAP, we repeated the specifications of columns (1)–(3), replacing ERP with a dummy for the presence of SAP's ERP only. The first-stage results are much stronger: the coefficient (standard error) on distance was −0.094 (0.029), and the second-stage coefficient on ERP was 1.770 (1.032). In fact, the instrument has no power at all for predicting non-SAP ERP systems. Given that the distance to Walldorf only predicts the adoption of SAP ERP (and not other makes of ERP), this suggests that it reflects some SAP effect rather than some other unobservable effect favorable to ERP adoption.[28] As a further check on instrument validity, we examined placebo regressions of whether the distance-to-Walldorf instrument could predict any other observable variables such as INTRANET and firm size. We found no significant correlation with any of these variables.[29] This suggests that the instrument is not correlated with other factors that could be driving higher plant manager autonomy.

We consider an alternative approach to identifying the effects of intranets. The cost of electronically communicating over intranets differs substantially between countries because of differential degrees of the roll-out of high-speed bandwidth and the pricing of telecommunications. Although there have been moves to liberalize the telecommunication sector in most countries, this has happened at very different speeds, and in some countries the incumbent state-run (or formerly state-run) monopolists retain considerable pricing power (e.g., Azmat et al. 2012, OECD 2007). We discuss these in more detail in the online appendix.

We exploit these differential costs using the OECD (2007) series on the prices of leased lines used for intranets (call this price p_k^c), which represent the cost of an annual subscription to a leased line contract at 2006 PPP USD. An obvious empirical problem is that these measured telecommunication price indices only vary across countries[30] and not within countries, so they are collinear with the country dummies. Industries will be differentially affected by these costs, however, depending on the degree to which they are reliant on intranets for exogenous technological reasons. We utilize the intensity of intranet use in the industry, pooling the data across all countries ($INTRANET_j$), as proxy for this reliance.[31] The instrument is defined

[28] The magnitude of the effect is much larger than in the simple OLS specifications. This could be caused by correcting attenuation bias from measurement error and/or reverse causality (e.g., plants that are for some exogenous reason more decentralized may find it difficult to coordinate the introduction of an ERP system that will require some consolidation of databases).

[29] We ran four separate placebo regressions where the dependent variables were INTRANET, PC intensity, skills, and firm size. The coefficient (standard error) on distance to Walldorf was 0.025 (0.067), −0.159 (0.177), 0.279 (0.276), and −0.165 (0.261), respectively. The specifications were the same as in column (2) of Table 6 except that we dropped the endogenous left-hand side variable from the covariate set.

[30] This is only partially true because there is some within-country variation. For example, the roll-out of broadband proceeds at a different rate across areas (see Stevenson 2006).

[31] This identification strategy parallels that of Rajan and Zingales (1998). We also considered specifications where we used intranet-intensive industries defined on U.S. data only and dropped the United States from the sample on which we estimated. This generated similar results.

as $p_k^c * INTRANET_j$. Since we also include a full set of industry and country dummies, we are essentially using $p_k^c * INTRANET_j$ as a direct proxy for communication costs, h, with the prediction that for the intranet-intensive industries we would expect to see more managerial autonomy in countries where communication prices are high (like Poland) than where they are low (like Sweden). The results for this experiment are presented in columns (4)–(6) of Table 6 (we can use a larger sample than in columns (1)–(3) because we have more countries). High telecommunications costs significantly reduce the probability of having an intranet in column (4). When this is entered in the reduced form in column (5), the variable enters with the expected positive sign: fewer intranets imply more decentralization. In column (6), the second-stage coefficient is large, negative, and significant as predicted by the theory.[32]

Column (7) of Table 6 uses both instruments together. Both coefficients take their expected sign and are similar in magnitude to columns (3) and (6), although only the ERP coefficient is significant at the 10% level. The problem is that, although the distance to Walldorf is significant in the first stage for ERP, the instrument for intranets has no power in this smaller subsample, where it is appropriate to use the distance to Walldorf IV.

Taking Table 6 as a whole suggests that the effects we identify are more likely to be causal impacts of technology on organizational form, rather than simply reflecting an endogeneity problem, although the results are stronger for ERP than for INTRANET and the first stages for the instruments are less powerful than we would like.[33]

5.4.2. Corporate Headquarters' Span of Control. Table A.4 in the appendix shows that the theory also generates predictions for the span of control of the corporate headquarters. Although we have a direct measure of the plant managers' span (number of direct reports), we do not have such a direct measure for the CHQ span. One proxy measure for this, however, is the number of plants in the firm, with more plants indicating a larger CHQ span. Because this variable is likely measured with error, we simply consider a dummy for a multiplant firm as a measure of the CHQ span and regress this on information acquisition technology for the plant manager (ERP) and INTRANET in Table A.6 in the appendix. The clear theoretical prediction is that ERP should be associated with a wider CHQ span because plant managers are able to make decisions more easily, so CHQ finds it easier to manage a larger number of them. This is supported by Table A.6: ERP has a significant and positive association with CHQ span of control in column (1), where we condition on the standard controls, and column (3), where we also condition on INTRANET.[34] The coefficient on INTRANET is positive and significant in column (2)—it has a theoretically ambiguous sign.

5.4.3. An Alternative Mechanism: Incentives. In §4.2 we discussed alternative mechanisms, such as agency and incentives, through which ICT could affect organizational structure. To investigate this, we explicitly condition on incentive pay in the regressions. From the survey we know the proportion of managerial pay that was in bonuses (direct incentive pay) and the increase in pay upon promotion (a career-concerns mechanism).

Columns (1)–(3) of Table A.7 in the appendix include a variable indicating the proportion of the plant manager's pay that was bonus (rather than flat salary).[35] Columns (4)–(6) of Table A.7 include the proportionate increase in pay when promoted for a typical plant manager. It is clear that the signs and significance of the technology variables are hardly affected by this additional variable. For example, in column (1) the incentive pay variable is positively but insignificantly associated with greater autonomy of the plant manager. The coefficient on ERP is 0.193, and the coefficient on INTRANET is −0.187, both basically unchanged from Table 3. The other incentive pay proxies are insignificant and do not change the qualitative results. Obviously, this is a crude test because there are other dimensions of incentive pay we have not captured (e.g., for production workers) and some incentive effects may operate independently of any remuneration scheme. However, the robustness of our results to explicit controls for incentives suggests that there is a role for the cognitive theory we emphasize when looking at the impact of ICT.

5.4.4. Further Results. We have examined a large variety of robustness tests and some of these are

[32] For example, we included regional ln(GDP per head) and ln(population) in columns (3) and (6) of Table 5. The coefficient (standard error) on *ERP* and *INTRANET* were 1.669 (0.626) and −2.970 (1.652), respectively.

[33] In the working paper version (Bloom et al. 2013), we consider some of the further "cross" effects of technologies by saturating the empirical models with all three types of technologies. Table A.4 presents the full set of predictions from the theory analogously to Table 1. We present the most general specifications for each of the three main organizational variables in Table A.5 in the appendix. None of the earlier conclusions change with respect to the earlier tests: INTRANET is associated with less autonomy, ERP is associated with more autonomy for managers, and CAD/CAM is associated with more autonomy for workers and a larger span of control.

[34] If we also include *CAD/CAM*, the *ERP* coefficient remains positive and significant. The theory predicts a zero effect of *CAD/CAM*, which indeed has an insignificant coefficient (−0.389 with a standard error of 0.432).

[35] See Lemieux et al. (2009) for how performance pay has grown in importance over time.

Table 7 Robustness Checks

	(1) Baseline	(2) Regional dummies and Lerner index	(3) Additional firm-level controls	(4) Alternative INTRANET (LAN/WAN)	(5) Include management quality	(6) Alternative dependent variable	(7) Drop size controls	(8) Condition on industries with at least three firms
				Panel A: Plant manager autonomy				
ERP	0.192**	0.181**	0.189**	0.179**	0.193**	0.206**	0.221**	0.194**
	(0.087)	(0.092)	(0.088)	(0.086)	(0.087)	(0.095)	(0.094)	(0.088)
INTRANET	−0.188**	−0.228**	−0.179*	−0.144*	−0.189**	−0.188**	−0.202**	−0.213**
	(0.090)	(0.095)	(0.092)	(0.084)	(0.090)	(0.096)	(0.096)	(0.092)
Observations	1,000	1,000	1,000	1,000	1,000	1,000	1,000	920
Firms	950	950	950	950	950	950	950	872
				Panel B: Worker autonomy				
CAD/CAM	0.915**	1.373***	0.862**	0.897**	0.822*	0.704*	0.917**	0.876**
	(0.411)	(0.503)	(0.409)	(0.425)	(0.429)	(0.373)	(0.415)	(0.398)
	[0.104]	[0.095]	[0.086]	[0.099]	[0.092]	[0.115]	[0.104]	[0.115]
INTRANET	−0.367	−0.500*	−0.428*	−0.011*	−0.404*	−0.409**	−0.358	−0.431*
	(0.225)	(0.282)	(0.235)	(0.006)	(0.230)	(0.193)	(0.226)	(0.228)
	[−0.042]	[−0.035]	[−0.043]	[−0.001]	[−0.045]	[−0.067]	[−0.041]	[−0.057]
Observations	649	547	646	649	649	840	649	608
Firms	614	512	611	614	614	796	614	574
				Panel C: Plant manager span of control				
CAD/CAM	0.246**	0.340***	0.263**	0.246**	0.246**		0.261**	0.255**
	(0.119)	(0.120)	(0.122)	(0.119)	(0.119)		(0.115)	(0.121)
INTRANET	−0.021	−0.010	−0.036	0.001	−0.021		−0.004	−0.035
	(0.058)	(0.062)	(0.059)	(0.002)	(0.058)		(0.058)	(0.058)
Observations	902	902	902	902	902		902	822
Firms	859	859	859	859	859		859	781

Notes. Panels A and C are estimated by OLS; panel B is estimated by probit with standard errors in parentheses and marginal effects (evaluated at the mean) in square brackets. Standard errors are clustered by firm in all columns. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the United Kingdom, and the United States (country dummies included). All columns exclude firms where the plant manager is the CEO and include a dummy equal to unity if the CEO is on site. All columns include noise controls, firm controls and industry dummies as in previous tables. *ERP* denotes enterprise resource planning, *INTRANET* denotes that the firm has an internal intranet (leased lines or frame relays), and *CAD/CAM* denotes computer-assisted design/computer-assisted manufacturing. In column (2), regional (Nomenclature of Territorial Units for Statistics region 2) dummies and the inverse of the Lerner index are included as additional controls. In column (3), ln(capital/employment ratio), ln(sales/employment ratio), ln(average wages), ln(global ultimate owner employment), ln(firm age), and a publicly listed dummy are included as additional controls. In column (4), the INTRANET variable denotes the presence of LAN/WAN systems. In column (5) we construct the ICT variables as equal to unity if there is a positive value in any plant. In column (5) the average management score (computed across the 18 management questions in Bloom and Van Reenen 2007) is included as additional control. In column (6) the dependent variable is the principal factor component of the four different plant manager autonomy questions (panel A) and a dummy equal to unity if the pace of work questions takes values above three (panel B). In column (7) we drop firm and plant size from the regressions. Column (8) conditions on having at least three firms per three-digit industry. There are more observations than firms because some firms were interviewed more than once across different plants.

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

presented in Table 7. Each panel presents a different dependent variable with different tests in each column (panel A for plant manager autonomy, panel B for worker autonomy, and panel C for plant manager span of control. Column (1) of Table 7 simply repeats the baseline specifications from column (6), respectively, in Tables 3–5.

In Bloom et al. (2012b) we found that cultural factors such as trust and other environmental factors such as religion and competition were associated with greater plant manager autonomy. We control for these in column (2) of Table 7 by including a full set of regional dummies and the industry-level Lerner index of competition. None of the main results change, with the exception of INTRANET in the worker autonomy equation. The sign is still negative, which is consistent with the theory (falls in communication costs lower autonomy) but it is now larger in absolute magnitude and significant at the 10% level, whereas it was insignificant in the baseline regression. Column (3) includes a variety of additional firm-level controls: the capital/labor ratio, sales per employee, total employment in the group where the firm belongs (i.e., consolidated worldwide employment for multinationals), firm age, and a listing dummy. The results are robust to these additional controls (which were individually and jointly insignificant).[36] Column (4) uses an alternative indicator of intranets based on the presence of LAN or WAN.[37] The LAN/WAN indicator is highly correlated with

[36] Other controls—like the log of firm average wage—also turned out not to change the results.

[37] We prefer our indicator of *INTRANET* because LAN was only included in earlier years of the Harte-Hanks data and WAN only included in later years.

INTRANET, and the results are very similar to the baseline. The only difference is, again, INTRANET in the worker autonomy equation, which is now significant (at the 10% level) with a theory-consistent negative sign. Again, nothing much changes, nor does including the Bloom and Van Reenen (2007) measure of management quality in column (5). Column (6) considers alternative ways of constructing the dependent variable. For the plant manager autonomy equation, we use the principal component of the four questions, and for the worker autonomy question we define it based only on the pace of work.[38] The results again seem robust to these alternatives. Column (7) drops the size controls because they are potentially endogenous, and column (8) conditions on the subsample with at least three firms per industry. Neither experiment has much effect on the results.

6. Conclusions

The empirical and theoretical literature that examines the economic effects of information and communication technologies (ICT) generally aggregates information technology (IT) and communication technology (CT) into a single homogeneous category. We argue that this is inappropriate because the impact of IT and CT on the organization of firms, and ultimately income inequality, will be quite different depending on the type of technology used. Falls in communication costs will tend to reduce employee autonomy, because decisions will be passed up to the center of the firm. Falls in information acquisition costs will have the opposite effect, facilitating more effective employee decision making. This matters, because the returns to skill at different levels of the organization depend on the importance of the decisions taken at those levels.

First, we consider nonproduction decisions (investment, hiring, new products, and pricing). These decisions can either be taken by the CEO at corporate headquarters or by the plant manager in the local business unit. The key piece of information technology that has affected these decisions is enterprise resource planning. ERP provides a range of data on metrics like production, waste, energy use, sales, inventories, and human resources. Modern ERP systems increase dramatically the availability of information to top and middle managers, which (according to our theory) should be associated with the decentralization of decision making toward middle managers. Second, we consider factory floor decisions on the allocation and pace of production tasks. These production decisions can either be taken by factory floor employees or by their superiors in the plant hierarchy, like the plant managers. Here, a key technological change has taken place with the adoption of computer-assisted design/computer-assisted manufacturing (CAD/CAM). A worker with access to those technologies can better solve design and production problems and thus needs less access to his superiors in making decisions. This should lead to the decentralization of nonproduction decisions toward the factory floor. Third, we expect the impact of communication technologies to be opposite to information technologies. The key technological innovation in within-firm communications is the growth of intranets. The spread of intranets should be associated with the centralization of both types of decisions within the firm, because providing input from afar becomes cheaper relative to making decisions on the spot.

We confirm all these predictions on a new data set that combines plant-level measures of organization and ICT hardware and software adoption across the United States and Europe. The organizational questions were collected as part of our large international management survey and were explicitly targeted at the theories we investigate. In terms of identification, we mainly focus on simple conditional correlations between the different ICT measures and the multiple dimensions of the organization of the firm, guided by our theoretical predictions. However, we also show that treating technology as endogenous strengthens the results. Our instrumental variables are distance from the place of origin of the market-leading ERP system (SAP) and the differential regulation of the telecommunication industry across countries (which generates exogenous differences in the effective prices of intranets).

There are several directions that could be pursued from this line of research. First, it would be interesting to examine in more detail the reasons for differential adoptions of technologies across firms and countries because the instruments suggest important factors that could explain the diffusion of communication and information technologies. This is of interest in itself but is also important in order to get more closely at the causal effects of changes in ICT on firm organization. Second, the theory could be developed to consider interactions between different type of production and nonproduction technologies at other layers of the hierarchy. Finally, one could more systematically examine the effect of differential types of ICT adoption and organization on other outcomes such as productivity and wage inequality at the level of the industry and economy.[39]

[38] The results are also robust to constructing the plant manager autonomy variable focusing solely on questions coded between 1 and 5, i.e., excluding the question on how much capital investment a plant manager could undertake without prior authorization from CHQ.

[39] For work in this area, see Bresnahan et al. (2002), Caroli and Van Reenen (2001), and, more recently, Caliendo et al. (2012).

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/mnsc.2014.2013.

Acknowledgments

The authors thank participants of seminars at the American Economic Association, the University of Chicago, Harvard University, the Massachusetts Institute of Technology, the London School of Economics, Microsoft, and the National Bureau of Economic Research for helpful comments, and Frank Nagle for excellent research assistance. The authors also thank the Economic and Social Research Council for help with financing this research through the Centre for Economic Performance. Nicholas Bloom and Luis Garicano also thank the Toulouse Network on Information Technology.

APPENDIX. Technology Description Appendix: The Effect of ERP, CAD/CAM, and Intranet on the Cost of Accessing and Communicating Information

A.1. Connected Real-Time Databases (ERP): Increasing Managerial Information Access (a_m, a_c)

The cost of access to information by local plant managers (a_m) and central headquarters' based managers (a_c) has been directly affected by the installation in firms of ERP systems. The main sellers of ERP are SAP and Oracle, both used by more than half of large U.S. businesses. The introduction of ERP systems is typically the largest investment in information technology in manufacturing-related business: in 2006, ERP was estimated to represent just under one-third of all application IT spend in large U.S. companies.[40]

To understand the impact of ERP, consider the example for an exhaust factory. After the introduction of SAP 5.0, such a production plant would have all of its data collected and stored in one unified computing system, allowing the plant manager (and all other managers) to easily access and compare data across a range of processes. For example, if a filter supplier were to shut down due to a fire, the plant manager could use his ERP system to generate an online inventory of current filter stocks, a read-out of work-in-progress, and customer orders outstanding, to evaluate which customer orders were most at risk from shortages. This would enable him to reschedule filter stocks toward the most imminent customer orders and pause production of less imminent orders until alternative suppliers could be found. He would also be able to call up a list of alternative filters and their suppliers to source a replacement supplier. Once the local manufacturing sites and the company headquarters are integrated in the company-wide ERP system, plant managers and the central headquarters have a full company-level overview of production, inventory, orders, and finance across the company. Therefore, the development of ERP enables managers to access timely information at an unprecedented rate, empowering plant managers to make decisions on a range of activities including investment, hiring, pricing, and product choice.[41] Given the theory, we thus expect ERP to be a decentralizing technology: because all managers have better access to information, lower-level managers can make more decisions without consulting their superiors.

A possible concern is that ERP might also affect communication costs by simplifying the transmission of information across hierarchical levels. To investigate this issue in more detail, we collected data in a survey of IT managers on ERP usage in 431 firms with 100–5,000 employees. The empirical evidence, which we discuss below, corroborates our discussions with technology experts that ERP is primarily related to information acquisition rather than communication.

In the summer and fall of 2008, Kretschmer and Mahr (2009) conducted a survey of IT managers in medium-sized (100–5,000 employees) German and Polish firms that were randomly chosen from the population of manufacturing firms. The aims of the survey were wider than just ERP and collected information on management and other factors. At our request, some questions on the use of ERP were inserted. Answers to the questions were on a 1-to-5 Likert scale from strongly disagree (1) to strongly agree (5). The key questions for our purposes were the following:

Q21: "Our ERP system is used to endow top management with more and better information."

Q24: "Our ERP system is used to endow middle managers with more and better information."

Q23: "Our ERP system is used to faster communicate information and directives from top management to employees."

Q26: "Our ERP system is used to faster communicate information and directives from middle management to employees."

Figure A.1 shows the distribution of answers to these questions. It is clear from this figure that most respondents were likely (a "4") or very likely (a "5") to agree with statements Q21 and Q24, suggesting that ERP was related to information acquisition. By contrast, as many people disagreed as agreed with the statements in Q23 and Q26 that ERP lowers communication costs. About three quarters of respondents said that ERP was "likely" or "very likely" to increase information flows (see panel Q1 in Figure A.1). When we asked whether "ERP is used for faster communication of information and directives from top management to other employees" (again from strongly disagree (1) to strongly agree (5)), only about a third of respondents answered that ERP was "likely" or "very likely" to increase this form of communication (see panel Q2 in Figure A.1). Using the cardinal scale, the mean of the information acquisition answer was 3.8, whereas the mean of the communication answer was 2.8, with the difference significant at the 1% level. A similar pattern is evident when respondents where asked about information acquisition versus communication for middle managers (see panels Q3 and Q4 in Figure A.1).

Table A.1 shows regression versions of these descriptive statistics. Likert scales between respondents can be biased because each respondent implicitly has a different scaling

[40] These estimates are from Shepard and Klein (2006), who conducted 175 interviews with IT managers in U.S.-based companies with 1,000 or more employees. ERP systems are also increasingly common in larger firms in developing countries; see, for example, Bloom et al. (2011).

[41] By improving the access of managers to local time information, ERP also allows managers to make better decisions (see Davenport et al. 2002).

when they answer such questions (Manski 2004). We can deal with this by only comparing "within respondent," that is, looking at the relative responses for the same individual across questions. We construct several such variables, but the key one is "DIF1,"the absolute difference between "Our ERP system is used to endow middle managers with more and better information" (Q24) and "Our ERP system is used to faster communicate information and directives from top management to employees" (Q23). This is an index from −4 to 4, indicating the degree to which ERP reduces information costs relative to communication costs. A positive value of this index indicates that managers are more likely to view ERP as improving information costs rather than reducing communication costs.

Column (1) of Table A.1 shows that the mean value of this index is just above one and significantly greater than zero—if ERP was on average thought to be equally important for communication as for information acquisition, the coefficient on the constant would be insignificantly different from zero. This is consistent with our assumption that ERP is used more as an information acquisition tool than a communication tool. We condition on some confounding influences—country dummies, industry dummies, and size in column (2), which shows the difference is robust. One might be concerned that the communication question relates to top managers, so we also used "DIF2," which keeps the information question the same (Q21) but deducts "Our ERP system is used to faster communicate information and directives from middle management to employees" (Q26). The results of using this as a dependent variable are in column (3), which are almost identical to column (2). Finally, we checked whether ERP is better at endowing top management with more information than middle management by constructing "DIF3," the absolute difference between "Our ERP system is used to endow middle managers with more and better information" (Q24) and "Our ERP system is used to endow top management with more and better information" (Q21). This difference is positive but completely insignificant. In terms of our theory, this means that ERP shifts a_m downward to a similar extent as a_c, which is again what we assumed for our interpretation of the empirical results.[42] See Kretschmer and Mahr (2009) for full details on the underlying survey.

A.2. Computer-Assisted Design/Computer-Assisted Manufacturing (CAD/CAM): Increasing Information Access at the Shop Floor (a_p)

A second important parameter in our model is the change in the cost of access to information on the production floor. A crucial recent change in these costs has been the introduction of CAD/CAM.

New manufacturing orders generally require design, testing, and redesign, typically by the engineering department. The process traditionally started with the design being provided by the supplier—for example, an exhaust pipe for a new military vehicle—which the engineers would mock up and produce in a trial run. Once this was successful, the engineers would go to the manufacturing facility, for example, the exhaust factory, to supervise a small-scale production run, and produce the first prototypes. The local manager would oversee this process, working with the engineers to ensure that his plant could implement the designs in-house, or have these externally procured. These initial production runs would then be shown to the customer, refined in a further design iteration, and finally set up for the full-scale production run by the engineers. The introduction of CAD (computer-aided design) allows the plant to directly design products, and CAM (computer-automated manufacturing) enables the production team to program up the Computer Numerical Control equipment to produce the key parts.[43] In this way, CAD/CAM has increased the amount of information available to the production team and enabled them to carry out the initial prototype design and production stage, reducing the involvement of both the plant manager and the remotely based central headquarters engineering team. Similar technologies in retail and banking, like customer databases and relationship management tools, have empowered store-level employees to cross-sell other products like insurance and credit (e.g., Hunter et al. 2001). Given the theory described above, we expect CAD/CAM to be a *decentralizing technology*: because workers have access to more/better information, they can make more decisions themselves without consulting their superiors.

A.3. The Rise of Intranets: Facilitating Communication Through the Organization (h)

A final parameter that affects the allocation of decisions in our model is communication costs. An important shifter of these costs over the last decade has been the introduction of corporate intranets. These allow companies to connect manufacturing plants to corporate headquarters, reducing the cost of communication between headquarters and local managers. In the past, for example, sharing documentation with headquarters required the use of fax or mail. These high communication costs made speedy decisions from the headquarters extremely difficult and costly, leading to the delegation of day-to-day control of the plant to local management. Once the leased lines and corporate intranet are installed, the cost of communication between local and central managers is reduced. This allows for the use of more experienced central management to be swiftly alerted to signs of production problems—for example, identifying specific types of output variations as fault indicators—and enables swift decision-making support. Intranets also reduced the cost of communication inside the production plants, facilitating the flow of information between the shop floor and the plant manager. These network technologies are equally important in retail, wholesale, and retail banking. Other general communication technologies include cell phones and email. Given the model, we expect the rise of intranets, which reduces communication cost, to be a *centralizing technology*, because it allows for increasing specialization as "questions" are more cheaply posed to the experts.

[42] There are differences in the comparative statistcs if ERP or another technology reduced c_c but not c_m.

[43] Traditionally these would be used to drive numerically controlled programming tools (see, e.g., the description of their use in the valve industry in Bartel et al. 2007).

Table A.1 ERP Survey: The Impact of ERP Is More on Information Costs Than on Communication Costs

Dependent variable	(1) DIF1	(2) DIF1	(3) DIF2	(4) DIF3
Constant	1.074***	1.068**	1.042**	0.102
	(0.060)	(0.512)	(0.496)	(0.383)
Firms	431	431	431	431
Country controls	No	Yes	Yes	Yes
Industry controls	No	Yes	Yes	Yes
Employment controls	No	Yes	Yes	Yes

Notes. The countries are Germany and Poland (Kretschmer and Mahr 2009). Estimation was made by OLS. Robust standard errors are given below coefficients. Industry controls are three-digit employment. Questions are on a 1-to-5 Likert scale from strongly disagree (1) to strongly agree (5).

Q21: "Our ERP system is used to endow top management with more and better information." Q24: "Our ERP system is used to endow (middle) managers with more and better information." Q23: "Our ERP system is used to faster communicate information and directives from top management to employees." Q26: "Our ERP system is used to faster communicate information and directives from (middle) management to employees."

Definitions of the dependent variables are as follows: DIF1 = Q24 − Q23; DIF2 = Q24 − Q26; and DIF3 = Q24 − Q21. So DIF1, for example, is the absolute difference between "ERP endows middle management with better information" less "ERP is used to faster communicate information and directives from top management to employees." This is an index from −4 to 4 indicating the degree to which ERP reduces information costs relative to communication costs. A positive value of this index indicates that managers are more likely to view ERP as improving information costs rather than reducing communication costs.

** and *** indicate significance at the 5% and 1% levels, respectively.

Table A.2 Details of the Decentralization Survey Questions

Question D1: "*To hire a FULL-TIME PERMANENT SHOP FLOOR worker what agreement would your plant need from corporate headquarters* (*CHQ*)?"
Probe until you can accurately score the question—For example, if they say "*It is my decision, but I need sign-off from CHQ,*" ask "*How often would sign-off be given*?"

	Score 1	Score 3	Score 5
Scoring grid:	No authority—Even for replacement hires	Requires sign-off from the CHQ based on the business case. Typically agreed (i.e., approximately 80% or 90% of the time).	Complete authority—It is my decision entirely

Question D2: "*What is the largest CAPITAL INVESTMENT your plant could make without prior authorization from CHQ*?"
Notes:
(a) Ignore form-filling
(b) Please cross-check any zero response by asking "*What about buying a new computer—Would that be possible*?" and then probe....
(c) Challenge any very large numbers (e.g., $> \$\frac{1}{4}$m in USD) by asking "*To confirm, your plant could spend* $X *on a new piece of equipment without prior clearance from CHQ*?"
(d) Use the national currency and do not omit zeros (i.e., for a U.S. firm twenty thousand dollars would be 20,000).

Question D3: "*Where are decisions taken on new product introductions—At the plant, at the CHQ, or both*?"
Probe until you can accurately score the question—For example, if they say "*It is complex, we both play a role,*" ask "*Could you talk me through the process for a recent product innovation*?"

	Score 1	Score 3	Score 5
Scoring grid:	All new product introduction decisions are taken at the CHQ	New product introductions are jointly determined by the plant and the CHQ	All new product introduction decisions taken at the plant level

Question D4: "*How much of sales and marketing is carried out at the plant level* (*rather than at the CHQ*)?"
Probe until you can accurately score the question. Also take an average score for sales and marketing if they are taken at different levels.

	Score 1	Score 3	Score 5
Scoring grid:	None—Sales and marketing is all run by the CHQ	Sales and marketing decisions are split between the plant and the CHQ	The plant runs all sales and marketing

Question D5: "*Is the CHQ on the site being interviewed*?"

Question D6: "*How much do managers decide how tasks are allocated across workers in their teams?*"

	Score 1	Score 2	Score 3	Score 4	Score 5
Interviewers are read the following five options, with our scoring for these noted above:	All managers	Mostly managers	About equal	Mostly workers	All workers

Question D7: "*Who decides the pace of work on the shop floor*?"

	Score 1	Score 2	Score 3	Score 4	Score 5
Interviewers are read the following five options, with "customer demand" an additional (i.e., not read option)	All managers	Mostly managers	About equal	Mostly workers	All workers

Question D8: "*How many people directly report to the PLANT MANAGER (i.e., the number of people the PLANT MANAGER manages directly in the hierarchy below him)*?" *Note: cross-check answers of X above 20 by asking "So you directly manage on a daily basis X people*?"

Note. For Questions D1, D3, and D4 any score can be given, but the scoring guide is only provided for scores of 1, 3, and 5. The electronic survey, training materials, and survey video footage are available at http://worldmanagementsurvey.org/.

Table A.3 Coordination Does Not Seem to Explain Our Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable: *Plant manager autonomy*	Whether the firm is a multinational (MNE)				Whether the firm operates in multiple four-digit industries			Whether the CHQ and plant are colocated		
	Baseline	Domestic	Foreign or domestic multinational	Pooled	Single industry	Multiple industry	Pooled	CHQ and plant colocated	CHQ and plant not colocated	Pooled
ERP	0.192**	0.182	0.059	0.181	0.233*	0.361**	0.177	0.249	0.193	0.183
	(0.087)	(0.125)	(0.173)	(0.111)	(0.126)	(0.152)	(0.121)	(0.168)	(0.124)	(0.127)
INTRANET	−0.188**	−0.235*	−0.177	−0.185*	−0.097	−0.186	−0.077	−0.106	−0.289**	−0.145
	(0.090)	(0.126)	(0.200)	(0.111)	(0.142)	(0.152)	(0.124)	(0.163)	(0.131)	(0.137)
ERP ∗ MNE				0.034						
				(0.165)						
INTRANET ∗ MNE				0.024						
				(0.175)						
ERP ∗ Multiple industries							0.087			
							(0.167)			
INTRANET ∗ Multiple industries							−0.213			
							(0.164)			
ERP ∗ CHQ and plant not colocated										0.016
										(0.162)
INTRANET ∗ CHQ and plant not colocated										−0.072
										(0.169)
MNE				0.073						
				(0.124)						
Multiple industries							0.019			
							(0.118)			
CHQ and plant not colocated										−0.130
										(0.148)
Observations	1,000	648	352	1,000	518	438	956	439	561	1,000
Firms	950	618	332	996	497	409	906	425	535	950
Test on joint significance of *ERP* and *INTRANET* interactions				0.96			0.39			0.91

Notes. The dependent variable is the z-score of plant manager autonomy (mean equals zero and standard deviation equals one) across four questions relating to plant manager control over hiring, investment, product introduction, and marketing (see text). All columns are estimated by OLS with standard errors in parentheses (clustered by firm). The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the United Kingdom, and the United States (country dummies included). All columns include a full set of three-digit industry dummies, noise controls (interviewer fixed effects, the interviewee's seniority and tenure in company, the day of the week the interview was conducted, and interview duration and reliability), and a variable summarizing the number of Harte-Hanks cross sections over which the technology variables have been computed. *ERP* denotes enterprise resource planning, and *INTRANET* denotes that the firm has an internal intranet (leased lines or frame relays). All columns exclude firms where the plant manager is the CEO and include a dummy equal to unity if the CEO is on site. There are more observations than firms because some firms were interviewed more than once across different plants. *MNE* is a dummy taking a value of one if the plant belongs to a domestic or foreign multinational. *Multiple industries* is a dummy taking a value of one if the firm appears to be active in multiple primary or secondary four-digit Standard Industrial Classification codes. *CHQ and plant not colocated* is a dummy taking a value of one if the plant and the firm headquarters are located in different postal codes, or if the plant manager reports that the CEO is not on site.

* and ** indicate significance at the 10% and 5% levels, respectively.

Table A.4 Extended Theory Predictions

	(1) Plant manager autonomy (x_m)	(2) Worker autonomy (z_p)	(3) Plant manager span of control (s_m)	(4) CEO span of control (s_c)
Reduction in communication costs (h)				
Technology indicator	*INTRANET* (h)	*INTRANET* (h)	*INTRANET* (h)	*INTRANET* (h)
Theoretical prediction	−	−	?	?
Reduction in information acquisition costs for nonproduction decisions (a_m)				
Technology indicator	*ERP* (a_m)	*ERP* (a_m)	*ERP* (a_m)	*ERP* (a_m)
Theoretical prediction	+	−	−	+
Reduction in information acquisition costs for production decisions (a_p)				
Technology indicator	*CAD/CAM* (a_p)	*CAD/CAM* (a_p)	*CAD/CAM* (a_p)	*CAD/CAM* (a_p)
Theoretical prediction	0	+	+	0

Notes. ERP denotes enterprise resource planning, *CAD/CAM* denotes computer-assisted design/computer-assisted manufacturing, and *INTRANET* denotes the presence of an intranet (leased line/frame relay). A "+" denotes an increase, a "−" denotes a decrease, a "0" denotes no effect, and "?" denotes an ambiguous sign.

Table A.5 Cross Effects of Technologies

Dependent variable:	(1) *Plant manager autonomy*	(2) *Worker autonomy*	(3) ln(*Plant manager span*)
ERP	0.193**	0.033	0.045
	(0.087)	(0.224)	(0.058)
		[0.003]	
CAD/CAM	0.219	0.950**	0.245**
	(0.221)	(0.420)	(0.119)
		[0.100]	
INTRANET	−0.189**	−0.402*	−0.019
	(0.090)	(0.227)	(0.059)
		[−0.042]	
Number of observations	1,000	649	902
Number of firms	950	614	859

Notes. Specifications correspond to the most general specifications of those in the final columns of Tables 3–5. All equations are estimated by OLS except the worker autonomy equation, which is estimated by probit ML with marginal effects (evaluated at the mean) reported in square brackets. Standard errors are clustered by firm. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the United Kingdom, and the United States (country dummies included). *ERP* denotes enterprise resource planning, *INTRANET* denotes that the firm has an internal intranet (leased lines or frame relays), and *CAD/CAM* denotes computer-assisted design/computer-assisted manufacturing software.

* and ** indicate significance at the 10% and 5% levels, respectively.

Table A.6 CEO Span of Control

Dependent variable:	(1)	(2) *CEO span of control*	(3)
ERP		0.378***	0.347***
		(0.130)	(0.132)
		[0.133]	[0.122]
INTRANET	0.412***		0.383***
	(0.142)		(0.143)
	[0.145]		[0.134]
ln(*Percentage college*)	0.101*	0.097*	0.102*
	(0.053)	(0.053)	(0.053)
	[0.036]	[0.034]	[0.036]
ln(*Computers/employee*)	−0.082	−0.079	−0.108
	(0.076)	(0.076)	(0.076)
	[−0.029]	[−0.028]	[−0.038]
ln(*Firm employment*)	0.248***	0.267***	0.250***
	(0.070)	(0.070)	(0.071)
	[0.087]	[0.094]	[0.088]
Plant employment	−0.504***	−0.513***	−0.516***
	(0.097)	(0.096)	(0.096)
	[−0.177]	[−0.180]	[−0.181]
Number of observations	1,116	1,116	1,116
Number of firms	1,061	1,061	1,061

Notes. The dependent variable in all columns is a dummy equal to one if the firm reports more than one production plant. All columns are estimated by probit ML with standard errors in parentheses (clustered by firm). Marginal effects (evaluated at the mean) reported in square brackets. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the United Kingdom, and the United States (country dummies included). All columns contain the same controls in Tables 3–5. *ERP* denotes enterprise resource planning, and *INTRANET* denotes that the firm has an internal intranet system (leased lines or frame relays).

* and *** indicate significance at the 10% and 1% levels, respectively.

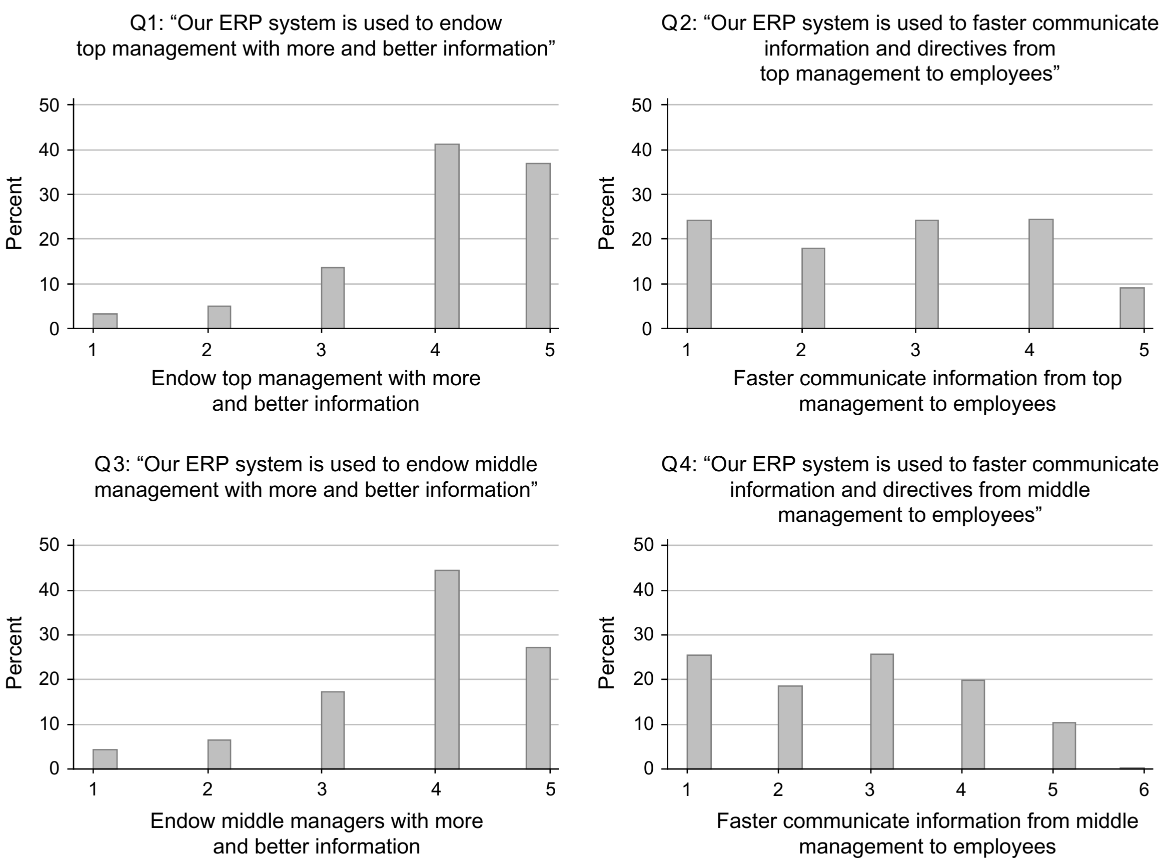
Table A.7 Controlling for Contingent Pay

Dependent variable:	(1) *Plant manager autonomy*	(2) *Worker autonomy*	(3) ln(*Plant manager span*)	(4) *Plant manager autonomy*	(5) *Worker autonomy*	(6) ln(*Plant manager span*)
ERP	0.193**			0.189**		
	(0.087)			(0.087)		
CAD/CAM		0.908**	0.239**		0.982**	0.247**
		(0.402)	(0.119)		(0.413)	(0.115)
		[0.101]			[0.104]	
INTRANET	−0.187**	−0.382*	−0.017	−0.186**	−0.329	−0.018
	(0.090)	(0.227)	(0.058)	(0.091)	(0.228)	(0.058)
		[−0.042]			[−0.035]	
Bonus as a % of total salary for typical manager	0.385	−1.121	0.152			
	(0.249)	(0.756)	(0.144)			
		[−0.124]				
% Salary increase on promotion for a typical manager				−0.060	0.303	0.175
				(0.221)	(0.479)	(0.128)
					[0.032]	
Number of observations	1,000	649	902	1,000	649	902
Number of firms	950	614	859	950	614	859

Notes. All columns are estimated by OLS except columns (2) and (5), which are estimated by probit ML with standard errors in parentheses and marginal effects (evaluated at the mean) reported in square brackets. Standard errors are clustered by firm in all columns. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the United Kingdom, and the United States (country dummies included). All columns include the same controls as Tables 3–5. *ERP* denotes enterprise resource planning, *INTRANET* denotes that the firm has an internal intranet (leased lines or frame relays), and *CAD/CAM* denotes computer-assisted design/computer-assisted manufacturing software.

* and ** indicate significance at the 10% and 5% levels, respectively.

Figure A.1 Enterprise Resource Planning (ERP) Use



Notes. Answers range from 1 = "strongly disagree" to 5 = "strongly agree." Each bar represents the percentage of respondents in the relevant bin from 431 firms. See the online appendix for details.

References

Acemoglu D, Aghion P, Lelarge C, Van Reenen J, Zilibotti F (2007) Technology, information and the decentralization of the firm. *Quart. J. Econom.* 122(4):1759–1799.

Aghion P, Tirole J (1997) Formal and real authority in organizations. *J. Political Econom.* 105(1):1–29.

Alonso R, Dessein W, Matouschek N (2008) When does coordination require centralization? *Amer. Econom. Rev.* 98(1):145–179.

Aral S, Brynjolfsson E, Wu L (2012) Three-way complementarities: Performance pay, human resource analytics, and information technology. *Management Sci.* 58(5):913–931.

Armbruster H, Kinkel S, Lay G, Maloca S (2005) Techno-organizational innovation in the European manufacturing industry. *Eur. Manufacturing Survey Bull.* 1:1–16.

Aubert P, Caroli E, Roger M (2006) New technologies, workplace organization and the structure of the workforce: Firm-level evidence. *Econom. J.* 116:F73–F93.

Autor D, Lavy F, Murnane R (2003) The skill content of recent technological change: An empirical exploration. *Quart. J. Econom.* 118(4):1279–1334.

Azmat G, Manning A, Van Reenen J (2012) Privatization, entry regulation and the decline of labour's share of GDP: A cross-country analysis of the network industries. *Economica* 79(315): 470–492.

Baker G, Hubbard T (2004) Contractibility and asset ownership: On board computers and governance in US trucking. *Quart. J. Econom.* 119(4):1443–1479.

Baker G, Gibbons R, Murphy KJ (1999) Informal authority in organizations. *J. Law, Econom., Organ.* 15(1):56–73.

Baptista R (2000) Do innovations diffuse faster within geographical clusters? *Internat. J. Indust. Organ.* 18(3):515–535.

Baron D, Besanko D (1992) Information, control, and organizational structure. *J. Econom. Management Strategy* 1(2):237–275.

Bartel A, Ichniowski C, Shaw K (2007) How does information technology really affect productivity? Plant-level comparisons of product innovation, process improvement and worker skills. *Quart. J. Econom.* 122(4):1721–1758.

Beaudry P, Doms M, Lewis E (2010) Should the personal computer be considered a technological revolution? Evidence from U.S. metropolitan areas. *J. Political Econom.* 118(5):988–1036.

Becker SO, Woessmann L (2009) Was Weber wrong? A human capital theory of Protestant economic history. *Quart. J. Econom.* 124(2):531–596.

Black S, Lynch L (2001) How to compete: The impact of workplace practices and information technology on productivity. *Rev. Econom. Statist.* 83(3):434–445.

Blanchard O (2004) The economic future of Europe. *J. Econom. Perspect.* 18(4):3–26.

Bloom N, Van Reenen J (2007) Measuring and explaining management practices across firms and nations. *Quart. J. Econom.* 122(4): 1351–1408.

Bloom N, Draca M, Van Reenen J (2011) Trade-induced technical change: The impact of Chinese imports on technology and jobs. Discussion Paper 1000, Centre for Economic Performance, London School of Economics, London.

Bloom N, Sadun R, Van Reenen J (2012a) Americans do I.T. better: American multinationals and the productivity miracle. *Amer. Econom. Rev.* 102(1):167–201.

Bloom N, Sadun R, Van Reenen J (2012b) Measuring and explaining organization across firms and countries. *Quart. J. Econom.* 127(4):1663–1705.

Bloom N, Garicano L, Sadun R, Van Reenen J (2013) The distinct effects of information technology and communication technology on firm organization. Discussion Paper 927, Centre for Economic Performance, London School of Economics, London.

Bresnahan T, Brynjolfsson E, Hitt L (2002) Information technology, workplace organization and the demand for skilled labor: Firm-level evidence. *Quart. J. Econom.* 117(1):339–376.

Brynjolfsson E (1994) Information assets, technology, and organization. *Management Sci.* 40(12):1645–1662.

Caliendo L, Monte F, Rossi-Hansberg E (2012) The anatomy of French production hierarchies. NBER Working Paper 18259, National Bureau of Economic Research, Cambridge, MA.

Caroli E, Van Reenen J (2001) Skill biased organizational change. *Quart. J. Econom.* 116(4):1448–1492.

Colombo MG, Delmastro M (2004) Delegation of authority in business organizations: An empirical test. *J. Indust. Econom.* 52(1):53–80.

Crémer J, Garicano L, Prat A (2007) Language and the theory of the firm. *Quart. J. Econom.* 122(1):373–407.

Davenport TH, Harris JG, Catrell S (2002) The return of enterprise solutions: The director's cut. Accenture Institute for High Performance Business Research Report, October 2002.

Dessein W (2002) Authority and communication in organizations. *Rev. Econom. Stud.* 69:811–838.

Dessein W, Santos T (2006) Adaptive organizations. *J. Political Econom.* 114(5):956–995.

Draca M, Sudun R, Van Reenen J (2007) Productivity and ICTs: A review of the evidence. Mansell R, Avgerou C, Quah D, Silverstone R, eds. *The Oxford Handbook of Information and Communication Technologies* (Oxford University Press, New York), 100–147.

Forman C, Goldfarb A, Greenstein S (2011) The Internet and local wages: A puzzle. Mimeo, Northwestern University, Evanston, IL.

Foster A, Rosenzweig M (2010) Microeconomics of technology adoption. *Annual Rev. Econom.* 2:395–424.

Garicano L (2000) Hierarchies and the organization of knowledge in production. *J. Political Econom.* 108(5):874–904.

Garicano L, Heaton P (2010) Information technology, organization, and productivity in the public sector: Evidence from police departments. *J. Labor Econom.* 18(1):167–201.

Garicano L, Rossi-Hansberg E (2006) Organization and inequality in a knowledge economy. *Quart. J. Econom.* 121(4):1383–1435.

Griffith R, Lee S, Van Reenen J (2011) Is distance dying at last? Falling home bias in fixed effects models of patent citations. *Quant. Econom.* 2(2):211–249.

Gu B, Xue L, Ray G (2008) IT governance and IT investment performance: An empirical analysis. *ICIS 2008 Proc.*, Paper 30, http://aisel.aisnet.org/icis2008/30.

Guadalupe M, Wulf J (2008) The flattening firm and product market competition: The effect of trade liberalization. *Amer. Econom. J.: Appl. Econom.* 2(4):105–127.

Gurbaxani V, Whang S (1991) The impact of information systems on organizations and markets. *Comm. ACM* 34(1):59–73.

Hagiu A, Yin P-L, Beyersdorfer D, Dessain V (2007) SAP: Industry transformation. HBS Case 9-707-435, Harvard Business School, Boston.

Hart O, Moore J (2005) On the design of hierarchies: Coordination versus specialization. *J. Political Econom.* 113(4):675–702.

Hitt L, Brynjolfsson E (1997) Information technology and internal firm organization: An exploratory analysis. *J. Management Inform. Systems* 14(2):81–101.

Holmes T (2011) The diffusion of Wal-Mart and the economics of density. *Econometrica* 79(1):252–301.

Hunter L, Bernhardt A, Hughes K, Skuratowicz E (2001) It's not just the ATMs: Technology, firm strategies, jobs and earnings in retail banking. *Indust. Labor Relations Rev.* 54(2):402–424.

Jensen MC, Meckling WH (1992) Specific and general knowledge and organizational structure. Werin L, Wijkander H, eds. *Contract Economics* (Blackwell, Oxford, UK), 251–274.

Kretschmer T, Mahr F (2009) Complementaries between technologies: Survey evidence. Mimeo, University of Munich, Munich, Germany.

Lemieux T, MacCleod B, Parent D (2009) Performance pay and wage inequality. *Quart. J. Econom.* 124(1):1–49.

Malone TW, Yates J, Benjamin RI (1987) Electronic markets and electronic hierarchies. *Comm. ACM* 30(6):484–497.

Manski C (2004) Measuring expectations. *Econometrica* 72(5): 1329–1376.

McElheran KS (2014) Delegation in multi-establishment firms: Adaptation vs. coordination in I.T. purchasing authority. *J. Econom. Management Strategy* 23(2):225–258.

Melumad ND, Mookherjee D, Reichelstein S (1995) Hierarchical decentralization of incentive contracts. *RAND J. Econom.* 26(4): 654–672.

Milgrom P, Roberts J (1990) The economics of modern manufacturing: Technology, strategy, and organization. *Amer. Econom. Rev.* 80(3): 511–528.

OECD (Organization for Economic Co-operation and Development) (2007) *Telecommunication Handbook* (OECD, Paris).

Prendergast C (2002) The tenuous trade-off between risk and incentives. *J. Political Econom.* 110(5):1071–1102.

Radner R (1993) The organization of decentralized information processing. *Econometrica* 61(5):1109–1146.

Rajan R, Wulf J (2006) The flattening firm: Evidence from panel data on the changing nature of corporate hierarchies. *Rev. Econom. Statist.* 88(4):759–773.

Rajan RG, Zingales L (1998) Financial dependence and growth. *Amer. Econom. Rev.* 88(3):559–586.

Sambamurthy V, Zmud RW (2000) Research commentary: The organizing logic for an enterprise's IT activities in the digital era—A prognosis of practice and a call for research. *Inform. Systems Res.* 11(2):105–114.

Shepard J, Klein E (2006) Enterprise resource planning spending report, 2006–2007. AMR Research, New York.

Skinner J, Staiger D (2007) Technological adoption from hybrid corn to beta blockers. Berndt ER, Hulten CR, eds. *Hard-to-Measure Goods and Services: Essays in Honor of Zvi Griliches*, Chap. 18 (University of Chicago Press, Chicago), 545–570.

Stevenson B (2006) The Impact of the Internet on worker flows. Mimeo, Wharton Business School, Philadelphia.

Timmer MP, Ypma G, van Ark B (2003) IT in the European Union: Driving productivity divergence. GCDC Research Memorandum GD-67, Groningen Growth and Development Center, Groningen, The Netherlands.