LS/PPL
7/25/08
10:00 am

The distinct effects of information technologies and communication technologies on firm organization[*]

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July 10, 2008

Abstract

Economic studies on information communication technologies (ICT) typically combine the 'information' and 'communication' components together. We show, however, that theoretically and empirically these have very different effects on the empowerment of employees, and therefore on wage inequality and productivity. If hierarchies are devices to acquire and transmit knowledge, technologies that enable agents to acquire knowledge will empower agents and allow the managers of those agents to increase their span of control. Conversely, technologies enabling communication will lead to the centralization of decision making. We study the impact of ICT on worker autonomy, plant manager autonomy and spans of control. Consistently with the theory we find that better information technologies (ERP, Enterprise Resource Planning for plant managers and CADCAM for production workers) increases autonomy and widens the span of control. By contrast, communication technologies (like data networks) decrease autonomy for both workers and plant managers. This is robust to using exogenous cross-country variation in the costs of data networks arising from differential regulatory regimes.

JEL No. O31, O32, O33, F23

Keywords: organization, information technology, communication technology, decentralization, span of control, theory of the firm.

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[*]**PRELIMINARY AND INCOMPLETE**. We would like to thank the ESRC for help with financing this research at the Centre for Economic Performance. Oriana Bandeira, Steven Pischke, Andrea Prat and participants at the LSE Labor workshop have given useful comments.

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1 Introduction

Most studies of the impact of information and communication technologies (ICT) on firm organization, inequality and productivity[1] treat ICT as an aggregate homogeneous capital stock. However, these technological changes have at least two distinct components. First, through the spread of cheap storage and processing of data, information is becoming cheaper to access. Second through the spread of cheap wired (IP-based) and wireless communications, agents find it easier to communicate with each other (e.g. e-mail and mobile phones). These two distinct changes can be expected to have a very different impact on individual expertise and firm organization. While cheaper communication technology generates a reduction in the variety of tasks performed by workers as agents can specialize further and rely more on others, cheaper information access has an 'empowering' effect, allowing agents to handle more of the problems they face without relying on others. This difference matters not just for firms, but also in the labor market, as information access and communication technology changes can be expected to affect the wage distribution in opposite directions.[2] In this paper, we utilize a new international firm-level dataset with directly measured indicators of organization and technologies to study whether indeed ICTs have these distinct effects. We argue that they do have distinct impacts, in a consistent direction to the theory.

Our starting point is the analysis in Garicano (2000) on the hierarchical organization of expertise. A decision is a solution to a problem and making decisions requires acquiring the relevant knowledge. In determining at what hierarchical level decisions should be made, firms face a trade-off between *knowledge 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 or not to invest in new capital equipment requires training plant managers to understand financial decision making, cash flows etc. 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. Through relying on the direction of headquarters, and using the local manager just for execution, the cognitive burden on the manager, and the total knowledge acquisition costs, are reduced as long as hierarchical spans are larger than one, but

[1] We review this literature below.

[2] See Garicano and Rossi-Hansberg (2006) for an analysis of these distinct impact of these changes on the equilibrium wage structure.

at the cost of increasing communication costs. From a cognitive perspective, decentralized decision making thus implies an increase in the cost of knowledge acquisition to economize on communication costs: trading-off knowing versus asking for directions.

As a result, the level at which decisions are taken responds to the cost of acquiring and communicating information. Reductions in the cost of communication allow for a reduction in knowledge acquisition costs through the increasing use of 'management by exception' - local managers will rely more on the corporate head quarters for decision making. Reductions in the cost of information access, on the other hand, reduce the cognitive burden imposed by decentralized decision making and thus make more decentralization efficient. Consequently, information and communication technology affect differently the hierarchical level at which different decisions are taken. Improvements in information technology, reducing the cost of accessing information and knowledge, should push decisions 'down' whilst 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 technologies. We consider two types of decisions (non-production and production decisions) and discuss in each case technologies that make it easier for agents to take them and technologies that improve communication. First, we consider non-production decisions. These decisions can either be taken at CHQ by top managers (the "CEO"), 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. The key piece of information technology that has recently affected information access by these managers is Enterprise Resource Planning (ERP). These ERP systems increase dramatically the availability of information to decision makers in the company, that is they reduce the cost of acquiring information to solve a problem and thus we expect them to increase the autonomy of the plant manager. Moreover, we expect their superiors to be able to deal with more plant managers as a result (expanding CEO span of control). Second, we consider factory-floor production decisions. These are decisions on the production process that can either be taken by factory floor employees or by those in the plant hierarchy, such as which tasks to undertake and how to pace them. Here, a key technological change has taken place reducing the cost for workers of being informed: Computer Assisted Design/Computer Assisted Manufacturing (CAD/CAM). A worker with access to those machines can solve problems better, and thus needs less access to his superiors in making decisions. This technology should increase their autonomy and, by reducing the amount of help they need from plant managers, the span of control of plant managers.

On the other hand, as we argued above, we expect communication technologies to have the opposite impact and centralize decision making. We expect it to reduce autonomy of production workers in production decisions and of plant managers on non-production ones and transfer those decisions upwards. The key technological innovation affecting communication is the growth of networks. We thus also test whether the availability of networks reduced the decision making autonomy in production decisions of workers and in non-production decisions of managers.

We utilize a new dataset that combines plant-level measures of organization and ICTs across the US and Europe. The organizational questions were collected as part of our own management survey work (see Bloom and Van Reenen, 2007; Bloom, Sadun and Van Reenen, 2008) 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 for hardware in large publicly listed firms (e.g. Bresnahan, Brynjolfsson and Hitt, 2001) whereas we focus on the underutilized software components of the survey.

In terms of identification, guided by our theoretical predictions we mainly focus on simple conditional correlations between the different ICT measures and four dimensions of the organization of the firm (plant manager autonomy, worker autonomy, plant manager span and CEO span). But we also utilize the fact that the differential regulation of the telecommunication industry across countries generates exogenous differences in the effective prices of networks. We show that industries that exogenously rely more in networks are at a greater disadvantage in countries with high communication costs and use this to identify the effect of lower communication costs on decentralization.

In short, we find evidence that 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 CEOs, and technologies that lead to falling information costs for production decisions (like CADCAM) tend to empower workers relative to plant managers. They also widen the span of control. By contrast, technologies that reduce communication costs (like Networks) lead to more centralization.

Most previous work on information technology has tended to lump ICT as one homogenous technology due to data constraints, often simply measured by computers per person. As noted above, this is highly problematic as hardware will simultaneously reduce information and communication costs, and we show that these should have very different effects on firm organization. In the case of autonomy, for example, falling information costs increases decentralization whereas falling communication costs increases centralization. A summary measure like computers combines these two effects resulting in an unknown net impact. One strand of the literature looks for complementarities between ICT and organizational aspects of the firm, but takes organization as exogenous[3]. A second branch tries to endogenize organization, but does not discriminate between types of ICT[4]. 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[5]. What is unique about our study is the disaggregation of types of ICT and organization across a number of industries and countries.

Note that an alternative to our cognitive perspective is that hierarchies may be a solution to incentive problems (e.g. Calvo and Weillisz, 1978; Aghion and Tirole, 1997; Dessein, 2004). Although we are not rejecting such incentive effects, we think our information perspective is first order. Interestingly, the effects of these incentive effects on centralization are ambiguous as monitoring becomes cheaper, but so does the communication of the agents' privately held information.

We proceed as follows. We first propose a basic theoretical framework and suggest its implications in our context (Section 2). We then discuss our data (Section 3), empirical modelling strategy (Section 4) and present our results (Section 5). The final section offers some concluding comments.

2 A cognitive view of hierarchies

2.1 Theory: the trade-off between communication and acquisition of information

Production involves facing problems (or tasks or decisions) in the interval $[0,1]$, distributed according to a density function $f(z)$, with z normalized so that $f'(z) < 0$−that is lower indexed tasks are the most common.[6] Production only takes place if all the problems are dealt with by someone in the organization. In order to deal with these problems, agents must have the relevant knowledge. For an agent i to learn to solve all tasks costs c_i. Normalize to 1 agents' output per unit of time. Then an agent who learns all the tasks produces profit (output net

[3] See the survey in Brynjolsson and Hitt (2001) and Draca, Sadun and Van Reenen (2007). Examples include Bresnahan et al (2002) and Bloom, Sadun and Van Reenen (2007).

[4] For example see Acemoglu et al (2007), Caroli and Van Reenen (2001), Colombo and Delmastro (2004), Crepon et al (2004), Greenan and Mairesse (1999) and Aubert et al (2004).

[5] See, for example, Baker and Hubbard (2003, 2004) or the case studies in Blanchard (2004) or Blanchard et al (2001).

[6] This is a highly stylized version of the model in Garicano (2000), where there are as many layers as necessary and where agents can decide which tasks to do and which ones not to do. It is there shown that the organization we set up (chacaterized by 'management by exception') is optimal. Here there are only two layers and all problems are (eventually) solved; the only choice is who learns the solution.

of learning costs) of $1 - c_i$. The cost of training agents can be reduced if agents only learn to deal with the most common problems, that is those in $(0, z_0)$, and ask for help on the rest (the 'exceptions') to an agent who is specialized in problem solving. The opportunity cost is the time wasted as this agent does not produce output, but instead uses his time in communicating with the other agents about the tasks they do not know. Suppose a team must deal with N problems per unit of tasks. The teams needs then N production workers in layer 0 and n_1 managers or problem solvers. The profits generated by this hierarchy with N workers, where workers (layer 0) are paid wage w_0, and n_1 managers specialized in 'problem solving' or 'helping' and paid wage w_1 is:[7]

$$\pi = N - N(c_0 z_0 + w_0) - n_1(c_1 z_1 + w_1)$$

that is, the z_0 most common problems are learned by the N production workers; while we assume the problem solver's knowledge must encompass the production workers knowledge , $z_1 = 1$ (nothing changes if the knowledge is non-overlapping, see Garicano, 2000). Whenever the agents who are producing confront decisions or tasks for which they do not have the knowledge, a communication cost h (for helping cost) must be incurred per question posed. A level 0 agent deals with a fraction $F(z_0)$ of the tasks and passes on $(1 - F(z_0))$, and thus the amount of time spent 'helping' by level 1 agents is $(1 - F(z_0))h$ per production worker; since there are N agents, the needed number of problem solvers is $Nh(1 - F(z_0)) = n_1$. This determines a trade-off between what the agents below can do and how many managers are needed- the more skilled the agents, the less managers are needed. Figure 1 illustrates the distribution of tasks in this simple hierarchy.

Figure 1: Delegation and centralization of Tasks in basic model

$$0\underbrace{-------}_{\text{Delegated tasks}}z_0\underbrace{---------}_{\text{Centralized Tasks}}1$$

($z \in [0,\ z_0]$ *done by the lower level agents;* $z \in [z_0, 1]$ *passed on to the higher level.*)

The problem then of the hierarchy is to decide the size or span (N/n_1) of the hierarchy and the training that lower level employees must have to maximize profits per problem, or equivalently:

[7] 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 (where wages are adjusting) see Garicano and Rossi-Hansberg (2006).

$$\pi = \max_{z_0} N \left(1 - (c_0 z_0 + w_0) - h(1 - F(z_0)) (c_1 + w_1)\right)$$

It is easy then easy to obtain the following comparative statics:

Proposition 1 *1. A drop in communications (or 'helping') costs (h) reduces lower level autonomy (z_0) and has an ambiguous impact on span of control N/n_1 (more questions are asked, but each one takes less time).*

2. A reduction in the cost of acquiring information of all agents (c), or one affecting only lower level agents, c_0, increases in lower level autonomy (z_0) and increases span of control, N/n_1, as less questions are asked.

3. A reduction in the cost of acquiring information by the problem solvers only (c_1) decreases the number of tasks production workers deal with (z_0); this reduces span of control (workers ask more questions).

The proof of the above is simple. Note first that $f'(z) < 0$ implies that the second order conditions for optimization is met, $\partial^2 \pi / \partial z_0^2 < 0$. Then the results follow straightforwardly from the fact that $\frac{\partial^2 y}{\partial z_0 \partial h} > 0$ (higher communication cost raises the value of additional worker knowledge, by reducing the amount of communication). Second, letting $c_0 = c_1 = c$, we have that: $\frac{\partial^2 y}{\partial z_0 \partial c} < 0$ (that is higher knowledge acquisition cost for all agents decreases the value of additional production worker knowledge), and similarly $\frac{\partial^2 y}{\partial z_0 \partial c_0} < 0$, if workers can learn cheaper they can learn more. Finally, $\frac{\partial^2 y}{\partial z_0 \partial c_1} > 0$; when technology used by managers to acquire knowledge improves, they acquire more of it. Essentially, while communication cost reductions facilitate the reliance on specialists and decrease what each worker can do, reductions in the cost of acquiring information make learning easier and reduce the need to rely on specialized problem solvers for help with solutions. The changes in span follow straightforwardly from $s = N/n_1 = 1/\left(h(1 - F(z_0))\right)$

2.2 Extension: Production and Non production Decisions

Middle managers perform two broadly different functions: they are at the top of the production hierarchy, dealing with the problems that production workers could not handle, as outlined in the model above. They also are at the bottom of a non-production hierarchy dealing with managerial decisions on things like investment, employment, pricing and marketing.

We extend the model in the simplest possible way next, by considering a multilayer hierarchy involving managers in the Corporate Head Quarters (CHQ), middle managers, and production workers. The CHQ and middle-managers deal with non-production (management) decisions, x, while middle-managers and production workers deal with production decisions, z.

Production Decisions: As above, each production worker confronts one production decision per unit of time. He can deal with a fraction z_p of this production decisions. If $z < z_p$ he can produce. If not, he asks a middle manager for help. A cost h is incurred each time the middle manager must be involved in production. Production workers can acquire knowledge at cost c_p and middle managers at cost c_m. A firm that must deal with N production problems requires, as previously $h(1 - F(z_p))\, N = n_m$ middle managers.

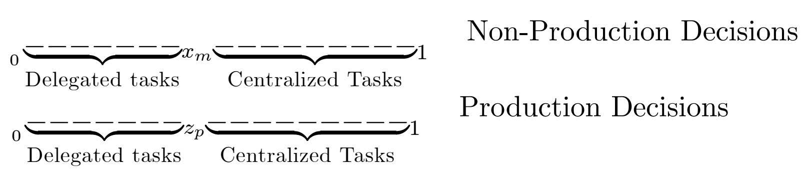
Non-production Decisions: We assume that from each of the N production problems generated, k non production problems, $x \in [0, 1]$, are drawn from a density function $g(x)$. These problems arrive directly in the hands of middle managers; Nk middle managers are needed to deal with non-production problems. Middle managers learn to deal with x_m of these problems, and ask for help from the CHQ for the rest. Thus if the problem drawn is $x < x_m$, a middle manager solves it; if not, the corporate manager intervenes. A cost h is incurred as before when top managers have to be drawn in decisions. It costs c_i for an agent i to learn all of the non-production problems (i.e. a unit of mass 1) so training middle managers to deal with non production problems costs $c_m x_m$, while the corporate managers are able to deal with all (a unit measure) of non-production problems at a cost c_c (c for corporate). A hierarchy with Nk non-production problems with middle managers with knowledge x_m requires $(1-G(x_m))hNK = n_c$ corporate managers.

Thus the profits of a hierarchy with production workers, middle managers and corporate managers are given by:

$$\pi = N - (c_p z_p + w_p)N - c_m(n_m + Nkx_m) - w_m(n_m + Nk) - (c_c + w_c)n_c$$

Tasks in $z < z_p$ are undertaken by production workers; the rest by middle managers; and tasks $x < x_m$ are undertaken by middle managers while the rest ($x > x_m$) are undertaken by corporate managers. This is illustrated in Figure 2.

Figure 2: Delegation and centralization of Tasks in extended model



The training and number of production workers determines the number of middle managers needed in production, $(h(1-F(z_p))\,N = n_m)$ and the training and time of middle managers in non-production determines the number of corporate managers needed, $(1-G(x_m))hNk = n_c$, and the profits can be written:

$$\pi = N\,(1-(c_p z_p + w_p) - c_m(h(1-F(z_p)) + kx_m) - \\ w_m(h(1-F(z_p)) + k) - (c_c + w_c)(1-G(x_m))hk)$$

Which allows us to generalize in a straightforward manner the results above.

Proposition 2

1. *A reduction in communications costs* (h) *leads to a reduction in production decision making by production workers* (z_p) *and in non-production decision making of middle managers* (x_m)*, and has an ambiguous impact on spans of control.*

2. *A reduction in the cost of acquiring information of production workers* (c_p) *leads to an increase in production workers autonomy* (z_p) *and has no impact on non production decisions* (x_m)*; it increases the span of control of middle managers* (N/n_m)*, and reduces the span of control of corporate managers* (n_m/n_c) *as less middle managers are needed to handle production problems).*

3. *A reduction in the cost of acquiring information by middle managers* (c_m) *or, equivalently, in the cost of acquiring information by both middle managers and corporate managers* $(c_m$ *and* $c_c)$ *reduces decision making autonomy of production workers* (z_p)*, and the span of control of middle managers (each worker asks more often); it also increases decision making autonomy of middle managers in non-production decisions* (x_m)*. Finally it increases the span of control of corporate managers (both because there are more middle managers in production and because they ask less often).*

We show these results formally in Appendix A and present a summary of them in Figure 3 below.

Figure 3: Delegation and centralization of Tasks in the extended model, Full set of theoretical predictions

Improvement in:	Model Parameter (falls in these costs)	Outcome	Prediction
Information access for middle manager	c_m	*Middle manager non-production decisions*	+
Information access for middle manager	c_m	*Production worker decisions*	-
Information access for middle manager	c_m	*middle manager span of control*	-
Information access for middle manager	c_m	*CEO Span of control*	+
Information access for production worker	c_p	*Middle manager non-production decisions*	0
Information access for production worker	c_p	*Production worker decisions*	+
Information access for production worker	c_p	*Middle manager span of control*	+
Information access for production worker	c_p	*CEO Span of control*	-
Communication Cost	h	*Middle manager non-production decisions*	-
Communication Cost	h	*Production worker decisions*	-
Communication Cost	h	*Middle manager span of control*	+/-
Communication Cost	h	*CEO Span of control*	+/-

Notes: These are the theoretical results from the full model. The empirical analogues with tests are given in Table 1.

2.3 From theory to empirics: decisions and technology

Our theory makes a sharp distinction between information and communication technologies. In reality the distinction is not so sharp: technological innovations such as the personal computer may improve both communication and access to information. We seek technologies that primarily fall under one or the other camps. The requirements for a technology to fall under each side, derived from the theory, are as follows:

- *Information access improvements* (c_i) : These are technologies that decrease the cost for an agent to access the solution to a problem he confronts. What is important is that these technologies allow a particular agent to access information in physical form more cheaply, and do not impact significantly the cost of accessing information held by other agents.

- *Communication or "helping" improvements* (h) : These are technologies that allow agents to access other agents knowledge- that is these are changes that take place primarily through reductions in agent-to-agent communication. What is key to these technological changes is that they affect how cheaply one agent can access and communicate with another agent.

We test our hypothesis by exploring the impact of information and communication technology on decision making and spans at two levels: (1) the corporate hierarchy and (2) the production floor. As in the model, production decisions may be decentralized towards the shop floor worker; non-production decisions may be decentralized towards the plant manager.

Non-production decisions, x_m : We analyze the extent to which four types of non-production decisions are allocated to plant managers (and away from corporate head quarters): the amount of capital investment the manager can decide on without headquarters involvement; the decision to hire permanent full time employees; the introduction of a new product and sales and marketing decisions. In all of these variables (which we define in detail in the Data section and Appendices), the decisions can be made by n_c corporate managers, or they can be decentralized towards the plant manager; we measure the extent of decentralization, x_m. Specifically, as we have argued, the lower are the information acquisition costs for managers, c_m, the less costly it is to decentralize these decisions to these middle managers, $\frac{dx_m}{\partial c_m} < 0$. The key information technology that has affected the access to information by plant managers (and those at headquarters) in firms, c_m is the implementation of Enterprise Resource Planning systems (ERP). These systems integrate the data of the different functions and divisions of a company with the underlying processes in order to provide a unified picture of the business and improve decision making. Our hypothesis is that, since these systems decrease the cost of accessing information, they should increase decision making autonomy of the plant manager vis-a-vis the headquarters. Moreover, given that plant managers are able to make more decisions, having multiple plant managers is cheaper in terms of the time cost to top managers, and thus we expect that more adoption of information acquisition technologies will lead to higher CEO span.

The main communication technology affecting the communication of information (h) has been the availability of computer networks. We expect that lower communication costs will result in less decision making on non-production decisions by plant managers, as more knowledge can be acquired by the specialized problem solvers at head quarters. We do not have a prediction on the impact of the networks on the span in terms of plant numbers, as we argued above.

Production decisions, z_p**:** We analyze two key production decisions potentially made by workers: the allocation of tasks across teams and the determination of pace in the shopfloor. Clearly, giving workers more autonomy requires that they have the cognitive skill and knowledge to make the best decisions. Again, to the extent that information acquisition by workers is cheaper, we expect that these decisions are more likely to be delegated. The main variable affecting the information collection costs (c_p) by workers is the presence of 'smart' machines, computer controlled machines etc. To the extent these technologies exist, we expect these decisions to be decentralized. Again, as information costs drop and workers do more, we expect spans to increase, as a particular plant manager may deal with more subordinates when these can solve a larger share of problems coming up.

As before, the main communication technology affecting communication costs (h) is the availability of computer networks. We again expect that lower communication costs will increase centralization, as asking for directions is cheap relative to learning. Table 1 translates Figure 3 into our predictions for the various variables on the basis of the model given the above discussion.

3 Data

We use a new international micro dataset combining novel sources from the US and eight European countries. Our two main sources 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 datasources such as firm-level accounting data, industry and macro-economic data.

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 in London 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. Appendix B provides a detailed data description for the full sample (see Bloom, Sadun and Van Reenen, 2008, for more details), 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 during the telephone survey[8]. This enabled scoring to be based on the interviewer's evaluation of the firm's actual practices, rather than their aspirations, the manager's perceptions or the interviewer's impressions. To run this "blind" scoring we introduced the exercise as an interview about

[8] 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, large household names are not included.

management practices, using open questions (i.e. "can you tell me how you promote your employees"), rather than closed questions (i.e. "do you promote your employees on tenure [yes/no]?"). Furthermore, these questions target actual practices and examples, with the discussion continuing until the interviewer can make an accurate assessment of the firm's typical practices based on these examples.

The survey is targeted at plant managers in firms randomly drawn from the population of all public and private firms with between 100 and 5,000 employees in the manufacturing sector. We had a response rate of 45% and the response rate was uncorrelated with firm performance. The interviews took an average of 50 minutes with the interviewers running an average of 78.5 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 self-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 help control for any potential measurement error.

3.1.2 Measuring plant manager autonomy

As part of this survey we also asked four questions on plant manager autonomy. First, we asked how much capital investment a plant manager could undertake without prior authorization from the corporate headquarters (CHQ). This is a continuous variable enumerated in national currency which we convert into US dollars using Purchasing Power Parities. We also inquired on 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 this from a score of one, defined as all decisions taken at the corporate headquarters, to a five defined as complete power ("real authority") of the plant manager. In Table A1 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 by practice to mean 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, but we also experiment with other weighting schemes and we also show what happens 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 Breshnahan et al. (2002) and are reported in Table A1 (questions D6 and D7). These questions are scaled on a one to five basis, with a five denoting workers have full control over the pace of work and allocation of tasks, a one denoting managers have full control, and intermediate scores varying degrees of joint decision making. 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). 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 A1 (question D8). The interviewers are 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 CEO span (since we did not interview the CEO). But we try to get a sense of senior management's (CEO) 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.

3.2 Harte-Hanks' ICT Data

We use an establishment level ICT data panel taken from the European Ci Technology Database (CiDB) produced by the international marketing and information company Harte-Hanks (HH). HH is a multinational that collects ICT data primarily for the purpose of selling on to large producers and suppliers of ICT. The fact that HH sells this data on to major firms like IBM and Cisco exerts a strong market discipline on the data quality. Major discrepancies in the data are likely to be rapidly picked up when HH customers' sales force placed calls using the survey data. Because of this HH conducts extensive internal random quality checks on its own data, enabling them to ensure high levels of data accuracy.

The HH data has been collected annually for over 300,000 establishments across 14 European countries since the late-1990s (and earlier in the US). They target all firms with 100 or more employees, obtaining about a 45% response rate. We use the data only for the firms we matched to those in the management survey (i.e. in the US, France, Germany, Italy, Poland, Portugal, Sweden and the UK). These were matched through the names of the firms (with the addresses and employment sizes also available to ensure clean matches). The HH survey contains detailed hardware and software information at the establishment level. Bresnahan et al (2002) and Brynjolfsson and Hitt (2003) have previously used the US HH data to match this to large publicly quoted firms in Compustat, while Beaudry, Doms and Lewis (2006) and Bloom, Draca and Van Reenen (2008) have used the complete panel of establishments in the US and Europe respectively. No one has combined the software data with information on organizational form in a single country, let alone internationally as we do here.

ICT hardware simultaneously reduces information and communication costs so although we will utilize the hardware measures from HH as is common in the literature, we do not expect a clear result. In order to operationalize the concepts of information acquisition costs and communication costs we have to classify software types. After consulting industry experts over our concepts[9], the three key software types we focus on are networks (for communication costs), Enterprise Resource Planning (ERP) for reducing information access costs for non-production decisions and CADCAM for reducing information access costs for production decisions. HH contains information on the presence of all of these software types in the establishment.

ERP is the generic name for software systems that integrate several datasources and processes of an organization into a unified system[10]. These applications are used to store, retrieve and share information on any aspect of the production and sales process in real time. This includes standard metrics like production, waste, deliveries, machine failures, orders and stocks, but also broader metrics on human resource and a range of financial variables. An ERP system is based on a common database and a modular software design. HH distinguishes many distinct types of *ERP*: the market leader is SAP[11] but Oracle, IBM and many others all offer products in this space. The development of *ERP* enables managers to access timely information at an unprecedented rate, empowering plant managers to make decisions on a range of activities including investment, hiring, pricing and product choice.

ERP is not commonly used by production workers, so for these type of decisions we focus on HH's Computer Assisted Manufacturing (*CADCAM*) software[12]. *CADCAM*'s are software tools that assist production workers, engineers and machinists in manufacturing in all phases of production (e.g. finishing, contour milling and roughing). Traditionally these would be used

[9] We thank software engineers at Sun Microsystems and EDS and consultants at McKinsey and Accenture for many useful discussions.

[10] See http://en.wikipedia.org/wiki/Enterprise_resource_planning for example.

[11] For example, SAP's R/3 client/server version launched in 1992 that replaced the older mainframe based R/2.

[12] HH defines this under "workstation applications". For more information see the description of *CADCAM* on http://en.wikipedia.org/wiki/Computer-aided_manufacturing

to drive numerically controlled programming tools (see for example, the description of their use in the valve industry in Bartel et al, 2007). Major players in the $CADCAM$ supply industry are UGS Corp (owned by Siemens), Dassault Systèmes and Hitachi Zosen.

Thirdly, our key indicator of communication costs is a variable that captures the presence of Leased Lines or Frame Relays ($NETWORK$). These are IT infrastructures used by businesses to connect offices or production sites. 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 it does not have a telephone number, each side of the line being permanently connected to the other. Leased lines can be used for telephone, data or Internet services. Frame relay consists of an efficient data transmission technique used to send digital information quickly and cheaply. It is a message forwarding "relay race" like system in which data packets, called frames, are passed from one or many start-points to one or many destinations via a series of intermediate node points. Frame relay is used for local area networks (LANs) over a wide area network (WAN). These systems are predominantly used to manage internal communication systems, although they can also be employed to link back to telecommunication providers. Typically they are used as intranets to send data but can also be used as voice channels such as internal telephone communication systems. This is not specifically about production or non-production decisions, but affects communication throughout the firm.

In terms of other technologies we considered using e-mail to capture communication costs, but e-mail is now so ubiquitous that there is little variation. We condition on PC intensity, but note its theoretical ambiguity. 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 $NETWORK$ variable.

3.3 Other Data

In addition to the organization variable, the CEP survey also collected a wide variety of other variables such as the skills and demographics in the workplace 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. For the country data on network prices we use the cost of an annual subscription to a leased line contract at 2006 PPP US$ taken from the OECD (2007).

Table A2 contains some descriptive statistics of the data we use. In the largest sample we have 1192 plants with 254 employees at the mean (150 at the median).

4 Empirical Strategy

4.1 Basic Model

Consider the following generic equation that we wish to estimate:

$$y_{ijk}^{O} = \alpha^{O} c_{ijk} + \beta^{O} h_{ijk} + x_{ijk}' \gamma^{O} + u_{ijk} \tag{1}$$

where the endogenous variable is y_{ijk}^{O} 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 CEO ($O =$ SC). As in the theory, c denotes information access (knowledge acquisition) costs and h denotes communication 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, managers' autonomy and managers' span of control from our survey. The management autonomy questions distinguish between "non-production" decisions the plant manager could have control over relative to the CEO (e.g. how much investment could be made without CEO 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 ($NETWORK$ lowers h; ERP and $CADCAM$ lower c). To be more explicit the four regressions we will estimate are:

Autonomy of the plant managers

$$y_{ijk}^{AP} = \alpha^{AP} ERP_{ijk} + \beta^{AP} NETWORK_{ijk} + x_{ijk}' \gamma^{AP} + u_{ijk}^{AP} \tag{2}$$

Autonomy of the worker

$$y_{ijk}^{AW} = \alpha^{AW} CADCAM_{ijk} + \beta^{AW} NETWORK_{ijk} + x_{ijk}' \gamma^{AW} + u_{ijk}^{AW} \tag{3}$$

Span of control of the plant manager

$$y_{ijk}^{SP} = \alpha^{SP} CADCAM_{ijk} + \beta^{SP} NETWORK_{ijk} + x_{ijk}' \gamma^{SP} + u_{ijk}^{SP} \tag{4}$$

Span of control of the CEO

$$y_{ijk}^{SC} = \alpha^{SC} ERP_{ijk} + \beta^{SC} NETWORK_{ijk} + x_{ijk}^{\prime} \gamma^{SC} + u_{ijk}^{SC} \quad (5)$$

Panel A of Table 1 contains the main theoretical predictions of the model that we have sketched together with the technologies we are using. Column (1) corresponds to the four organizational outcomes we examine. Columns (2) through (4) refer to the effects of a fall in information costs and columns (5) through (7) to a fall in communication costs. Falls in information costs are associated with greater autonomy and larger spans of control (Column (3)). By contrast falls in communication costs are associated with decreases in autonomy and ambiguous effects on spans.

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.

4.2 Endogeneity

An obvious criticism of our modelling strategy is that there may be unobservables in equation (1) that are correlated with both the organizational outcomes and the ICT measures biasing our estimates of α^O and β^O. We have no plausible natural experiment to exploit so the evidence in this paper should be considered suggestive conditional correlations rather than causal.

Nevertheless, we do consider an alternative approach to identifying the effects of networks. The cost of electronically communicating over networks 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, 2008; OECD, 2005, 2007). We discuss these more in Appendix B. We exploit these differential costs using OECD series on the prices of leased lines used for networks (call this price p_k^c). An obvious empirical problem is that these measured telecommunication price indices only vary across countries[13] and not within countries, so they are collinear with the country dummies. Industries will be differentially affected by these costs, however, depending on the degree to which they are reliant on networks for exogenous technological reasons. We proxy this reliance by using the intensity of network use in the industry pooling the data across all countries ($NETWORK_j$). We then estimate models of the form:

$$y_{ijk} = \lambda(p_k^c * NETWORK_j) + x'_{ijk}\mu + v_{ijk} \tag{6}$$

Note that the controls (x'_{ijk}) include a full set of industry and country dummies, so we are essentially using $p_k^c * NETWORK_j$ as a direct proxy for h, so the prediction is that $\lambda > 0$: for the network-intensive industries we would expect to see more managerial autonomy in countries where communication prices are high (like Poland) than were they are low (like Sweden). More ambitiously we can potentially use $p_k^c * NETWORK_j$ as an instrumental variable for $NETWORK_{ijk}$. This is ambitious because we do not know exactly how intensively networks are used so $p_k^c * NETWORK_j$ may reflect this. We will try and assess the quality of this identification strategy (which parallels Rajan and Zingales, 1998) by using placebo experiments replacing p_k^c which other country-specific features such as GDP per head and education supply to make sure it is differential communication prices driving the results. We find that this is indeed the case. Unfortunately we do not have such a compelling identification strategy for information acquisition costs. We consider some experiments in the robustness section relating to the timing of when SAP entered a country to predict current ERP usage.

4.3 Extended model: Cross effects of technologies

In the extended theoretical model we found "cross effects" of technologies between equations. For example, ERP_{ijk} enters equation (3) with a negative sign: because plant managers can make more decisions workers need to make less. This leads to an additional set of cross effects with predicted signs given in Figure 3 and Panel B of Table 1. We will also look at these predictions in the robustness tests (and generally find supportive evidence). To be explicit, we estimate the four augmented equations:

Autonomy of plant managers

$$y_{ijk}^{AP} = \alpha^{AP} ERP_{ijk} + \beta^{AP} NETWORK_{ijk} + \delta^{AP} CADCAM_{ijk} + x'_{ijk}\gamma^{AP} + u_{ijk}^{AP} \tag{7}$$

[13] 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).

Autonomy of workers

$$y_{ijk}^{AW} = \alpha^{AW} CADCAM_{ijk} + \beta^{AW} NETWORK_{ijk} + \delta^{AW} ERP_{ijk} + x'_{ijk}\gamma^{AW} + u_{ijk}^{AW} \quad (8)$$

Span of control of the plant manager

$$y_{ijk}^{SP} = \alpha^{SP} CADCAM_{ijk} + \beta^{SP} NETWORK_{ijk} + \delta^{SP} ERP_{ijk} + x'_{ijk}\gamma^{SP} + u_{ijk}^{SP} \quad (9)$$

Span of control of the CEO

$$y_{ijk}^{SC} = \alpha^{SC} ERP_{ijk} + \beta^{SC} NETWORK_{ijk} + \delta^{SC} CADCAM_{ijk} + x'_{ijk}\gamma^{SC} + u_{ijk}^{SC} \quad (10)$$

We now turn to the empirical results.

5 Empirical Results

5.1 Basic Results

Tables 2 through 5 present the main results, each table has a different dependent variable and corresponds to equations (2) to (5). Table 2 contains the empirical results for plant managers' autonomy. All columns control for employment size (of the firm and plant), multinational status (foreign multinational or domestic multinational with the base as a purely domestic firm), whether the CEO is located on the same site as the plant manager[14], "noise" controls as discussed in the data section and a full set of country and three digit industry dummies. Column (1) uses the presence of Enterprise Resource Planning (ERP) as a measure of information acquisition by plant managers. As we expected, this is associated with more autonomy of plant managers (relative to the CEO) as the plant manager is allowed greater flexibility in making decisions over investment, hiring, marketing and product introduction. In our model this is because ERP enables him to access information more easily and solve more problems without referring them upwards to the CEO. In terms of the other covariates we find that larger and more complex enterprises (as indicated by employment size and multinational status) are more likely to decentralize decision-making to the plant manager. Column (2) includes the proportion of skilled workers (as measured by proportion of employees with college degrees) which takes a positive and significant coefficient, indicating that more skilled workplaces tend

[14]Note that firms where the CEO was the same individual as the plant manager are dropped.

to be more decentralized (consistently with Caroli and Van Reenen, 2001). This column also includes the PC intensity of establishment which enters with a negative and insignificant sign. The ambiguity of the IT hardware variable should not be surprising as greater IT intensity simultaneously lowers information costs and communication costs which, according to our theoretical model, have opposite effects on autonomy.

The third column of Table 2 includes an indicator for the presence of networks, which we have argued indicates lower communication costs. As the theory predicts, there is a negative coefficient on the network variable (significant at the 10% level) which may reflect the fact that lower communication costs for the CEO means that he makes more decisions than the plant manager as it is now easier for the CHQ to pass on solutions. This result is robust to including skills and PC intensity in column (4). Columns (5) and (6) includes both information and communications technologies at the same time. Since these are positively correlated, the results are a little stronger now we include both together. In short, Table 2 is consistent with the theoretical model sketched earlier: falling information costs are associated with decentralization, whereas falling communication costs are associated with centralization.

The next three tables follow exactly the same structure as Table 1. Table 3 is a probit model of workers' autonomy (whether the workers control both the pace of work and task allocation). Our indicator of information acquisition over production decisions is $CADCAM$. In columns (1) and (2), the coefficient on workstation applications is positive and significant, indicating that such technologies are associated with worker empowerment. In columns (3) and (4), by contrast, the presence of networks has a negative coefficient which is consistent with the theoretical notion that greater communication leads to centralization. Although the coefficient on $NETWORK$ is correctly signed, it is insignificant even when both technologies are included simultaneously (in the final two columns). We discuss this result in more detail in the next sub-section

Table 4 examines the plant manager's span of control as measured by the number of employees who directly report to him. $CADCAM$ is associated with significantly *greater* plant manager span, consistent with the idea that production technologies that help worker information access enable them to do more tasks which makes it possible for the plant manager to oversee more production workers (greater span). The coefficient on $NETWORK$ is positive and insignificant (the theory does not have an unambiguous prediction for this coefficient).

Finally, Table 5 presents the proxy for CEO span. ERP is positively and significantly associated with CEO span. This is consistent with the theory as we would expect ERP enables plant managers to make more decisions without referring them upwards enabling the CEO, enabling the CEO to control more plant managers under him. Networks are positively associated with CEO's span (again the theory has no unambiguous prediction for this).

Comparing the empirical results with our expectations in Panel A of 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 (with the exception of $NETWORK$ in the worker autonomy equation which we will discuss this more below). 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.

5.2 Endogeneity

Tables 2 through 5 present 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 all positively correlated, 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 ($NETWORK$) 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 $NETWORK$ and a positive covariance with ERP. This is always a theoretical possibility, but it is not obvious what would generate this.

Nevertheless, we implemented the idea discussed earlier in the econometrics section of using the differential communication costs at the country level of "leased lines" (for internal communication networks like intranets) as an exogenous factor shifting communication costs. We interacted this country-specific variable (p_k^c) with the average adoption of networks in a three-digit industry across *all* countries included in our sample[15] (i.e. $p_k^c * NETWORK_j$). The identification strategy is that for the same high network use industry, we are likely to have higher communication costs in Poland where telecommunications are still dominated by state-run incumbents compared to the Sweden where prices are lower due to a higher degree of

[15] We also considered specifications where we used network intensive industries defined on US data only and dropped the US from the sample we estimated on. This generated similar results.

liberalization. All specifications absorb the linear effects with a full set of industry and country dummies[16].

The results for this experiment are presented in Table 6. The first column simply repeats the baseline from the final column of Table 2 showing that network presence is associated with less decentralization to the plant manager. The second column includes the key variable representing effective network prices. The positive coefficient on this variable is consistent with the idea that higher network costs reduces the use of networking technologies, and so enable plant managers to retain more autonomy.

A concern is that the country-level network price variable simply proxies some other variable. We substitute network prices for country-level schooling year in column (3) and GDP per person in column (4). These variables are completely insignificant. When entered alongside the network price interaction in column (5), the network price variable remains positive and significant in sign and these other variables remain insignificant.

We also examined an instrumental version of this identification strategy in the final two columns of Table 6. The first stage is in (6) and the second stage is in column (7). The first stage is correctly signed but not significant, which explains the poor precision of the second stage. Part of the problem appears to be related to smaller firms who may pay higher prices than the (discount adjusted) OECD averages. Columns (8) and (9) include only firms with over 200 employees. We see that the first stage is much stronger (now significant at the 5% level) and the 2SLS results are now significantly different from zero at the 10% level. The larger coefficient on $NETWORK$ suggests that endogeneity, if anything, biases the coefficient towards zero.

Table 7 repeats the analysis, but this time using worker autonomy as the outcome. The results are somewhat weaker - as they were in Table 3. In column (1) $NETWORK$ presence is associated with less autonomy for workers, but if we look at the network cost variable, it is insignificant (and incorrectly signed) in column (2). On deeper investigation, part of the problem appears to be that Sweden scored exceptionally highly on this measure of worker autonomy, suggesting some biases in the Swedish sample on this question. When Sweden was excluded from the sample, the results move much more in line with theory. In column (3) network presence is significantly and negatively correlated with worker autonomy. In column (4) the effective network cost variable *is* associated with significantly less decentralization[17].Columns (5)

[16] Since the theoretical and empirical signs of the effects of $NETWORK$ on the span of control are ambiguous, we have not presented the results (they are all insignificant).

[17] Dropping Sweden from the sample does not affect any of the other qualitative findings in the other regressions.

presents the first stage and (6) the 2SLS results. As with plant manager autonomy the results are stronger when we drop the smaller firms. Column (7) shows that the excluded instrument has some power in the first stage and that the coefficient on $NETWORK$ is significant (and larger) in 2SLS.

Taken as a whole, Table 6 and 7 are consistent with the hypothesis that there is some causal effect of communication costs on organizational design.

5.3 Cross effects of technologies in extended model

We now consider some of the further cross effects of technologies in Table 8. We present the most general specifications for each of the four organizational variables. In column (1) $CADCAM$ is insignificant in the plant manager autonomy equation as predicted by the theory. $CADCAM$ is used to inform production decisions, and it not directly related to non-production decisions that the CEO might delegate down to the plant manager. In column (2) ERP is negative and significant in the workers autonomy which is again as predicted by the theory - better informed plant managers will take more decision directly and delegate less to workers. In column (3) ERP is positive and insignificant in the plant-manager span equation. The theory predicts this should be negative as more informed plant managers take more decisions, so each worker refers more questions so they manage less workers. Finally, in column (4) we see that $CADCAM$ is negative in the CEO span. This is as predicted by the theory since this increases production workers information, so they require less plant managers to direct them, which reduces the CEO span. Thus both cross impacts of $CADCAM$ are consistent with the theory (see Panel B of Table 1) - we expect worker knowledge acquisition costs to reduce CEO span and have no effect on plant manager autonomy. ERP is negative and significant in the worker autonomy regression in column (3) which is also consistent with the theory.

Thus, the only rejection of the theory is that the coefficient on ERP is positive in the plant manger's span equation whereas it should be negative. The coefficient is not significant, however, and it is the only coefficient (out of the twelve in Table 1) to be of opposite sign to the theory. Overall then, we think our cognitive based theory does a reasonably good job at representing the data.

5.4 Further Results

We have examined a large variety of robustness tests and some of these are presented in Table 9. Each panel presents a different dependent variable with different tests in each column (Panel A for plant manager autonomy, Panel B for worker autonomy, Panel C for plant manager span of control and Panel D for CEO span of control). Column (1) simply repeats the baseline specifications from the final column in Tables 2 through 5.

In Bloom, Sadun and Van Reenen (2008) we found that product market competition and cultural factors such as trust and non-hierarchical religions were associated with greater plant manager autonomy. We control for these in column (2) through 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 $NETWORK$ in the worker autonomy equation which is now significant with a theory consistent negative sign, whereas it was insignificant in the baseline regression. Column (3) includes a variety of additional firm level controls: the capital-labor ratio, sales per employee, total employment in the group where the firm belong (i.e. consolidated worldwide employment for multinationals), firm age and a listing dummy. The results are robust to these additional controls (which were individually insignificant). Column (4) uses an alternative indicator of networks based on the presence of LAN (Local Area Networks) or WAN (Wide Area Networks)[18]. The LAN/WAN indicator is highly correlated with $NETWORK$ and the results are very similar to the baseline. The only difference is that, again, $NETWORK$ in the worker autonomy equation which is now significant (at the 5% level) with a theory consistent negative sign. Note that our ICT variables from HH are averaged over all the plants in the firm using plant employment as weights. Although these are usually either one or zero, in-between values are also possible. We consider a discrete alternative where all the firms with non-zero values of ICT are coded as unity and present these results in column (5). Again, nothing much changes, nor does including the Bloom and Van Reenen (2007) measure of management quality in column (6). The final two columns consider alternative ways of constructing the dependent variable. For the plant manager autonomy equation (Panel A) we use the principal component of the four questions in column (7) and drop the investment question in column (8). For the worker autonomy question (Panel B) we define it based only on the pace of work and in column (8) and only on task allocation in column (9). The results again seem robust to these alternatives.

6 Conclusions

With a few notable exceptions, the empirical (and much of the theoretical) literature that examines the economic effects of information and communication technologies, ICT is usually lumped together as a single homogeneous mass. We argue that this is a serious error because

[18]We prefer our indicator of $NETWORK$ as LAN was included only in earlier years of HH and WAN only in later years. In addition, our exogenous shifter of network prices refers to leased lines.

the impact of ICT on the organization of firms (and also on other outcomes such as inequality and productivity), will be quite different depending on the type of technology used. For example, falls in communication costs will tend to generate increased centralization, lowering the autonomy of those further down the hierarchy, whereas falls in information costs will have exactly the opposite effect. We show these effects in a theoretical model extending Garicano (2000) tracing out implications for plant managerial autonomy from the CEO, worker autonomy from plan managers and the span of control. Using a new unique international dataset combining our survey on plant-level organization and a private sector database on the adoption of different types of technology, we show results that are broadly consistent with our theory.

There are several directions we are currently pursuing in this line of research. Firstly, we are examining in more detail the reasons for differential adoptions of technologies across firms and countries. 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 organization. Although we have plausible exogenous variation for network costs of communication, we do not have a similar quasi-experiment for information access. Secondly, we are developing the theory to consider interactions between different type of production and non-production technologies at other layers of the hierarchy. Finally, we are examining the effect of differential type of IT adoption on other outcomes such as productivity and wage inequality.

References

[1] Acemoglu Daron, Philippe Aghion, Claire Lelarge, John Van Reenen, and Fabrizio Zilibotti (2006) "Technology, Information and the Decentralization of the Firm" *Quarterly Journal of Economics* 122 (4), 1759–1799

[2] Acemoglu, Daron, and Zilibotti, Fabrizio (1999), "Information Accumulation in Development," *Journal of Economic Growth*, 4, 5-38.

[3] Aghion, Philippe, and Tirole, Jean (1997), "Formal and Real Authority in Organizations," *Journal of Political Economy*, 105, 1-29.

[4] Aubert, Patrick, Caroli, Eve, and Roger, Muriel (2006), "New Technologies, Workplace Organization and the Structure of the Workforce: Firm-Level Evidence," *Economic Journal*, 116, 73-93.

[5] Azmat, Ghazala, Manning, Alan, and Van Reenen, John (2008) "Privatization, Entry Regulation and the Decline of Labour's Share of GDP: A Cross-Country Analysis of the Network Industries" Centre for Economic Performance Discussion Paper No. 806

[6] Baker, George, Gibbons, Robert, and Murphy, Kevin (1999), "Informal Authority in Organizations," *Journal of Law, Economics, and Organization*, 15, 56-73.

[7] Baker, George, and Hubbard, Thomas (2003), "Make Versus Buy In Trucking: Asset Ownership, Job Design and Information", *American Economic Review*, 93, 551-72.

[8] Baker, George, and Hubbard, Thomas (2004), "Contractibility and Asset Ownership: On Board Computers and Governance in US Trucking," *Quarterly Journal of Economics*, 119, 1443-79.

[9] Baron, David, and Besanko, David (1992), "Information, Control, and Organizational Structure", *Journal of Economics and Management Strategy*, 1, 237-275.

[10] Bartel, Ann, Ichniowski, Casey and Kathryn Shaw (2007) "How Does Information Technology Really Affect Productivity? Plant-Level Comparisons of Product Innovation, Process Improvement and Worker Skills" *Quarterly Journal of Economics,* 122, No. 4, 1721-1758

[11] Beaudry, Paul, Doms, Mark and Lewis, Ethan (2006) "Endogenous Skill Bias in Technology Adoption: City-Level Evidence from the IT Revolution". NBER Working Paper, No 1251

[12] Black, Sandra, and Lynch, Lisa (2001), "How to Compete: The Impact of Workplace Practices and Information Technology on Productivity," *Review of Economics and Statistics*, 83, 434-445.

[13] Blanchard, Olivier (2004) "The Economic Future of Europe", *Journal of Economic Perspectives*, 18, 3-26.

[14] Blanchard, Olivier, Bailey, Martin, Gersbach, Hans, Schnitzer, Monika, Tirole, Jean (2002) *Reaching Higher Productivity Growth in France and Germany, Sector case: Retail Trade*, McKinsey Global Institute.

[15] Bloom, Nick, Draca, Mirko and Van Reenen, John (2008) "Trade induced technical change: The impact of Chinese imports on technology and jobs" Stanford/LSE mimeo

[16] Bloom, Nicholas, Schankerman, Mark, and Van Reenen, John (2004), "Technological Spillovers and Product Market Rivalry", *Centre for Economic Performance Discussion Paper*, 675.

[17] Bloom, Nick, Sadun, Raffaella and Van Reenen, John (2007) "Americans do I.T. Better: American multinationals and the productivity miracle" NBER Working Paper 13085

[18] Bloom, Nick, Sadun, Raffaella and Van Reenen, John (2008) "Measuring and Explaining Organization across firms and countries" LSE/Stanford mimeo

[19] Bolton, Patrick, and Dewatripont, Mathias (1994), "The Firm as a Communication Network," *Quarterly Journal of Economics*, 109, 809-839.

[20] Bresnahan, Timothy, Brynjolfsson, Erik, and Hitt, Lorin (2002), "Information Technology, Workplace Organization and the Demand for Skilled Labor: Firm-level Evidence," *Quarterly Journal of Economics*, 117, 339-376.

[21] Calvo, Guillermo, Wellisz, Stanislaw (1978) "Supervision, Loss of Control, and the Optimum Size of the Firm" *Journal of Political Economy,* 86, 943-952

[22] Caroli, Eve, and Van Reenen, John, (2001) "Skill Biased Organizational Change," *Quarterly Journal of Economics*, 116, 1448-1492.

[23] Colombo, Massimo, and Delmastro, Marco (2004), "Delegation of Authority in business organizations: An empirical test," *Journal of Industrial Economics*, 52, 53-80.

[24] Dessein, Wouter (2002) "Authority and Communication in Organizations," *Review of Economic Studies*, 69, 811-838.

[25] Draca, Mirko, Sadun Raffaella and Van Reenen, John (2007), "Productivity and ICTs: a Review of the Evidence", in Robin Mansell, Chrisanthi Avgerou, Danny Quah and Roger Silverstone (eds.) *The Oxford Handbook of Information and Communication Technologies,* Oxford University Press.

[26] Garicano, Luis (2000), "Hierarchies and the Organization of Knowledge in Production," *Journal of Political Economy*, 108, 874-904.

[27] Garicano, Luis and Rossi-Hansberg, Estaban (2006) "Organizing Growth" NBER Discussion Paper

[28] Geanakoplos, John, and Milgrom, Paul (1991), "A Theory of Hierarchies Based on Limited Managerial Attention," *Journal of the Japanese and International Economies*, 5, 205-225.

[29] Greenan, Nathalie, and Mairesse, Jacques, (1999), "Organizational Change in French Manufacturing: What Do We Learn From Firm Representatives and From Their Employees," *NBER Working Paper*, 7285.

[30] Hart, Oliver, and Moore, John (2005), "On the Design of Hierarchies: Coordination versus Specialization," *Journal of Political Economy*, 113, 675-702.

[31] Ichniowski, Casey, Prenushi, Giovanna, and Shaw, Kathryn (1997), "The effects of Human Resource Management: A Study of Steel Finishing Lines," *American Economic Review*, 87, 291-313.

[32] Jensen, Michael C. and Meckling, William H. (1992) "Specific and General Knowledge, and Organizational Structure," in Lars Werin and Hans Wijkander (eds) *Contract Economics*, Blackwell: Oxford

[33] Lee, Lung-Fei (1981), "Simultaneous equation models with discrete and censored dependent variables," in Manski, Charles, and McFadden, Daniel (eds), *Structural Analysis of Discrete Data and Econometric Applications*, Cambridge MA: MIT Press, 346-364.

[34] Lerner, Josh, and Merges, Robert (1998), "The Control of Biotechnological Alliances: An Empirical Examination of the Biotechnology Industry," *Journal of Industrial Economics*, 46, 125-156

[35] McKinsey Global Institute (2002), "Reaching Higher Productivity Growth in France and Germany," *MGI Reports*, http://www.mckinsey.com/knowledge/mgi/europe/index.asp

[36] Melumad, Nahum, Mookherjee, Dilip, and Reichelstein, Stefan (1995), "Hierarchical Decentralization of Incentive Contracts," *Rand Journal of Economics*, 26, 654-672.

[37] Milgrom, Paul, and Roberts, John (1990), "The Economics of Modern Manufacturing: Technology, Strategy and Organization," *American Economic Review*, 80, 511-528.

[38] Milgrom, Paul, and Roberts, John (1992), *Economics, Organization and Management*, New Jersey: Prentice Hall.

[39] Mookherjee, Dilip (2006), "Decentralization, Hierarchies and Incentives: A Mechanism Design Approach," *Journal of Economic Literature*, 64, 367-390.

[40] Nickell, Stephen (1996), "Competition and Corporate Performance," *Journal of Political Economy*, 104, 724-746.

[41] Nickell, Stephen, Nicolitsas, Daphne, and Patterson, Malcolm (2001), "Does Doing Badly Encourage Managerial Innovation?," *Oxford Bulletin of Economics and Statistics*, 3, 5-28.

[42] OECD (2005) *Communication Outlook,* Paris: OECD

[43] OECD (2007) *Telecommunication Handbook*, (2007) Paris: OECD

[44] Radner, Roy (1993), "The Organization of Decentralized Information Processing," *Econometrica*, 61, 1109-1146.

[45] Radner, Roy, and Van Zandt, Timothy (1992), "Information Processing in Firms and Returns to Scale," *Annales d'Economie et de Statistique*, 25/26, 265-298.

[46] Rajan, Raghuram G and Zingales, Luigi (1998) "Financial Dependence and Growth" *American Economic Review*, 88(3), 559-86

[47] Rajan, Raghuram, and Zingales, Luigi (2001), "The Firm as a Dedicated Hierarchy: A Theory of the Origin and Growth of Firms," *Quarterly Journal of Economics*, 116, 805-851.

[48] Rajan, Raghuram, and Wulf, Julie (2005), "The Flattening Firm: Evidence from Panel Data on the Changing Nature of Corporate Hierarchies," *Review of Economics and Statistics*, forthcoming.

[49] Sah, Raaj, and Stiglitz, Joseph (1986), "The Architecture of Economic Systems: Hierarchies and Polyarchies," *American Economic Review*, 76, 716-727.

[50] Stephenson, Betsy (2006) "The Impact of the Internet on worker flows" mimeo, Univeristy of Pennsylvania

[51] Wooldridge, Jeffrey (2002) *Econometric Analysis of Cross Section and Panel Data*, Cambridge: MIT Press.

[52] World Bank (2006) *World Development Indicators*, Washington DC

APPENDICES

A Appendix A: Theory

To show proposition 2, first take first order conditions with respect to the two types of decisions, z_p and x_m. These are:

$$\begin{aligned} foc_{z_p} &: -c_p + (c_m + w_m)hf(z_p) = 0 \\ foc_{x_m} &: -c_m k + (c_c + w_c)hkg(x_m)) = 0 \end{aligned}$$

$$H = \begin{pmatrix} h(c_m + w_m)f'(z_p) & 0 \\ 0 & h(c_c + w_c)kg'(x_m) \end{pmatrix}$$

with $f'(z_p) < 0$ and $g'(x_m)$ (management by exception– those higher up specialized in exceptions) and, letting the vector foc= $(foc_{z_p} foc_{x_m})$:

$$\frac{\partial foc}{\partial c_p} = \begin{pmatrix} -1 \\ 0 \end{pmatrix}; \frac{\partial foc}{\partial c_m} = \begin{pmatrix} hf(z_p) \\ -k \end{pmatrix}; \frac{\partial foc}{\partial h} = \begin{pmatrix} (c_m + w_m)f(z_p) \\ (c_c + w_c)kg(x_m) \end{pmatrix}$$

Let the vector $vars = (z_p \ x_m)$ .Then for each parameter, $\frac{\partial vars}{\partial t} = -H^{-1}\frac{\partial foc}{\partial t}$ gives:

$$sign \begin{pmatrix} \frac{\partial z_p}{\partial c_p} \\ \frac{\partial x_m}{\partial c_p} \end{pmatrix} = \begin{pmatrix} < 0 \\ 0 \end{pmatrix}; sign \begin{pmatrix} \frac{\partial z_p}{\partial c_m} \\ \frac{\partial x_m}{\partial c_m} \end{pmatrix} = \begin{pmatrix} > 0 \\ < 0 \end{pmatrix}; sign \begin{pmatrix} \frac{\partial z_p}{\partial h} \\ \frac{\partial x_m}{\partial h} \end{pmatrix} = \begin{pmatrix} > 0 \\ > 0 \end{pmatrix}.$$

For the effects in span, simply note that the span of control of corporate managers is $s_c = (Nk + n_m)/n_c = (k + (1 - F(z_p)h) / ((1 - G(x_m))h)$ and that of middle managers: $s_m = N/(Nk + n_m) = 1/(k + (1 - F(z_p)h)$, thus

$$sign \begin{pmatrix} \frac{\partial s_m}{\partial c_p} \\ \frac{\partial s_c}{\partial c_p} \end{pmatrix} = \begin{pmatrix} < 0 \\ > 0 \end{pmatrix}; sign \begin{pmatrix} \frac{\partial s_m}{\partial c_m} \\ \frac{\partial s_c}{\partial c_m} \end{pmatrix} = \begin{pmatrix} > 0 \\ < 0 \end{pmatrix}; sign \begin{pmatrix} \frac{\partial s_m}{\partial h} \\ \frac{\partial s_c}{\partial h} \end{pmatrix} = \begin{pmatrix} \lesseqgtr 0 \\ \lesseqgtr 0 \end{pmatrix}.$$

To get the table in the paper, note that the predictions are with respect to a *fall* in these costs and thus all of the signs must be reversed to obtain the prediction.

Finally, note also that if we let c_m be also the acquisition cost of CEOs, so that ERP affects both CEOs and plant managers equally nothing changes (as the proposition states), so that $c_c = c_m$. The first foc is the same, foc_{x_m} changes to: $-c_m k + (c_m + w_c)hkg(x_m))$, and

$$\frac{\partial foc}{\partial c_m} = \begin{pmatrix} hf(z_p) \\ -k + hkg(x_m) = -w_c kg(x_m)h/c_m < 0 \end{pmatrix}$$

so that sign$\begin{pmatrix} \frac{\partial z_p}{\partial c_m} \\ \frac{\partial x_m}{\partial c_m} \end{pmatrix} = \begin{pmatrix} > 0 \\ < 0 \end{pmatrix}$ is still true.

B Appendix B: Data

B.1 CEP Management Survey Data

B.1.1 The Survey Sampling Frame

Our sampling frame was based on the Bureau van Dijk (BVD) Amadeus dataset for Europe (France, Germany, Greece, Italy, Poland, Portugal and the U.K.), on Bureau van Dijk Icarus for the US, on CMIE Firstsource dataset for India, and on the Bureau van Dijk Oriana dataset for China and Japan. These databases all provide sufficient information on companies to conduct a stratified telephone survey (company name, address and a size indicator). These databases also typically have some accounting information, such employment, sales of capital assets. Apart from size, we did not insist on having accounting information to form the sampling population, however.

Amadeus and Firstsource are constructed from a range of sources, primarily the National registries of companies (such as Companies House in the UK and the Registry of Companies in India). Icarus is constructed from the Dun & Bradstreet database, which is a private database of over 5 million US trading locations built up from credit records, business telephone directories and direct research. Oriana is constructed from Huaxia credit in China and Teikoku Database in Japan, covering all public and all private firms with one of the following: 150 or more employees, 10 million US$ of sales or 20 million US$ of assets.

In every country the sampling frame was all firms with a manufacturing primary industry code with between 100 and 5000 employees on average over the most recent three years of data (typically 2002 to 2004)[19]. In Japan and China we used all manufacturing firms with 150 to 5000 employees since Oriana only samples firms with over 150 employees[20]. In Portugal the population of firms with 100 to 5000 employees was only 242, so we supplemented this with the 72 firms with 75 to 100 employees. We checked the results by conditioning on common size bands (above 150 in all countries).

Interviewers were each given a randomly selected list of firms from the sampling frame. This should therefore be representative of medium sized manufacturing firms. The size of this sampling frame by country is shown in Table B1, along with some basic statistics on firm size and public listing status.

Looking at Table B1 three points are worth highlighting on the sampling frame. First, the size of the sampling frame appears broadly proportional to the absolute size of each country's manufacturing base, with China, the US, India and Japan having the most firms and Sweden, Greece and Portugal the fewest[21]. Second, China has the largest firms on average, presumably reflecting both the higher size cut-off for its sampling frame (150 employees versus 100 employees for other countries) and also the presence of many current and ex state-owned enterprises (11% in the survey are still Government owned). Figure B1 shows the histogram of firms' sizes by country, with China having a much smaller share of the smallest firms. Third, Greece, India and Japan have a much higher share of publicly quoted firms then the other countries, with this presumably reflecting their more limited provision of data on privately held firms. Because of this potential bias across countries will control for firm size and listing status in all the main regressions.

In addition to randomly surveying from the sampling frame described above we also tried to resurvey the firms we interviewed in the 2004 survey wave used in Bloom and Van Reenen

[19] In the US only the most recent year of employment is provided. In India employment is not reported for private firms, so for these companies we used forecast employment, predicted from their total assets (which are reported) using the coefficients from regressing log(employees) on log (assets) for public firms.

[20] Note that the Oriana database does include firms with less than 150 employees if they meet the sales or assets criteria, but we excluded this to avoid using a selected sample.

[21] The size of the manufacturing sector can be obtained from http://laborsta.ilo.org/, a database maintained by ILO. Indian data can be obtained from Indiastat, from the "Employment in Industry" table.

(2007). This was a sample of 732 firms from France, Germany, the UK and the US, with a manufacturing primary industry code and 50 to 10,000 employees (on average between 2000 and 2003). This sample was drawn from the Amadeus dataset for Europe and the Compustat dataset for the U.S. Only companies with accounting data were selected. So, for the UK and France this sampling frame was very similar to the 2006 sampling frame. For Germany it is more heavily skewed towards publicly quoted firms since smaller privately held firms do not report balance sheet information. For the US it comprised only publicly quoted firms. As a result when we present results we always include controls for firm size. As a robustness test we drop the firms that were resurveyed from 2004. These resurveyed firms were randomly distributed among the relevant country interviewers.

B.1.2 The Representativeness of the Sample

Table B2 compares the number of employees for different size bands from our sample with the figures for the corresponding manufacturing populations in each of the twelve countries obtain from national census data. Since figures for the population distributions are not available from every country in the same format from the Census data, we present a variety of statistics.

The broad picture that arises is that in nine countries the sample broadly matches up with the population of medium sized manufacturing firms. This suggests our sampling frame covers the population of all firms. In three countries the coverage is less complete – China, Germany and Portugal - where the sample appears to cover around a third of manufacturing employees. This will be a problem if our sampling frame is non-randomly omitting firms – for example under-representing smaller firms – because it would bias our cross-country comparisons. We try a couple of approach to try and address this. First, in almost all the tables of results we include country fixed-effects to try to control for any differences across countries in sample selection bias. Hence, are key results are identified by within country and region variation. Second, in our quantification table when we compare across countries we control for size, public listing status and industry. This should help to condition on the types of factors that lead to under/over sampling of firms. Since these factors explain only a limited share of cross country variation in decentralization this suggests this differential sampling bias is not likely to be particularly severe.[22]

B.1.3 The Survey Response Rate

As shown in Table B3 of the firms we contacted 44.9% took part in the survey: a high success rate given the voluntary nature of participation. Of the remaining firms 16.8% refused to be surveyed, while the remaining 38.3% were in the process of being scheduled when the survey ended.

The reason for this high share of 'scheduling in progress' firms was the need for interviewers to keep a portfolio of firms who they cycle though when trying to set up interviews. Since interviewers only ran an average of 2.8 interviews a day the majority of their time was spent trying to contact managers to schedule future interviews. For scheduling it was efficient for interviewers to keep a stock of between 100 to 500 firms to cycle through. The optimal level of this stock varied by the country – in the US and UK many managers operated voicemail, so that large stocks of firms were needed. In Japan after two weeks the team switched from working Japanese hours (midnight to 8am) to Japanese afternoons and UK morning (4am till midday)[23], which left large stocks of contacted firms in Japan. In Continental Europe, in

[22] We found a similar result in Bloom and Van Reenen (2007), when we include size and public listing status as controls in evaluating cross-country management practice differences and found these played almost no role.

[23] After two weeks of the Japanese team working midnight to 8am it became clear this schedule was not sustainable due to the unsociability of the hours, with one of the Japanese interviewers quitting. The rest of the team then switched to working 4am until noon.

contrast, managers typically had personnel assistants rather than voicemail, who wanted to see Government endorsement materials before connecting with the managers. So each approach was more time consuming, requiring a smaller stock of firms.

The ratio of successful interviews to rejections (ignoring 'scheduling in progress') is above 1 in every country. Hence, managers typically agreed to the survey proposition when interviewers were able to connect with them. This agreement ratio is lowest in China and Japan. There were two reasons for this: first, the Chinese and Japanese firms did appear to be genuinely more willing to refuse to be interviewed; and second, the time-zone meant that our interviewers could not run talk during the Chinese or Japanese morning; which sometimes led to rejections if managers were too busy to talk in the afternoon.

Table B4, column (1), evaluates the decision to accept the interview proposition[24]. The decisions to reject the interview are the baseline, with all 'scheduling in progress' interviews dropped. The decision to accept is uncorrelated with revenues per worker, listing status of the firm or firm age. Large firms and multinationals did appear to be more predisposed to accepting interview proposition, although the size of this effect if not large – multinationals were about 7 percentage points more likely to agree to the interview and firms about 4 percentage points more likely for a doubling in size. The likelihood of managers accepting the interview proposition did not rise significantly through the survey. Finally, compared to the US only four countries had a significantly higher conditional acceptance rate – France, Greece, Italy and Poland – while none had a significantly lower acceptance rate.

Table B4 column (2), compares the probability of running an interview conditional on contacting the firm, so including rejections and 'scheduling in progress' firms in the baseline. This interview probability is also uncorrelated with revenues per worker, listing status or the firm age. Large firms and multinational subsidiaries were more likely to have a completed interview after being contacted. Firms that were contacted earlier on in the survey were also significantly more likely to end up being interviewed. The size of this time effect is quantitatively large – firms contacted at the beginning of the survey were over 20 percentage points more likely to be interviewer than those contacted towards the end (3 months later). The reason is that firms contacted early on in the survey were subsequently contacted many more times as interviewers cycled through their stocks of 'scheduling in progress firms'. Finally, columns (3) and (4) show that the likelihood of a contacted firm eventually being interviewed is also uncorrelated with firm growth rates and return on capital employed, a basic profits measure.

So, in summary, respondents were not significantly more productive, profitable or fast growing than non-responders. Respondents did tend to be slightly larger and more likely to be a multinational subsidiary, but were not more likely to be stock-market listed or older. Chinese and Japanese firms less likely to respond and European firms more likely to respond. Firms contacted earlier on in the survey process were more likely to end up being interviewed.

B.2 Firm level accounting data

Our firm accounting data on sales, employment, capital, profits, shareholder equity, long-term debt, market values (for quoted firms) and wages (where available) came from Amadeus dataset for Europe (France, Germany, Greece, Italy, Poland, Portugal and the U.K.), on Bureau van Dijk Icarus for the US, on CMIE Firstsource dataset for India, and on the Bureau van Dijk Oriana dataset for China and Japan.

[24]Note this sample is smaller than the total survey sample because some firms do not report data for certain explanatory variables, for example US private firms do not report sales.

B.3 Harte Hanks Data

The main data that we use in this paper is constructed using the Ci Technology Database (CiDB) produced by the international marketing and information company Harte Hanks (HH). Harte-Hanks is a global company that collects IT data primarily for the purpose of selling on to large producers and suppliers of IT products (e.g. IBM, Dell etc). Their data is collected for roughly 160,000 establishments across 20 European countries as well as the US. The US branch has the longest history with the company beginning its data collection activities in the mid 1980s. The papers by Bresnahan et al (2002) and Brynjolfsson and Hitt (2003) use a sub-set of the US Harte-Hanks data matched to large publicly listed firms in Compustat. In Europe, the company began surveying the major Western European countries (UK, France, Germany, Italy, Spain) in the early 1990s, and by the late 1990s had expanded to cover the rest of Western Europe.

Harte Hanks surveys establishments (referred to as “sites” in the CiTB database) on a rolling basis with an average of 11 months between surveys. This means that at any given time, the data provides a “snapshot” of the stock of a firm’s IT. The CiTDB contains detailed hardware, equipment and software information at the establishment level. Areas covered by the survey include PCs, many types of software, servers, storage and IT staff (including development staff such as programmers). We focus on using PC per worker as our key measure of IT hardware intensity because this is available for all the establishments and is measured in a comparable way across time and countries. This PC per worker measure of IT has also been used by other papers in the micro-literature on technological change and is highly correlated with other measures of IT use like the firm’s total IT capital stock (see, for example, Doms et al, 2006).

The fact that HH sells this data on to major firms like IBM and Cisco, who use this to target their sales efforts, exerts a strong market discipline on the data quality. If there were major discrepancies in the collected data this would rapidly be picked up by HH’s clients when they placed sales calls using the survey data, and would obviously be a severe problem for HH future sales[25]. Because of this HH run extensive internal random quality checks on its own data, enabling them to ensure high levels of data accuracy.

Another valuable feature of the CiDB is its consistency of collection across countries. The data for Europe is collected via a central call centre in Dublin and this ensures that all variables are defined on an identical basis across countries. This provides some advantages over alternative strategies such as (for example) harmonizing government statistical register data collected by independent country level survey agencies.

HH samples all firms with over 100 employees in each country. Thus, we do lose smaller firms, but since we focus on manufacturing the majority of employees are in these larger firms. It is also worth noting this survey frame is based on firm employment - rather than establishment employment - so the data contains establishments with less than 100 employees in firms with multiple establishments. Furthermore, HH only drops establishments from the survey if they die or repeatedly refuse to answer over several years, so that the sampling frame covers all firms that have had at 100 employees in any year since the survey began.

In terms of survey response rate HH reports that for the large European countries (UK, France, Germany, Italy, and Spain) they had a response rate of 37.2% in 2004 for firms with 100 or more employees[26]. As mentioned above, the sampling strategy followed by HH allows us to construct a measure of establishment survival. The company’s policy is to continue to conduct follow up surveys with all establishments after they have entered the survey. Since the

[25] HH also refunds data-purchases for any samples with error levels above 5%.

[26] This is close to the 44.9% response rate achieved by Bloom, Sadun and Van Reenen (2008) using a similar telephone survey technology, in which the response rate appeared to be uncorrelated with any firm-level performance characteristics. HH claim no systematic response bias and we are currently matching the HH database against the population of firms in Europe obtained from the AMADEUS database to analyze the factors determining the response rate in the HH data.

"first contact" or initial survey of an establishment is arguably the most difficult to achieve it makes sense for HH to capitalize on this sunk cost and conduct regular follow-up interviews. Hence, while the company defines no formal measure of establishment survival in their data we able to infer exit by the disappearance of an establishment from a dataset. Practically, we classify any establishment that has not appeared in the survey for 36 months as an exit. We cross checked these assumptions against matched firms from the Amadeus database and found it to be an accurate rule in almost all cases.

The site-level information we use is taken from HH's "equipment file". This details the presence of various types of software. For multi-plant firms we take a weighted average of the ICT used using plant-level employment as weights. Mostly these are wither zero or one, but we also present experiments using only discrete indicators of technology presence at the firm level for multi-plant firms.

B.4 Effective Network Prices (Leased Line Data)

The data on cross national prices is given by OECD (2007). Although European prices have been falling over the past decade due to liberalizations and pressures from the competition commissions (e.g. EU), there remains considerable concern about differential degrees of competition and regulation generating cross-national price disparities. "Local leased line prices remain of concern where there is insufficient competition. For users in these areas this means that incumbents can continue to charge prices that are not disciplined by competition. For new entrants it means that incumbents may price local leased circuits in an anti-competitive manner" (*OECD Communication Outlook,* 2005).

"Leased lines are provided by traditional telecom operators. New market entrants have their own networks but need to link their customers' premises to it. This link is called a 'leased line part circuit' and is usually provided by the incumbent. The availability at the wholesale level of these links at reasonable prices is a necessary condition for a competitive leased lines retail market and for pro-competitive downstream 'knock-on' effects" (*European Commission Report*, 2002)

A major turning point in the pricing of leased lines took place in1998 when a significant number of European countries fully liberalised their telecommunication markets. The impact of increasing liberalisation is evident in the OECD's Index of leased line prices. At the distances of 50 and 200 kilometres the leased lines (2Mbit/s) index fell from 77 in1997 to 32 and 31 by 2004. This process happened at a much faster rate in some countries than others (see OECD, 2005).

TABLE 1 – SUMMARY OF MAIN THEORETICAL PREDICTIONS AND OUR EMPIRICAL FINDINGS

Panel A: Basic Predictions

		Reduction in Information costs (c)			Reduction in Communication costs (h)		
(1)		(2)	(3)	(4)	(5)	(6)	(7)
Organizational Outcome		**Technology Indicator**	**Theoretical Prediction**	**Empirical Finding**	**Technology Indicator**	**Theoretical Prediction**	**Empirical Finding**
Plant Manager Autonomy	**(Table 2)**	*ERP* (c_m)	+	+	*NETWORK (h)*	**-**	**-**
Worker Autonomy	**(Table 3)**	*CADCAM* (c_p)	+	+	*NETWORK (h)*	**-**	**-** (insig)
Plant Manager Span of Control	**(Table 4)**	*CADCAM* (c_p)	+	+	*NETWORK (h)*	+/-	+ (insig)
CEO Span of Control	**(Table 5)**	*ERP* (c_m)	+	+	*NETWORK (h)*	+/-	+

Panel B: Extended Predictions (Table 8)

(1)	(2)	(3)	(4)
Organizational Outcome	**Technology Indicator**	**Theoretical Prediction**	**Empirical Finding**
Plant Manager Autonomy	*CADCAM* (c_p)	0	+ (insig.)
Worker Autonomy	*ERP* (c_m)	**-**	**-**
Plant Manager Span	*ERP* (c_m)	**-**	+ (insig.)
CEO Span	*CADCAM* (c_p)	**-**	**-**

Notes: This table presents the theoretical predictions and the empirical findings. Column (1) has the 4 organizational outcomes: autonomy (for plant manager and worker) and span of control (for plant manager and CEO). We consider the comparative statics of these organizational variables with respect to reductions in information costs (columns (2) - (4)) and communication costs (columns (5) - (7)). ERP denotes Enterprise Resource Planning, CADCAM denotes Computer Assisted Design/Computer Assisted Manufacturing and NETWORK denotes the presence of a network (leased line/frame relay). A "+" denotes an increase, a "-'' a decrease and "+/-'' an ambiguous sign. "insig.'' denotes the variable was insignificant at the 5% level (all other signs were significant at this level).

TABLE 2 - PLANT MANAGER AUTONOMY

	(1)	(2)	(3)	(4)	(5)	(6)
ERP	0.097*	0.104*	-	-	0.113**	0.115**
	(0.053)	(0.054)			(0.053)	(0.054)
NETWORK	-	-	-0.107**	-0.098*	-0.123**	-0.111**
			(0.053)	(0.053)	(0.053)	(0.053)
Percentage College	-	0.101***	-	0.098***	-	0.099***
		(0.032)		(0.032)		(0.032)
ln(PC/Employee)	-	-0.042	-	-0.021	-	-0.031
		(0.031)		(0.031)		(0.031)
ln(Firm Employment)	0.069*	0.061	0.072*	0.067*	0.072*	0.065
	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)
Plant Employment	0.151***	0.147***	0.151***	0.150***	0.148***	0.147***
	(0.044)	(0.045)	(0.044)	(0.045)	(0.044)	(0.045)
Foreign Multinational	0.178**	0.181**	0.204**	0.200**	0.195**	0.193**
	(0.080)	(0.080)	(0.080)	(0.080)	(0.081)	(0.080)
Domestic Multinational	0.196**	0.187**	0.209**	0.196**	0.204**	0.192**
	(0.083)	(0.083)	(0.083)	(0.083)	(0.082)	(0.083)
Number of Firms	947	947	947	947	947	947
Industry and country dummies	yes	yes	yes	yes	yes	yes
Noise controls (60)	yes	yes	yes	yes	yes	yes

Notes: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. The dependent variable in all columns is the z-score of plant manager autonomy. All columns are estimated by OLS with standard errors in parentheses (clustered by firm). All columns exclude firms where the plant manager is the CEO and include a dummy equal to unity if the CEO is on site. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the UK and the US (country dummies included). "Industry dummies" are three digit industry dummies. "Noise controls" include analyst dummies, plant manager seniority and tenure in company, the day of the week the interview was conducted, interview duration and reliability. "ERP" denotes Enterprise Resource Planning and "NETWORK" denotes the firm has an internal network system (leased lines or frame relays). The time period covered by the ICT variables is 2001-2006 (year dummies included).

TABLE 3 - WORKER AUTONOMY

	(1)	(2)	(3)	(4)	(5)	(6)
CADCAM	0.626**	0.597**	-	-	0.627**	0.590**
	(0.267)	(0.272)			(0.265)	(0.271)
	[0.090]	[0.070]			[0.090]	[0.069]
NETWORK	-		-0.131	-0.193	-0.133	-0.188
			(0.160)	(0.170)	(0.161)	(0.170)
			[-0.019]	[-0.023]	[-0.019]	[-0.022]
Percentage College	-	0.523***	-	0.529***	-	0.529***
		(0.116)		(0.116)		(0.116)
		[0.062]		[0.063]		[0.062]
ln(PC/Employee)	-	-0.004	-	0.025	-	0.010
		(0.108)		(0.108)		(0.109)
		[-0.000]		[0.003]		[0.001]
ln(Firm Employment)	-0.062	-0.099	-0.053	-0.085	-0.057	-0.091
	(0.105)	(0.102)	(0.105)	(0.101)	(0.104)	(0.101)
	[-0.009]	[-0.012]	[-0.008]	[-0.010]	[-0.008]	[-0.011]
Plant Employment	-0.143	-0.168	-0.140	-0.157	-0.141	-0.162
	(0.130)	(0.134)	(0.131)	(0.133)	(0.130)	(0.134)
	[-0.021]	[-0.020]	[-0.020]	[-0.019]	[-0.020]	[-0.019]
Foreign Multinational	0.439*	0.416*	0.468**	0.451*	0.455*	0.437*
	(0.231)	(0.242)	(0.232)	(0.243)	(0.233)	(0.244)
	[0.072]	[0.056]	[0.077]	[0.062]	[0.074]	[0.059]
Domestic Multinational	0.380*	0.339	0.405*	0.380	0.401*	0.369
	(0.227)	(0.234)	(0.228)	(0.237)	(0.228)	(0.237)
	[0.060]	[0.044]	[0.065]	[0.050]	[0.064]	[0.048]
Number of firms	1056	1056	1056	1056	1056	1056
Industry and country dummies	yes	yes	yes	yes	yes	yes
Noise controls (60)	yes	yes	yes	yes	yes	yes

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 (clustered by firm). Marginal effects 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). "Industry dummies" are three digit industry dummies. "Noise controls" include analyst dummies, plant manager seniority and tenure in company, the day of the week the interview was conducted, interview duration and reliability. "CADCAM" denotes Computer Aided Design or Manufacturing software. and "NETWORK" denotes the firm has an internal network system (leased lines or frame relays). The time period covered by the ICT variables is 2001-2006 (year dummies included).

TABLE 4 - PLANT MANAGER SPAN OF CONTROL

	(1)	(2)	(3)	(4)	(5)	(6)
CADCAM	0.164**	0.152**	-	-	0.165**	0.154**
	(0.072)	(0.076)			(0.072)	(0.076)
NETWORK	-		0.034	0.028	0.035	0.030
			(0.043)	(0.042)	(0.043)	(0.042)
Percentage College	-	0.056**	-	0.058**	-	0.056**
		(0.023)		(0.023)		(0.023)
ln(PC/Employee)	-	0.013	-	0.012	-	0.011
		(0.024)		(0.024)		(0.024)
ln(Firm Employment)	0.058**	0.058**	0.059**	0.059**	0.056**	0.056**
	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)
Plant Employment	0.039	0.047	0.042	0.049	0.039	0.046
	(0.032)	(0.033)	(0.032)	(0.032)	(0.032)	(0.033)
Foreign Multinational	0.058	0.035	0.055	0.033	0.054	0.033
	(0.058)	(0.055)	(0.058)	(0.056)	(0.058)	(0.056)
Domestic Multinational	0.128**	0.107*	0.124**	0.103*	0.125**	0.105*
	(0.060)	(0.058)	(0.060)	(0.057)	(0.060)	(0.057)
Number of firms	862	862	862	862	862	862
Industry and country dummies	yes	yes	yes	yes	yes	yes
Noise controls (60)	yes	yes	yes	yes	yes	yes

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 (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). "Industry dummies" are three digit industry dummies. "Noise controls" include analyst dummies, plant manager seniority and tenure in company, the day of the week the interview was conducted, interview duration and reliability. "CADCAM" denotes Computer Aided Design or Manufacturing software. and "NETWORK" denotes the firm has an internal network system (leased lines or frame relays). The time period covered by the ICT variables is 2001-2006 (year dummies included).

TABLE 5 – CEO SPAN OF CONTROL (MULTI-PLANT FIRMS)

	(1)	(2)	(3)	(4)	(5)	(6)
ERP	0.227**	0.230**	-	-	0.193**	0.203**
	(0.091)	(0.093)			(0.093)	(0.094)
	[0.034]	[0.035]			[0.028]	[0.030]
NETWORK	-		0.344***	0.375***	0.321***	0.357***
			(0.091)	(0.096)	(0.092)	(0.096)
			[0.051]	[0.056]	[0.047]	[0.053]
Percentage College	-	0.088	-	0.091	-	0.092
		(0.060)		(0.059)		(0.059)
		[0.013]		[0.014]		[0.013]
ln(PC/Employee)	-	-0.118*	-	-0.132**	-	-0.149**
		(0.064)		(0.064)		(0.064)
		[-0.018]		[-0.020]		[-0.022]
ln(Firm Employment)	0.404***	0.398***	0.395***	0.387***	0.399***	0.389***
	(0.079)	(0.080)	(0.078)	(0.080)	(0.079)	(0.080)
	[0.061]	[0.061]	[0.059]	[0.058]	[0.059]	[0.057]
Plant Employment	-0.570***	-0.604***	-0.559***	-0.598***	-0.566***	-0.608***
	(0.123)	(0.122)	(0.123)	(0.123)	(0.124)	(0.122)
	[-0.086]	[-0.092]	[-0.083]	[-0.089]	[-0.083]	[-0.089]
Foreign Multinational	0.495***	0.512***	0.470***	0.487***	0.457***	0.476***
	(0.151)	(0.153)	(0.150)	(0.153)	(0.151)	(0.153)
	[0.068]	[0.071]	[0.064]	[0.066]	[0.061]	[0.064]
Domestic Multinational	0.848***	0.853***	0.837***	0.841***	0.828***	0.832***
	(0.158)	(0.160)	(0.157)	(0.160)	(0.158)	(0.160)
	[0.104]	[0.106]	[0.101]	[0.102]	[0.099]	[0.099]
Number of Firms	1092	1092	1092	1092	1092	1092
Industry and country dummies	yes	yes	yes	yes	yes	yes
Noise controls	yes	yes	yes	yes	yes	yes

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 (clustered by firm). Marginal effects 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). "Industry dummies" are three digit industry dummies. "Noise controls" include analyst dummies, plant manager seniority and tenure in company, the day of the week the interview was conducted, interview duration and reliability. "ERP" denotes Enterprise Resource Planning and "NETWORK" denotes the firm has an internal network system (leased lines or frame relays). The time period covered by the ICT variables is 2001-2006 (year dummies included).

TABLE 6 –PLANT MANAGER AUTONOMY
(USING EFFECTIVE NETWORK PRICES AS EXOGENOUS SHIFTER OF NETWORK USAGE)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Regression	**Basic**	**Reduced Form**	**Reduced Form**	**Reduced Form**	**Reduced Form**	**First Stage**	**Second Stage**	**First Stage**	**Second Stage**
Estimation Method	**OLS**	**OLS**	**OLS**	**OLS**	**OLS**	**OLS**	**2SLS**	**OLS**	**2SLS**
Dependent Variable	**Plant Manager Autonomy**	**Plant Manager Autonomy**	**Plant Manager Autonomy**	**Plant Manager Autonomy**	**Plant Manager Autonomy**	**Firm Level NETWORK**	**Plant Manager Autonomy**	**Firm Level NETWORK**	**Plant Manager Autonomy**
Sample	**All**	**All**	**All**	**All**	**All**	**All**	**All**	**Firms>200 employees**	**Firms>200 employees**
Firm-level NETWORK	-0.132* (0.068)	-	-	-	-	-	-2.954 (1.879)	-	-1.704* (0.953)
(Industry-level NETWORK %) *ln(NETWORK Price)	-	4.774** (2.188)	-	-	5.778** (2.766)	-1.616 (1.005)	-	-2.787** (1.217)	-
(Industry-level NETWORK %)* ln(Average Years of Schooling)	-	-	-1.420 (5.028)	-	1.477 (5.027)	-	-	-	-
(Industry-level NETWORK %)*ln(GDP Per Capita)	-	-	-	-1.463 (2.009)	1.520 (2.548)	-	-	-	-
Number of Firms	1019	1019	1019	1019	1019	1019	1019	757	757

Notes: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. The dependent variable in columns 1-5 and 7 is the z-score of plant manager autonomy. The dependent variable in column 6 is a dummy equal to one if the firms reports to adopt internal networks. Columns 1-6 and 8 are estimated by OLS. Columns 7 and 9 are estimated by 2SLS. Standard errors are clustered at the country-SIC3 level in all columns. 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 noise controls, firm controls and industry dummies as in previous tables. The time period covered by the ICT variables is 2001-2006 (year dummies included). The variable "Firm-level NETWORK" represents the access to an internal network system (leased lines or frame relays); measured in the last year the variable is measured for the specific firm level. The variable "Industry-level NETWORK" represents the average fraction of SIC3 employment reporting access to an internal network system (leased lines or frame relays), computed using cross country data between 2001 and 2006. The variable "Network Price" is the cost of an annual subscription to a leased line contract at 2006 PPP USD (taken from the OECD *Telecommunication Handbook*, 2007). The variables "Average Years of Schooling" and "GDP Per Capita PPP" are taken from the World Development Indicators, 2006.

TABLE 7 – WORKER AUTONOMY
(USING EFFECTIVE NETWORK PRICES AS EXOGENOUS SHIFTER OF NETWORK USAGE)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Regression	**Basic**	**Reduced Form**	**Reduced Form**	**Reduced Form**	**First Stage**	**Second Stage**	**First Stage**	**Second Stage**
Estimation Method	**Probit**	**Probit**	**Probit**	**Probit**	**OLS**	**2SLS**	**OLS**	**2SLS**
Dependent Variable	**Workers' Autonomy**	**Workers' Autonomy**	**Workers' Autonomy**	**Workers' Autonomy**	**Firm Level NETWORK**	**Workers' Autonomy**	**Firm Level NETWORK**	**Workers' Autonomy**
Sample	**All**	**All**	**Drop Sweden**	**Drop Sweden**	**Drop Sweden**	**Drop Sweden**	**Drop Sweden and firms under 200 employees**	**Drop Sweden and firms under 200 employees**
Firm-level NETWORK	-0.270 (0.186) [-0.029]	-	-0.825*** (0.293) [-0.042]	-	-	-0.736 (0.591)	-	-1.367** (0.651)
(Industry-level NETWORK %) *ln(NETWORK Price)	-	-8.480 (6.408) [-0.920]	-	28.383** (14.269) [1.707]	-3.959* (2.213)	-	-6.931* (3.627)	-
Number of Firms	1190	1190	1062	1062	1062	1062	730	730

Notes: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. The dependent variable in columns 1-4 and 6 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). Columns 1-4 are estimated by probit ML with standard errors in parentheses and marginal effects reported in square brackets. Columns 5 and 7 are estimated by OLS. Column 6 and 8 are estimated by 2SLS. Standard errors are clustered at the country-SIC3 level in all columns. 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" sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the UK and the US (country dummies included). All columns include noise controls, firm controls and industry dummies as in previous tables. The time period covered by the ICT variables is 2001-2006 (year dummies included). The variable "Firm-level NETWORK" represents the access to an internal network system (leased lines or frame relays); measured in the last year the variable is measured for the specific firm level. The variable "Industry-level NETWORK" represents the average fraction of SIC3 employment reporting access to an internal network system (leased lines or frame relays), computed using cross country data between 2001 and 2006. The variable "Network Price" is the cost of an annual subscription to a leased line contract at 2006 PPP USD (taken from the OECD *Telecommunication Handbook*, 2007). The variables "Average Years of Schooling" and "GDP Per Capita PPP" are taken from the World Development Indicators, 2006.

TABLE 8 – CROSS EFFECTS OF TECHNOLOGIES

	(1)	(2)	(3)	(4)
Dependent Variable	**Plant Manager Autonomy**	**Workers' Autonomy**	**Ln(PM Span)**	**CEO Span**
ERP	0.116**	-0.303*	0.020	0.203**
	(0.054)	(0.170)	(0.055)	(0.094)
		[-0.035]		[0.030]
CADCAM	0.091	0.587**	0.154**	-0.760*
	(0.223)	(0.272)	(0.076)	(0.443)
		[0.068]		[-0.112]
NETWORK	-0.111**	-0.189	0.030	0.358***
	(0.053)	(0.170)	(0.042)	(0.096)
		[-0.022]		[0.053]
Number of Firms	947	1056	862	1092
Observations	3430	1861	1527	3985
Firm controls	yes	yes	yes	yes
Industry and country dummies	yes	yes	yes	yes
Noise controls	yes	yes	yes	yes

Notes: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. Columns 1 and 3 are estimated by OLS; columns 2 and 4 are estimated by probit ML with standard errors in parentheses and marginal effects in square brackets. Standard errors are clustered by firm in all columns. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the 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. "Industry dummies" are three digit industry dummies. "Noise controls" include analyst dummies, plant manager seniority and tenure in company, the day of the week the interview was conducted, interview duration and reliability. "ERP" denotes Enterprise Resource Planning, "NETWORK" denotes the firm has an internal network system (leased lines or frame relays) and "CADCAM" denotes Computer Aided Design or Manufacturing software. The time period covered by the ICT variables is 2001-2006 (year dummies included).

TABLE 9 - ROBUSTNESS CHECKS

	(1) Baseline	(2) Regional dummies and Lerner index	(3) Additional firm level controls	(4) Alternative NETWORK (LAN/WAN)	(5) Alternative construction of ICT variables	(6) Management quality as an additional control	(7) Alternative dependent variable 1	(8) Alternative dependent variable 2
				Panel A: Plant Manager Autonomy				
ERP	0.115**	0.095*	0.111**	0.114**	0.118**	0.119**	0.133**	0.106**
	(0.054)	(0.052)	(0.054)	(0.053)	(0.053)	(0.054)	(0.059)	(0.042)
NETWORK	-0.111**	-0.128**	-0.099*	-0.136**	-0.125**	-0.112**	-0.099*	-0.082**
	(0.053)	(0.052)	(0.053)	(0.063)	(0.051)	(0.053)	(0.056)	(0.041)
Firms	947	947	947	947	947	947	947	947
Obs	3430	3430	3430	3430	3430	3430	3430	3430
				Panel B: Workers' Autonomy				
CADCAM	0.590**	0.614**	0.589**	0.690**	0.515*	0.564**	0.843**	0.486*
	(0.271)	(0.297)	(0.285)	(0.269)	(0.279)	(0.273)	(0.352)	(0.258)
	[0.069]	[0.067]	[0.064]	[0.078]	[0.086]	[0.066]	[0.234]	[0.079]
NETWORK	-0.188	-0.317*	-0.211	-0.594**	-0.184	-0.209	0.040	-0.228
	(0.170)	(0.190)	(0.175)	(0.248)	(0.165)	(0.174)	(0.219)	(0.167)
	[-0.022]	[-0.035]	[-0.023]	[-0.067]	[-0.020]	[-0.024]	[0.007]	[-0.037]
Firms	1056	1056	1056	1056	1056	1056	777	1056
Obs	1861	1861	1861	1861	1861	1861	1372	1861
				Panel C: Plant Manager Span of Control				
CADCAM	0.152**	0.207***	0.153**	0.151**	0.153**	0.153**	-	-
	(0.076)	(0.074)	(0.076)	(0.075)	(0.075)	(0.074)		
NETWORK	0.013	0.018	0.007	0.050	0.027	0.013	-	-
	(0.041)	(0.041)	(0.041)	(0.057)	(0.040)	(0.041)		
Firms	862	862	862	862	862	862	-	-
Obs	1527	1527	1527	1527	1527	1527	-	-
				Panel D: CEO Span of Control				
ERP	0.203**	0.130	0.204**	0.216**	0.221**	0.205**	-	-
	(0.094)	(0.097)	(0.094)	(0.093)	(0.093)	(0.094)		
	[0.030]	[0.014]	[0.027]	[0.031]	[0.031]	[0.030]		
NETWORK	0.357***	0.394***	0.358***	0.489***	0.389***	0.357***	-	-
	(0.096)	(0.100)	(0.098)	(0.114)	(0.095)	(0.096)		
	[0.053]	[0.043]	[0.048]	[0.071]	[0.054]	[0.052]		
Firms	1092	1092	1092	1092	1092	1092	-	-
Obs	3985	3985	3985	3985	3985	3985	-	-

Notes: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. Panel A and C estimated by OLS. Panel B and D estimated by probit ML with standard errors in parentheses and marginal effects in square brackets. Standard errors are clustered by firm in all columns and panels. The 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" denotes Enterprise Resource Planning, "NETWORK" denotes the firm has an internal network system (leased lines or frame relays) and "CADCAM" denotes Computer Aided Design or Manufacturing software. The time period covered by the ICT variables is 2001-2006 (year dummies included). In **column 2** regional (NUTS2) dummies and the inverse of the Lerner index are included as additional controls. In **column 3** the log capital over employment, log sales over employment, log average wages, log global ultimate owner employment, log firm age and a dummy equal to unity if the firm is publicly listed are included as additional controls. In **column 4** the network 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 6** the average management score (computed across the 18 management questions in Bloom and Van Reenen, 2007) is included as additional controls. **Panel A:** in **column 7** the dependent variable is the principal factor component of the four different Plant Manager Autonomy questions; in **column 8** the dependent variable is the average across three of the four autonomy questions (investment autonomy excluded). **Panel B:** in **column 7** the dependent variable is a dummy equal to unity if the pace of work question takes values above three; in **column 8** the dependent variable is a dummy equal to unity if the task allocation question takes values above three.

TABLE A1: 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://cep.lse.ac.uk/management/default.asp

TABLE A2 - SUMMARY STATISTICS

Variable	Mean	Median	Standard Deviation	Firms
Employment (Firm)	957.34	350	3260.34	947
Employment (Plant)	251.84	150	285.67	947
Foreign Multinational	0.35	0	0.48	947
Domestic Multinational	0.29	0	0.45	947
%College	16.04	10.25	17.17	947
CEO on site	0.08	0	7.23	947
Plant Manager Autonomy	0.25	0.20	0.99	947
Workers' Autonomy	0.08	0	0.26	937
Ln(Plant Manager Span)	1.89	1.95	0.52	875
CEO Span (Multi-plant dummy)	0.66	1	0.47	928
PC per Employee	0.47	0.38	0.37	947
ERP	0.37	0	0.48	947
CADCAM	0.04	0	0.19	1056
NETWORK	0.35	0	0.47	947
LAN/WAN	0.43	0	0.49	947

Notes: These are descriptive statistics from the sample in Table 2 (except for CADCAM which is Table 3)

TABLE B1: THE 2006 SAMPLING FRAME

	CN	FR	GE	GR	IN§	IT	JP	PO	PT	SW	UK	US
Sampling frame, number of firms (#)	30,125	4,716	4,659	489	15,737	4,733	14,165	2,793	304	919	5,409	30,765
Employees (median)	670	194	190	180	187	157	300	214	163	192	221	200
Publicly listed (%)	5.6	2.3	2.5	19.8	15.2	1.0	27.2	3.2	4.9	2.1	4.4	2.7

Notes: CN=China, FR=France, GE=Germany, GR=Greece, IN=India, IT=Italy, JP=Japan, PO=Poland, PT=Portugal, SW=Sweden, UK=United Kingdom, US=United States. **Sampling frame** is the total number of eligible firms for the survey. **Employees** are the median number of employees in the firm. **Publicly listed** is the percentage of firms which are directly publicly listed (note that some firms may be privately incorporate subsidiaries of publicly listed parents). § Indian employment numbers predicted from balance sheet information for privately held firms.

TABLE B2: THE SAMPLING FRAME POPULATION COVERAGE

	CN	FR	GE	GR	IN	IT	JP	PO	PT	SW	UK	US
Employees in firms in sample with 100+ employees, 000's	15,165	1,640	1,636	139	4,245	1,273	7,247	942	91	305	2,224	8,941
Employees in firms with 100 to 5000 in our sample as % of Census data	30%				90%							
Employees in firms with 50+ employees in our sample as % Census data		64%	30%	87%		65%	150%	56%	22%	57%	83%	89%
Employees in firms with 250+ in our sample as % Census data		94%	43%	157%		126%	298%	98%	55%	83%	141%	

Notes: CN=China, FR=France, GE=Germany, GR=Greece, IN=India, IT=Italy, JP=Japan, PO=Poland, PT=Portugal, SW=Sweden, UK=United Kingdom, US=United States. **Employees in firms is sample with 100+ employees, 000's** reports the number of firms in our sampling frame with 100+ employees in thousands (so for example China has 15.2 million employees in firms in our sampling frame). **Employees in firms with 100 to 5000 in our sample as % of Census data** reports the share of firms in our sample in firms with 100 to 5000 employees as a % of the values reported in national Census data (where available). **Employees in firms with 50+ in our sample as % of Census data** reports the share of firms in our sample in firms with 50+ employees as a % of the values reported in national Census data (where available). **Employees in firms with 250+ in our sample as % of Census data** reports the share of firms in our sample in firms with 250+ employees as a % of the values reported in national Census data (where available). Census data comes from Eurostat for the European countries, OECD for Japan and the US, and calculations done on the underlying Census micro data for China and India by Albert Bollard on data provided by Pete Klenow.

TABLE B3: THE SURVEY RESPONSE RATE

	All	CN	FR	GE	GR	IN	IT	JP	PO	PT	SW	UK	US
Interviews completed (%)	44.9	43.9	59.3	58.6	53.4	61.4	68.2	21.5	37.5	60.5	68.2	32.9	37.2
Interviews refused (%)	16.8	13.7	13.7	27.2	10.7	13.7	20.0	20.1	16.5	15.8	16.9	19.6	13.7
Scheduling in progress (%)	38.3	40.1	27.0	14.2	35.9	25.0	11.8	58.4	46.0	23.7	14.9	47.4	49.1
Survey sample, number firms (#)	8690	727	528	526	350	761	304	563	637	293	380	1851	1833
Interviews completed (#)	3,902	319	313	308	187	467	207	121	239	177	259	609	682

Notes: All=All countries combined, CN=China, FR=France, GE=Germany, GR=Greece, IN=India, IT=Italy, JP=Japan, PO=Poland, PT=Portugal, SW=Sweden, UK=United Kingdom, US=United States. **Interviews completed** reports the percentage of companies contacted for which a management interview was completed. **Interviews refused** reports the percentage of companies contacted in which the manager contacted refused to take part in the interview. **Scheduling in progress** reports the percentage of companies contacted for which the scheduling was still in progress at the end of the survey period (so the firm had been contacted, with no interview run nor any manager refusing to be interviewed). **Survey sample** is the total number of firms that were randomly selected from the complete sampling frame.

TABLE B4: THE SURVEY RESPONSE PROBIT

	(1)	(2)	(3)	(4)
Sample	**Firms with interviews completed or refused**	**All firms contacted**	**All firms contacted**	**All firms contacted**
Log (Sales/employee)	0.017 (0.014)	0.010 (0.011)	-	-
Sales growth rate	-	-	-0.058 (0.082)	-
Return on Capital Employed (ROCE) [§]	-	-		0.044 (0.037)
Log (employment)	0.040*** (0.011)	0.026*** (0.008)	0.012 (0.011)	0.025*** (0.010)
Listed	0.045 (0.031)	-0.020 (0.024)	-0.048 (0.033)	0.016 (0.034)
Log (Age of firm), in years	-0.002 (0.010)	0.002 (0.009)	0.001 (0.012)	0.001 (0.011)
Multinational subsidiary	0.070*** (0.020)	0.050*** (0.018)	0.066*** (0.020)	0.054*** (0.020)
Days from the start of the survey until firm contacted[§]	0.051 (0.052)	-0.214*** (0.041)	-0.239*** (0.051)	-0.208*** (0.051)
Country is China	-0.052 (0.235)	-0.195* (0.092)	-0.363*** (0.020)	n/a
Country is France	0.163** (0.062)	0.259*** (0.065)	0.230** (0.062)	0.255* (0.058)
Country is Germany	-0.081 (0.078)	0.200*** (0.058)	0.164*** (0.055)	0.332*** (0.051)
Country is Greece	0.208*** (0.045)	0.112* (0.065)	0.129** (0.066)	0.130** (0.065)
Country is India	0.222*** (0.048)	0.405*** (0.054)	n/a	n/a
Country is Italy	0.059 (0.099)	0.201** (0.089)	0.232*** (0.085)	0.223*** (0.081)
Country is Japan	-0.089 (0.107)	0.084 (0.076)	0.100 (0.071)	n/a
Country is Poland	0.207** (0.062)	0.254*** (0.078)	0.236*** (0.079)	0.250*** (0.077)
Country is Portugal	0.132 (0.101)	0.189* (0.010)	0.171** (0.111)	0.281*** (0.094)
Country is Sweden	0.115 (0.068)	0.237*** (0.066)	0.274*** (0.076)	0.246*** (0.060)
Country is UK	-0.061 (0.048)	-0.000 (0.034)	baseline	Baseline
Country is US	Baseline	Baseline	n/a	n/a
Pseudo R^2	0.111	0.119	0.122	0.116
Number of firms	3688	6349	4364	4123

Notes: The dependent variable is interview completed. All columns estimated by probit with robust standard errors in parentheses. All columns include a full set of 44 interviewer dummies, and 142 SIC 3-digit industry dummies. Column (1) uses only firms which were interviewed or refused to interview (dropping firms for which scheduling was still in progress as the end of the project). Columns (2), (3) and (4) use all firms contacted. In columns (2), (3) and (4) firms are dropped if no sales, sales growth and Return on Capital Employed data is available. [§] Coefficient and standard-errors multiplied by 100 for scaling purposes.