The distinct effects of Information Technology and Communication Technology on firm organization

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Abstract

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 dataset of American and European manufacturing firms, we find indeed that better information technologies (Enterprise Resource Planning for plant managers and CAD/CAM for production workers) are associated with more autonomy and a wider span, while technologies that improve communication (like data intranets) decrease autonomy for workers and plant managers. Using instrumental variables (distance from ERP's birthplace and heterogeneous telecommunication costs arising from regulation) strengthens our results.

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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 sales man. 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 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?

In this paper we argue that while most economic studies of the effect of ICT on firm organization, inequality and productivity treat ICT as an aggregate capital stock, these technologies have at least two distinct components. First, through the spread of cheap storage and processing of data, information is becoming cheaper to access (IT). Second, through the spread of cheap wired and wireless communications (CT), agents find it easier to communicate with each other (e.g. through e-mail 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. But when matching problems and solutions is expensive, the organization of knowledge is hierarchical: those "below" deal with the routine prob-

[1] IThe full phrase in the "Ambassador" entry of Wikipedia says (accessed on October 11, 2013) "Before the development of modern communications, ambassadors were entrusted with extensive powers; they have since been reduced to spokespeople for their foreign offices."

[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.

lems, and those "above" deal with the exceptions. For example, in a law firm, low level lawyers handle the document making, partners add the expert knowledge. Similarly, in the shop floor, lower level production supervisors deal with routine issues, while 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 from the corporate head quarters (CHQ) to plant managers over the decision whether to invest in new equipment 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 head quarters. Relying more on the direction of corporate head quarters 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 allows 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 makes 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 while 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 technologies (information vs. communication). We apply this framework in a world with two types of decisions, production and non-production ones.

First, we consider *non-production decisions*. These decisions can either be taken at the corporate head quarters 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 Section 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

[3] We present survey evidence consistent with our discussions with technology experts that *ERP* primarily reduces

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 in the plant hierarchy. 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 to access less their superiors to inform their decisions. Thus this technology should increase worker autonomy and, by reducing the amount of help workers need from plant managers, increase the span of control of plant managers. In sum, we expect 'information technologies' (ERP and CAD/CAM) to decentralize decision making respectively in non production decisions (from CHQ to plant managers) and in production decisions (from plant managers towards production workers).

On the other hand, as we argued above, we expect *communication technologies* to increase centralized decision making. This will be true both for types of decisions 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 head quarters will take more of their decisions). A key technological innovation affecting communication is the growth of intranets ("INTRANET"). We test whether the availability of intranets reduced the decision making autonomy in production decisions of workers, and in non-production decisions of managers.

We utilize a new data set that combines manufacturing plant-level measures of organization and ICT across the US 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 dataset is from a private sector data source (Harte-Hanks) that has been used mainly to measure hardware utilization in large publicly listed firms (e.g. Bresnahan et al, 2002). We will 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 the firm organization: (i) decentralization from head quarters to plant manager; (ii) decentralization from plant manager to workers and (iii) the plant manager's span of control. But 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 which was the German birthplace of the *SAP* company and 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

information acquisition costs rather than reducing communication costs (see Appendix B).

[4]Examples of how geographical proximity is important for diffusion include Henderson, Jaffe and Trajtenberg (2003), Skinner and Staiger (2007), Griffith, Lee and Van Reenen (2011), Holmes (2011) and (for a survey) Foster and Rosenzweig (2010). Becker and Woessmann (2009) use distance from Wittenberg as in instrument for the spread of Protestantism in Germany which they show fosters human capital. Note that in our regressions we control for human

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 use this to identify the effect of communication costs on decentralization. Our 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 non-production decisions (like ERP) tend to empower plant managers (relative to the head quarters) 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 due to 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 takes typically organization as exogenous.[5] A second branch tries to endogenize organization, but 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 the result of coordination issues (Cremer et al., 2007 and 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

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 due to its impact on coordination costs (Malone, Yates, and Benjamin, 1987; McElheran, forthcoming), informational economies of scale (Brynjolfsson, 1994), and increased speed and quality of decisionmaking (Gurbaxani and Whang, 1991). However, others suggest that ICT may complement decentralization thanks to ite 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, forthcoming), 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 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, Brynjolsson and Hitt (2002), Bartel, Ichinowski and Shaw (2007) and Bloom, Sadun and Van Reenen (2012a). See also the survey in Draca, Sadun and Van Reenen (2007).

[6]For example see Acemoglu et al (2007), Caroli and Van Reenen (2001), Colombo and Delmastro (2004), Crepon et al (2004) and Aubert et al (2004). 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 (2003, 2004), Garicano and Heaton (2010), or the case studies in Blanchard (2004).

robustness tests.[8]

We proceed as follows. In Section 2 we discuss a basic theoretical framework that allows us to study the impact of information and communication technologies. We then discuss our data (Section 3), and map the model to the data by focusing on some key factors that affected information and communication costs. Finally, we discuss possible alternative mechanisms driving the relationship between the technological variables and the organizational outcomes that we consider (Section 4) and present our results (Section 5). The final section 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' only deal with a fraction of problems - that is, those in $(0, z_p)$- and ask for help on the rest to 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, that is 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

[8] Our work also relates to the wider theoretical literature on firm delegation. For example, see Baron and Besanko (1992), Melumad et al (1995), Mookherjee (2006), 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 the cost of learning is linear so that learning z problems costs az. This is without loss, as we can redefine problems of tasks so that $f(z)$ is the frequency of a renormalized (equal cost) problem.

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 solve their problems.

Suppose a team must deal with N problems per unit of time. The team needs N production workers 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', receiving a wage w_m, is:[11]

$$\pi = N - N(a_p z_p + w_p) - n_m(a_m z_m + w_m) \tag{1}$$

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 less 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:

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

The following comparative statics follow immediately.

[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- while 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 learnt 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 Section 3.2. extends the framework in Garicano (2000).

[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 $h(1 - F(z_p))(a_m + w_m)$ by $h(1 - F(z_p))(a_m(1 - z_p) + w_m)$. Overlapping knoweldge could result from learning that takes place on the job or because the process of learning involves learning the 'easy' tasks first.

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 on span of control $s = N/n_m$ (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 (as less questions are asked).*

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

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 sum, while communication cost reductions facilitate the reliance of 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 non-production decisions. We show that the same comparative statics that govern the allocation of production decisions between production workers managers also hold for the allocation of non production decisions between the plant manager and the company head. That is, we can equivalently interpret the theoretical result in the proposition above by only relabelling the workers and managers as respectively middle managers and corporate headquarters.

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 non production case), while a technology that lowers communication costs reduces this autonomy. Figures 3 and 4 below graphically shows 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 autonomy, plant manager autonomy and plant manager span.

3 Data

We use a new international micro dataset combining novel sources from the US and several European countries to test the empirical relevance of the model presented in Section 2. Our two main sources of data are the Center for Economic Performance (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, industry and macro-economic data. The full dataset plus all Stata do files are available on 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 US and Asia. In this paper we use data on approximately 1,000 firms from the US, France, Germany, Italy, Poland, Portugal, Sweden and the UK for which we were able to match the organization data with ICT data from an independent database (which only has data on a sub-sample of our countries). Appendix B provides detailed information on our sources, but we summarize relevant details here.

The CEP survey uses the "double-blind" technique developed in Bloom and Van Reenen (2007) to try and obtain unbiased accurate responses to the survey questions. One part of this double-blind methodology is that managers were 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 knew nothing about the performance of the firm as they were 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% which was uncorrelated with firm profitability or productivity overall and in 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 3 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 head quarters. This is a continuous variable enumerated in national currency (which we convert into US dollars using Purchasing Power Parities). We also asked where decisions were effectively made in three other dimensions: (a) hiring a new full-time permanent shopfloor 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 head quarters, to a five, defined as complete power ("real authority") of the plant manager, and intermediate scores varying degrees of joint decision making. In Table A2 we detail the individual questions (D1 to D4) and scoring grids in the same order as they appeared in the survey.

Since the scaling may vary across all 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 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 A2 (questions D6 and D7). These questions are scaled on a one to five basis, with a one denoting managers have full control, and a five denoting workers have full control over the pace of work and allocation of tasks. Our measure of workers' autonomy is a dummy taking value 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 A2 (question D8). The interviewers were explicitly trained to probe the number of people that *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). But we try to get a sense of senior management's (CHQ) span of control by asking about whether the firm was single or multi-plant firm, with the idea being that multi-plant firms lead to larger spans at senior management level.

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

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

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 our sampling frames from BVD (Amadeus in Europe and ICARUS in the US), 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 an plant level ICT panel 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, as 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, enabling them to ensure high levels of accuracy.

The HH data has 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 to 2006 (i.e. prior to the 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 US HH hardware data, but few papers have used the software data. And 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 affect differentially 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, in the form most notably 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 they map clearly into reductions in communication costs (INTRANET) and reductions

[15] This is based on reviewing the literature, US, UK, China and India factory visits and discussions with engineers and consultants at Sun Microsystems, EDS, HP, McKinsey and Accenture.

in information acquisition costs in production (CAD/CAM) and management (ERP), as we discuss in detail in the Appendix A. In sum, our hypothesis concerning these variables, given the model presented in Section 2 are as follows:

- Falling information acquisition costs for non-production decisions (proxied by ERP) 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 (they can manage more workers if these workers are making more of their own decisions)
- Finally, falling communication costs (proxied by INTRANET) have negative effects on autonomy and ambiguous effects on spans (each worker does more but will ask more question).

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

In practice, the presence of any of these technologies at the plant level is codified 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 then those pending the go-live decision) which Aral et al (2009) highlight as important.
- HH defines under "workstation applications" the presence of CAD/CAM's, 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 to be both 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.

[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 PSTN 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 quickly, and 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 non-production decisions, but affects communication through out the firm.

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.

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 'hierarchical/vertical' communication by 'horizontal' or peer-to-peer communication as Cremer et al (2007) have noted. As a result, if coordination across units becomes easier and less hierarchical, we could also expect (similarly 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 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 hypothesis, 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 A3 and discussed in section 5.2.2). Our tests rely on the observation that, as Hart and Moore (2005) have argued if technology is affecting centralization through its impact on coordination, its impact must be higher where coordination needs are particularly relevant. 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) where the headquarters and the plant are located separately. We do not find 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 Cremer 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, as 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, decrease 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 (less incentives and less delegation).

We do not have clear priors 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, Levy and Murnane (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

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

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 allows 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, which the automation perspective is largely silent on.

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 four types of organizational outcomes for which we have data: the autonomy of the worker (O = AW), the autonomy of the plant manager (O = AP), the span of control of the plant manager (O = SP) and the span of control of the CHQ (O = SC). As in the theory, a denotes information access costs and h denotes communication (helping) costs. The x_{ijk} denote 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 "non-production" autonomy the plant manager has from the corporate head quarters (e.g. how much investment could be made without corporate head quarters' 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 substitute in the relevant indicator from HH (INTRANET lowers h; ERP and CAD/CAM lower a). To be more explicit the three regressions we will estimate are:

Autonomy of the plant managers (AP)

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

Autonomy of the worker (AW)

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

Span of control of the plant manager (SP)

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

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 workers' 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 $1 \geqslant \eta_1, \eta_2 > \frac{1}{2}$. 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 which may potentially confound our key results.

5.2 Basic Results

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

5.2.1 Plant Manager Autonomy

Table 3 contains the empirical results for plant managers' 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

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

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 non-production decisions. As the theory predicts, ERP is associated with more autonomy of plant managers (relative to the corporate head quarters) as 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 him to access information more easily and solve more problems without referring them upwards. 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 plant which enters with a negative and insignificant sign. The ambiguity of the IT hardware variable is unsurprising as greater computer intensity simultaneously lowers information costs and communication costs which, according to our theoretical model, have opposite effects on autonomy. Despite the extra controls, the coefficient on ERP remains positive and significant at the 10% level.

The third column 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 which our theory suggests reflects the fact that lower communication costs imply that corporate head quarters make more decisions than the plant manager as 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) includes 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.

5.2.2 Coordination Costs

As discussed in sub-section 4.1, an alternative reason why 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. That 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 which show that ERP tends to result in decentralization (a positive coefficient in Table 3), while

[21] We investigate the endogeneity of the technology variables in depth in Table 6. One inital check on whether the OLS results are upwards 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.

[22] The results are robust to clustering at a higher level, such as by industry country cell. For example, in the final column the coefficients (standard errors) are 0.192(0.085) and -0.188(0.096)

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 co-located. We examine this in Table A3 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 sub-sample of domestic firms and column (3) at multinational firms. The results for domestic firms look like those in the overall sample in column (1). The results in column (3) are actually weaker for ERP which goes against a coordination story, while 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) to (7) of Table A3 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 sub-samples and neither ERP or INTRANET have a significant interaction with the industry terms. Finally, columns (8) to (10) use an indicator of whether the plant we interviewed is co-located 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 are 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 co-ordination is unlikely to be responsible for generating the covariance patterns between plant manager autonomy and the ICT we examine here.

5.2.3 Workers' Autonomy and Managerial Span of Control

Table 4 and 5 analyze the relationship between information and communication technologies with workers' autonomy and plant manager span of control (this follows exactly the order of 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 coefficient which 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 help worker information access enable

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

them 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 (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 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 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 sub-section 3.3.). Thus, we interpret our evidence on ICT and firm organization as providing some support for the cognitive view of hierarchies discussed in section 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 to simulate an increase in the diffusion of our ICT indicators. Given the debate over whether the increasing productivity gap between Europe and the US in the decade since 1995 was related to ICT (e.g. Bloom, Sadun and Van Reenen, 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 EU and the US 2000-2004).[24]

An increase in the penetration of ERP of 60% over the sample average of 34% is about 20 percentage points. Using the final column 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 by 38% (using the coefficients in the plant manger autonomy regression) which is a third higher than the increase in education achieved by the US between 1990 and 2000 of about 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's autonomy by about 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 0.8% (equivalent to a 27% fall in the college share using the coefficients in the worker autonomy regression). Finally, consider a 60% increase in CAD/CAM. This is associated with a 0.4% increase in plant manager's span (equivalent to a 10% rise in the college share) and a 1.6% increase in worker autonomy (equivalent to 5.7% increase in the college share). This is lower because the mean of CAD/CAM is lower than the other technologies.

[24] This is based on the EU KLEMS data. See Timmer, Yppa and Van Ark (2003) Table 5 for a similar figure for 2001 and a description of the data.

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's autonomy and INTRANET on all three organizational dimensions.

5.4 Extensions and Robustness

5.4.1 Endogeneity

Tables 3 through 5 presented conditional correlations that seemed 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 as there may be some unobservable that is correlated with the organizational outcomes and our measures of information and communication costs (especially as these are all measured at the firm level). We take some reassurance in the fact that although these ICT indicators are positively correlated in the data,[25] 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 (proxied by ERP) is opposite in sign to communication technologies (INTRANET) both theoretically and empirically. For endogeneity to generate these results, the hypothetical unobservable positively correlated with decentralization would have to mimic this 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 sub-section 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 remains 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 plays a role in 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 equal. Since our firms are medium sized enterprises who could also learn from these earlier adopters (ERP is more common among very large enterprises), we use the closeness to Walldorf as an exogenous factor that shifts the probability of adopting an ERP. We focus on Continental Europe as the US and UK are separated by sea from Germany, making "distance" harder to define, and drop subsidiaries of multinational firms as there is no obvious distance measure for such global corporations.

We regress the presence of ERP in the plant on the ln(distance in kilometers) to Walldorf in

[25] For example, the pairwise 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 re-estimate Table 3 using this alternative identification strategy.

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 (around 24%) to adopt an ERP system. When entered instead of ERP in the plant manager autonomy equation (the "reduced form" of column (2)), the coefficient on distance is again negative and (weakly) significant. Column (3) 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 sub-sample of Table 6, 45% of firms use ERP, of whom 30% use SAP and 70% use a variety of other ERPs offered by vendors like Oracle, Sage and Microsoft. Since our instrumental variable should be most powerful for 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 the distance to Walldorf only predicts the adoption of SAP ERP and not other makes of ERP this suggests it reflects some SAP effect rather than some other unobservable 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 observables such as INTRANET 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. Nicoletti and Scarpetta, 2003; Azmat et al, 2012; OECD, 2005, 2007). We discuss these in more detail Appendix C.

We exploit these differential costs using 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 US$. 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

[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).

[28] The magnitude of the effect is much larger than in the simple OLS specifications. This could be due to correcting attenuation bias from measurement error and/or reverse causality - for example, plants which are for some exogenous reason more decentralized may find it difficult to coordinate on introducing an ERP system which will require some consolidation of databases.

[29] We ran four separate placebo regressions where the dependent variables were INTRANET, PC intensity, skills or 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 Table 6 column (2) except we dropped the endogenous left hand side variable from the covariate set.

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

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 proxy this reliance by using the intensity of intranet use in the industry pooling the data across all countries ($INTRANET_j$).[31] The instrument is defined 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 the first three columns as 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: less intranets imply more decentralization. In column (6), the second stage coefficient is large, negative and significant as predicted by the theory.[32]

The final column 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 sub-sample 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 Head Quarters' Span of Control

Table A4 showed that the theory also generates predictions for the span of control of the corporate head quarters (CHQ). Although we had 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 A6. The clear theoretical prediction is that ERP should

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

[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 (.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 A4 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 A5. None of the earlier conclusions change with respect to the earlier tests: INTRANET are 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.

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 A6, 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 Section 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 bonus (direct incentive pay) and the increase in pay upon promotion (a career concerns mechanism).

Columns (1) through (3) of Table A7 include a variable indicating the proportion of the plant manager's pay that was bonus (rather than flat salary).[35] Columns (4) through (6) includes 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 as 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. But the robustness of our results to explicit controls for incentives suggest that there is a role for the cognitive theory we emphasis 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 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) simply repeats the baseline specifications from the final column in Tables 3 through 5.

In Bloom, Sadun and Van Reenen (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) 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 cost 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

[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, MacLeod and Parent (2009) for how performance pay has grown in importance over time.

(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 (Local Area Networks) or WAN (Wide Area Networks).[37] The LAN/WAN indicator is highly correlated with INTRANET and the results are very similar to the baseline. The only difference is that, 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 as they are potentially endogenous and column (8) conditions on the sub-sample 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 together 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, as decisions will be passed up to the centre of the firm. Falls in information acquisition costs will have the opposite effect, facilitating more effective employee decision-making. This matters, as the returns to skill at different levels of the organization depend on the importance of the decisions taken at those levels.

First, we consider non-production decisions (investment, hiring, new products and pricing). These decisions can either be taken by the CEO at corporate head quarters 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 should (according to our theory) be associated with decentralization of decision making towards middle managers. Second, we consider

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

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

[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.

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 the adoption of Computer Assisted Design and Computer Assisted Manufacturing (CAD/CAM). A worker with access to those technologies can solve design and production problems better, and thus needs less access to his superiors in making decisions. This should lead to the decentralization of non-production decisions towards the factory floor. Third, we expect the impact of communication technologies to be the 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 centralization of both types of decisions within the firm, as providing input from afar becomes cheaper relative to making decisions on the spot.

We confirm all these predictions on a new dataset that combines plant-level measures of organization and ICT hardware and software adoption across the US 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. But we also show that treating technology as endogenous strengthens the results. Our instrumental variables are distance from the birthplace 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. Firstly, it would be interesting to examine in more detail the reasons for differential adoptions of technologies across firms and countries as 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. Secondly, the theory could be developed to consider interactions between different type of production and non-production technologies at other layers of the hierarchy. Finally, one could more systematically examine the effect of differential type of ICT adoption and organization on other outcomes such as productivity and wage inequality at the level of the industry and economy.[39]

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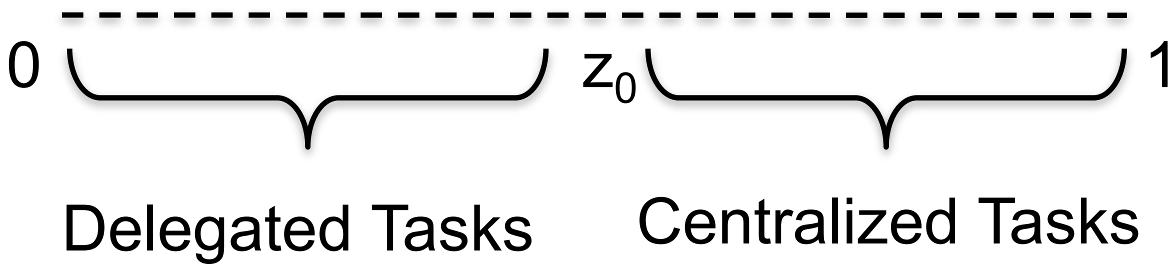
Figure 1: Delegation of tasks in the Basic Model



Notes: $z \in [0, z_0]$ Performed by lower level agents

$z \in (z_0, 1]$ Passed on to the higher level

Figure 2: Management span and autonomy

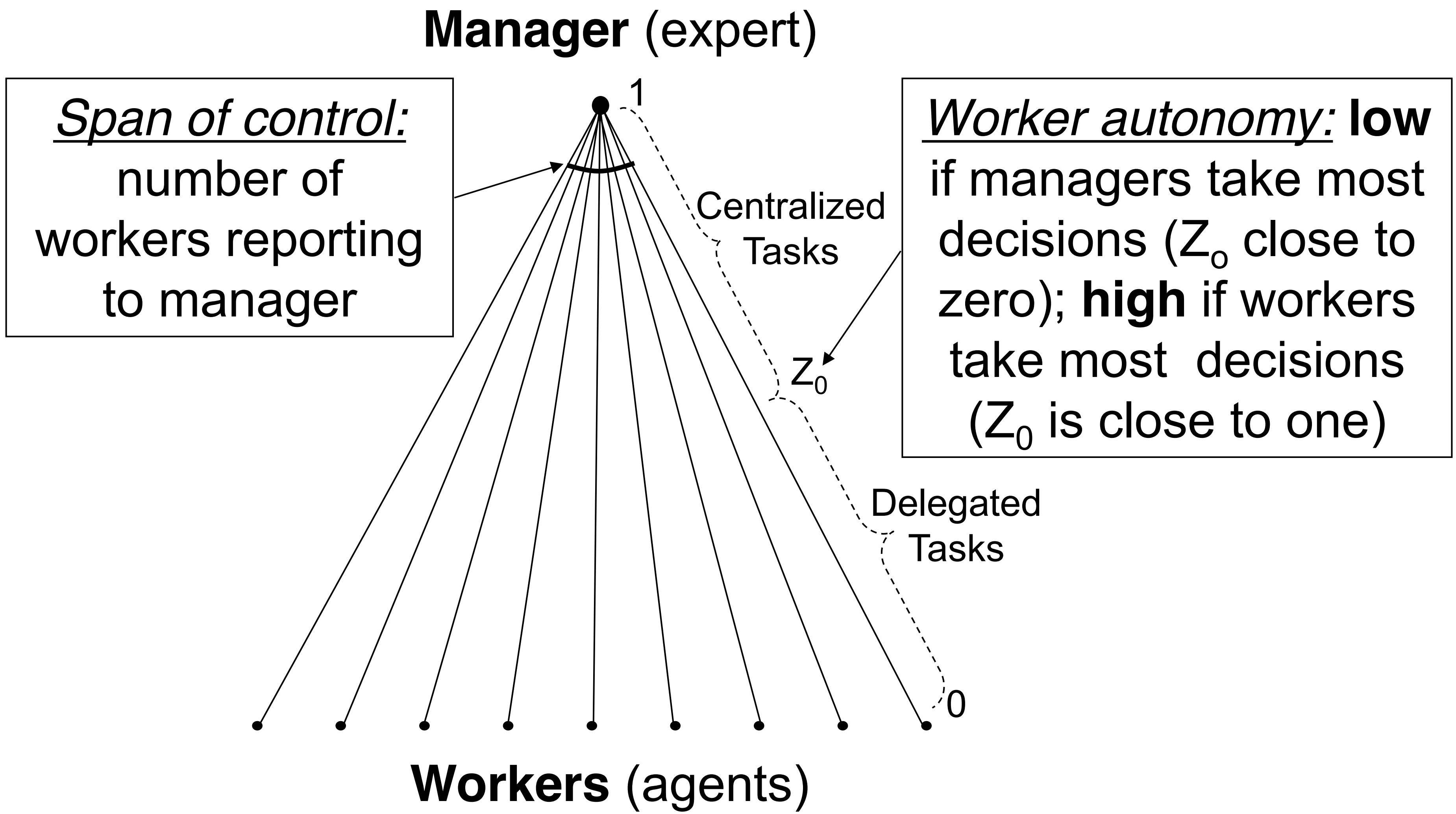
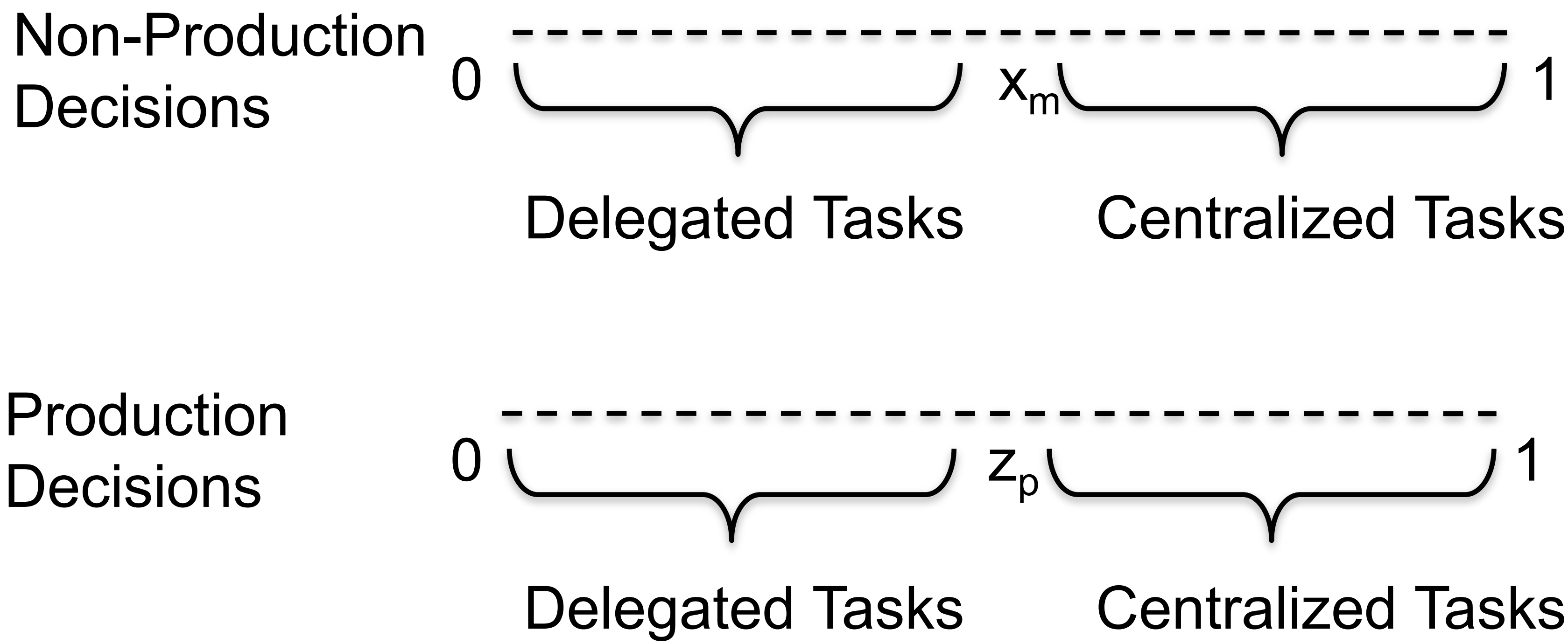


Figure 3: Delegation of tasks in the extended model



Notes: This generalizes Figure 1 where we allow for non-production decisions and production decisions. Non-production decisions below x_m are performed by plant managers, the rest by central head quarters. Production decisions below z_0 are performed by production workers, the rest by plant managers

Figure 4: Information and communication

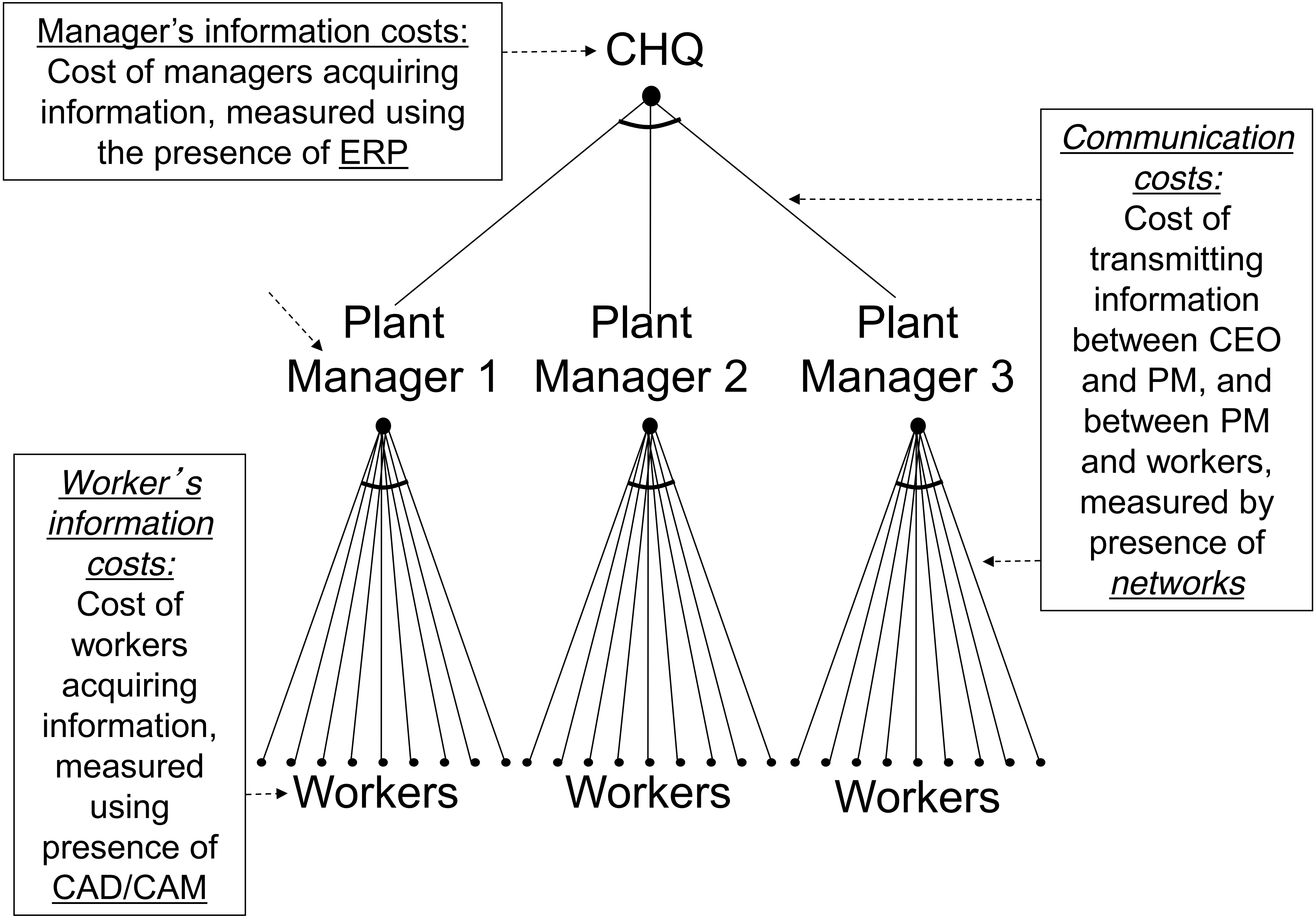
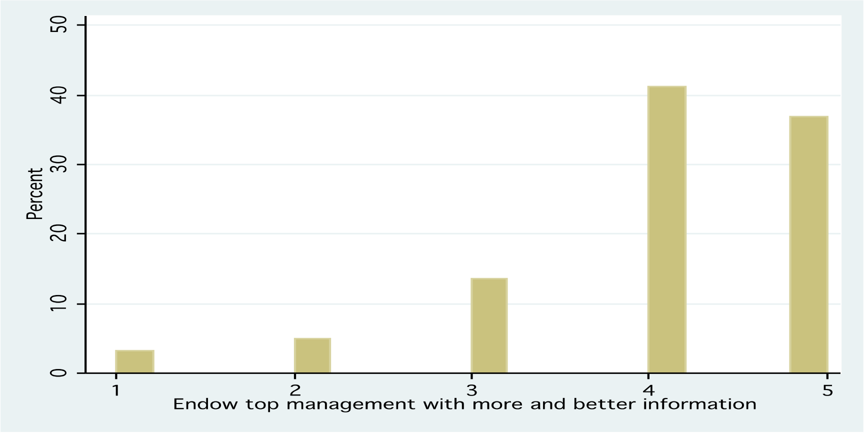
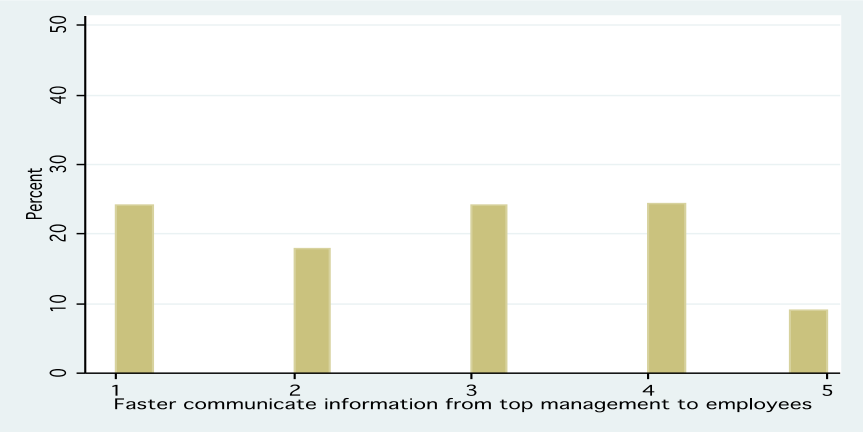


Figure A1: Enterprise Resource Planning (ERP) use

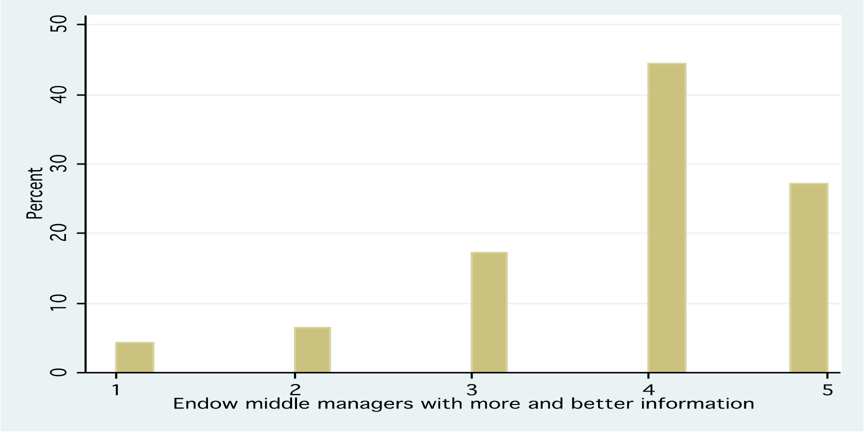
Q1: *"Our ERP System is used to endow* ***top management*** *with more & better* ***information****"*



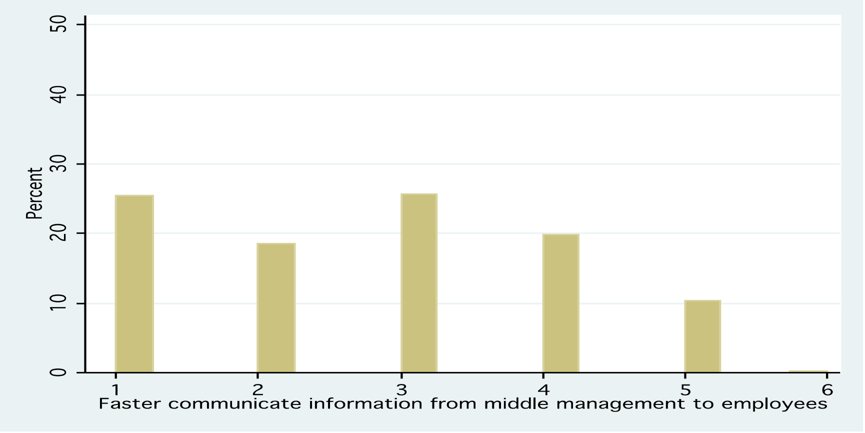
Q2: *"Our ERP System is used to faster* ***communicate*** *information and directives from* ***top management*** *to employees"*



Q3: *"Our ERP System is used to endow* ***middle management*** *with more & better* ***information****"*



Q4: *"Our ERP System is used to faster* ***communicate*** *information and directives from* ***middle management*** *to employees"*



Notes: Answers range from 1="strongly disagree" to 5="strongly agree". Each bar represents the % of respondents in the relevant bin from 431 firms. See Appendix B for details.

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 workers' autonomy; and Column (3) refers to span of control (for plant manager and CEO). *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 "-'' a decrease a "0" denotes no effect and "?'' denotes an ambiguous sign. All empirical coefficients are statistically significant at the 5% level except those marked ("insig.").

TABLE 2 - SUMMARY STATISTICS

Variable	Mean	Median	Standard Deviation	Firms
Employment (Firm)	961.701	350	3255.548	945
Employment (Plant)	249.521	153	276.077	912
Plant Manager Autonomy	0.255	0	0.982	950
Workers' Autonomy	0.076	0	0.265	937
Ln(Plant Manager SPAN)	1.891	2	0.523	875
CEO Span (Multi-plant 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
% Increase salary on promotion	0.214	0	0.189	611
Leased Line Price (PPP 2006 USD)	4985.139	5260	1437.936	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 Table 4). The mean of plant manager's autonomy is not zero as it was z-scored over the (larger) CEP sample.

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: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. The dependent variable is the z-score of plant manager autonomy (mean=0 and standard deviation=1) across four questions relating to plant manager's control over hiring, investment, product introduction and marketing (see text). All columns are estimated by OLS with standard errors in parentheses (robust and clustered by firm). The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the UK and the US (country dummies included). All columns include a full set of three digit industry dummies, "Noise controls" (analyst fixed effects, plant manager seniority and tenure in company, the day of the week the interview was conducted, 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 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 number of firms because some firms were interviewed more than once across different plants.

TABLE 4 – WORKERS' AUTONOMY

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable			Workers' Autonomy			
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: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. The dependent variable in all columns is a dummy equal to unity if the plant manager reports that tasks allocation and pace of work are determined mostly by workers (instead of managers). All columns are estimated by probit ML with standard errors in parentheses (robust and clustered by firm). Marginal effects (evaluated at the mean) 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 UK and the US (country dummies included). A full set of three digit industry dummies, "Noise controls" (analyst fixed effects, plant manager seniority and tenure in company, the day of the week the interview was conducted, interview duration and reliability) and a variable summarizing the number of Harte Hanks cross sections over which the technology variables have been computed. "CAD/CAM" denotes Computer Assisted Design/ Computer Assisted Manufacturing and "INTRANET" denotes the firm has an internal intranet (leased lines or frame relays). There are more observations than number of firms because some firms were interviewed more than once across different plants.

TABLE 5 - PLANT MANAGER SPAN OF CONTROL

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	**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: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. 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 (robust and 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 UK and the US (country dummies included). All columns include a full set of three digit industry dummies, "Noise controls" (analyst fixed effects, plant manager seniority and tenure in company, the day of the week the interview was conducted, interview duration and reliability) and a variable summarizing the number of Harte Hanks cross sections over which the technology variables have been computed. "CAD/CAM" denotes Computer Assisted Design or Manufacturing software and "INTRANET" denotes the firm has an internal intranet (leased lines or frame relays). There are more observations than number of firms because some firms were interviewed more than once across different plants.

TABLE 6 – PLANT MANAGER AUTONOMY, INSTRUMENTAL VARIABLE ESTIMATES

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent Variable	**ERP**	**Plant Manager Autonomy**	**Plant Manager Autonomy**	**INTRANET**	**Plant Manager Autonomy**	**Plant Manager Autonomy**	**Plant Manager Autonomy**
Regression	**1st Stage**	**Reduced Form**	**2nd Stage**	**1st Stage**	**Reduced Form**	**2nd Stage**	**2nd Stage**
ERP			1.876**				1.540*
			(0.780)				(0.799)
INTRANET						-2.771*	-3.198
						(1.517)	(2.248)
Ln(Distance to Walldorf)	-0.237**	-0.445*					
	(0.104)	(0.242)					
Ln(INTRANET Price) *(Industry INTRANET Intensity)				-1.439*	3.988**		
				(0.779)	(1.928)		
Number of observations	165	165	165	956	956	956	165
Number of firms	161	161	161	908	908	908	161

Notes: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. The dependent variable is the z-score of plant manager autonomy. Standard errors are robust and 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, Heidelberg (the head quarters and founding place of SAP). The instrument for INTRANETs 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 PPP USD (taken from the OECD *Telecommunication Handbook*, 2007). Regressions weighted by the plant's share of firm employment. There are more observations than number of firms because some firms were interviewed more than once across different plants.

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 3 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: Workers' 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: * = significant at the 10%, ** = 5%, ***= 1%. Panel A and C 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. sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the UK and the US (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" = Enterprise Resource Planning, "INTRANET" = firm has an internal intranet (leased lines or frame relays) and "CAD/CAM" = Computer Assisted Design or Manufacturing. In column (2) regional (NUTS2) dummies and the inverse of the Lerner index are included as additional controls. In column (3) the 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 question 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 number of firms because some firms were interviewed more than once across different plants.

TABLE A1 - ERP SURVEY: THE IMPACT OF ERP IS MORE ON INFORMATION COSTS THAN ON COMMUNICATION COSTS

	(1)	(2)	(3)	(4)
Dependent Variable	**DIF1**	**DIF1**	**DIF2**	**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: Countries are Germany and Poland (Kretschmer and Mahr, 2009). Estimation by OLS. Robust standard errors below coefficients. Industry controls are three digit employment. Questions are on a 1 to 7 Lickert 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 dependent variable:
DIF1 = Q24 – Q23
DIF2 = Q24 – Q26
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.

TABLE A2: DETAILS OF THE DECENTRALIZATION SURVEY QUESTIONS

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.

Question D1: "*To hire a FULL-TIME PERMANENT SHOPFLOOR worker what agreement would your plant need from CHQ (Central Head Quarters)?*"
Probe until you can accurately score the question – for example if they say "*It is my decision, but I need sign-off from corporate HQ*." 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 CHQ based on the business case. Typically agreed (i.e. about 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. >$¼m in US) 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 US firm twenty thousand dollars would be 20000).

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 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 CHQ	Sales and marketing decisions are split between the plant and 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 out the following five options, with our scoring for these note above:	All managers	Mostly managers	About equal	Mostly workers	All workers

Question D7: "Who decides the pace of work on the shopfloor"

	Score 1	Score 2	Score 3	Score 4	Score 5
Interviewers are read out the following five options, with "customer demand" an additional not read-out 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?"

Notes: The electronic survey, training materials and survey video footage are available on http://worldmanagementsurvey.org/

TABLE A3: CO-ORDINATION 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 HQ and plant are co-located**		
	Baseline	**Domestic**	**Foreign or Domestic Multinational**	**Pooled**	**Single industry**	**Multiple industry**	**Pooled**	**HQ and plant co-located**	**HQ and plant not co-located**	**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*HQ and plant not co-located										0.016
										(0.162)
INTRANET* HQ and plant not co-located										-0.072
										(0.169)
MNE				0.073						
				(0.124)						
Multiple Industries							0.019			
							(0.118)			
HQ and plant not co-located										-0.130
										(0.148)
Observations	1000	648	352	1000	518	438	956	439	561	1000
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: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. The dependent variable is the z-score of plant manager autonomy (mean=0 and standard deviation=1) across four questions relating to plant manager's control over hiring, investment, product introduction and marketing (see text). All columns are estimated by OLS with standard errors in parentheses (robust and clustered by firm). The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the UK and the US (country dummies included). All columns include a full set of three digit industry dummies, "Noise controls" (analyst fixed effects, plant manager seniority and tenure in company, the day of the week the interview was conducted, 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 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 number of firms because some firms were interviewed more than once across different plants. MNE is a dummy taking value one if the plant belongs to a domestic or foreign multinational. "Multiple industries" is a dummy taking value one if the firm appears to be active in multiple primary or secondary four digit SIC codes. "HQ and plant not co-located" is a dummy taking value 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 onsite.

TABLE A4 – EXTENDED THEORY PREDICTIONS

		(1)	(2)	(3)	(4)
		Plant Manager Autonomy (x_m)	**Worker Autonomy (z_p)**	**Plant Manager Span of Control (s_m)**	**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 non-production 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 "-'' a decrease a "0" denotes no effect and "?'' denotes an ambiguous sign.

TABLE A5 – CROSS EFFECTS OF TECHNOLOGIES

	(1)	(2)	(3)
Dependent Variable	**Plant Manager Autonomy**	**Workers' Autonomy**	**Ln(PM 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: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. Rows correspond to separate regressions based on final most general specifications in Tables 3 - 5. All equations estimated by OLS except Worker autonomy equation which is estimated by probit ML with marginal effects (evaluated at the mean) in square brackets. Standard errors are robust and clustered by firm. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the UK and the US (country dummies included). ERP" denotes Enterprise Resource Planning, "INTRANET" denotes the firm has an internal intranet (leased lines or frame relays) and "CAD/CAM" denotes Computer Assisted Design or Manufacturing software.

TABLE A6 – CEO SPAN OF CONTROL

	(1)	(2)	(3)
Dependent Variable		**CEO Span of Control**	
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: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. 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 (robust and 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 UK and the US (country dummies included). All columns contain the same controls in Table 3-5 "ERP" denotes Enterprise Resource Planning and "INTRANET" denotes the firm has an internal intranet system (leased lines or frame relays).

TABLE A7 - CONTROLLING FOR CONTINGENT PAY

Dependent Variable	(1) Plant Manager Autonomy	(2) Workers' Autonomy	(3) Ln(Plant Manager Span)	(4) Plant Manager Autonomy	(5) Workers' 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: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. All columns 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) in square brackets. Standard errors are robust and clustered by firm in all columns. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the UK and the US (country dummies included). All columns include the same controls as Table 3 through 5. "ERP" denotes Enterprise Resource Planning, "INTRANET" denotes the firm has an internal intranet (leased lines or frame relays) and "CAD/CAM" denotes Computer Assisted Design or Manufacturing software.