Managerial spans, industry tasks and ICT: evidence from the U.S.

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24 May 2012

Managerial Spans, Industry Tasks and ICT: Evidence from the U.S.*

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June 12, 2012

Abstract

The knowledge theoretic view of organization of production postulates that ICT, tasks and hierarchies intertwine. Utilizing Occupational Employment Statistics and O*NET data, this study investigates the proposition by exploiting the substantial cross-industry variation in hierarchical forms, which are here captured by spans of control among middle and corporate managers. Information [IT] and communication technologies [CT] are explored separately, and the parsimonious task taxonomy depicts industries in four dimensions: tacit knowledge, cognitive, physical/technical and interaction. The key predictions of the knowledge hierarchy literature can hence be tested and the findings largely reverberate with theory. First, ICT influences middle and corporate manager spans dissimilarly reflecting technological asymmetries in hierarchies. Higher IT utilization narrows organizations yet CT expands middle management. Second, industry tasks govern organizational outcomes. Cognitive tasks flatten and technical/physical tasks narrow hierarchies. Third, the descriptive evidence suggests that hierarchies are highly non-pyramidal across U.S. industries. Finally, the key insight is that spans in top hierarchy are insular to tasks yet organizations down the middle management reflect the nature of industry. With some exceptions the results are robust to exogenous variation in ICT utilization.

Keywords: *organization, hierarchy, span of control, tasks, ICT, cross-industry*

JEL Classification: *L22, L23, J21*

*I thank Otto Kässi and Klaus Kultti for their comments.

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1 Introduction

Organizations are complex and multi-faceted coordination devices. As a result, theoretical literature has proposed various metaphors to depict their salient qualities. They can be seen as knowledge hierarchies [Garicano, 2000; Garicano & Rossi-Hansberg, 2006], information processors [Radner, 1993] or even risk allocators [Knight, 1921]. Indeed the transaction cost literature [Coase, 1937] deems hierarchical organizations as negations of markets – institutions where authority and control supersede the price mechanism. Chandler [1962] represents an another strand of literature, and stresses the inextricable nature of organization's activities, strategy and structure. Nevertheless, despite the abundance of theoretical literature, empirical research of hierarchical forms remains relatively scarce. This study provides an empirical investigation of organizations, with a particular focus on the predictions of the knowledge hierarchic frameworks. Hence the question how ICT and tasks shape hierarchical forms is addressed here.

As said, the knowledge hierarchic approach was inaugurated in Garicano [2000]. By disentangling between information and communication technologies, it offers a nuanced view of the ways ICT transforms organizations. Importantly, it shows that technologies can have dissimilar effects on key organizational design parameters such as managerial spans and decentralization. Tasks are fundamental to hierarchical fabric. In the knowledge theoretic literature organizations are depicted as processors which solve problems originating at the shop floor.[1] Hierarchical form, decision authority and centralization then reflect the nature of problems or tasks the workers confront.

In short, the objective of this study is to test three salient predictions of the knowledge theoretical literature. First, that better communication technology generally results in higher spans and flatter hierarchy. Second, that better information technology among managers leads to lower spans and narrower hierarchy. Third, that industry tasks transform the shape of hierarchies. These theoretical predictions are explored by exploiting the substantial cross-industry variation in managerial spans of control. Spans are attractive measures as they neatly summarize the hierarchical shapes of organizations.[2] To allow for non-pyramidal hierarchies three organizational layers are identified: workers, middle managers and corporate managers. Two facets are of interest: ICT and tasks. The former captures information and communication technology. The latter pins down the industry tasks: tacit knowledge, cognitive, physical/technical and interaction. These four dimensions depict the nature of activities in the industry. The study seeks to reconcile the empirical task findings within the knowledge hierarchic frameworks.

The motivations are many. First, the interplay between ICT and organizational outcomes yields elegant theoretical predictions yet their empirical validity are still open. Second, somewhat paradoxically 'optimal managerial spans' have remained relatively stable for centuries despite tremendous advances in ICT [van Fleet & Bedeian, 1977]. Third, utilizing industry tasks to explore hierarchies is novel and yields interesting insights.[3] Compared to industry fixed effects, the

[1] In these frameworks tasks are captured by the distribution of predictability or complexity of the production process, $F[z]$.

[2] Managerial span is the number of direct subordinates.

[3] Industry tasks have been used in other contexts. For example, Autor et al. [2003] uses

industry tasks are significantly more explanatory and informative, and of lower dimensionality. For example, the below average middle manager spans in metal industry can be pinned down on operations that require tacit knowledge and physical/technical tasks, not on the fact that it represents manufacturing *per se*. Finally, the cross-industry variation in managerial spans is considerable. Put simply, it deserves exploration.

This study uses Occupational Employment Statistics [OES] by the U.S. Bureau of Labor Statistics, and augments it with occupation and work activity data from the Department of Labor's O*NET database. The data covers the period from 2002 to 2010. Although OES is coded at industry-level and represents both manufacturing and service sectors, the detailed occupational classification allows the reconstruction of the underlying organizational forms.[4] With information on occupational work activities in the O*NET, a compact set of industry tasks slightly like those in Autor et al. [2003] can be constructed. Furthermore, the occupation-level data on technology use allows for rich measures of workplace ICT utilization across industries.

Somewhat related studies include Pinsonneault & Kraemer [1997], Colombo & Delmastro [2004], Rajan & Wulf [2006], Bloom et al. [2009] and Caliendo et al. [2012]. Three differences are noteworthy. First, here only managerial spans are concerned. The questions pertaining to decision rights, decentralization, formalization and other organization design parameters remain obscure in this study. Although organizational concepts are tightly interwoven, only indirect inferences about design parameters beyond managerial spans can be made here. Second, the data employed here is less detailed. This entails costs and benefits, but is almost unavoidable in a cross-industry setting. Third, managerial spans within corporate management – between the top executives and the CEO – are not studied here. Although an interesting topic itself, CEO spans have been extensively studied with a more granular approach in Rajan & Wulf [2006], for example.

This study makes three contributions. First, the study yields insights on the interplay between ICT and tasks in shaping hierarchical shapes. The author is not aware of other attempts to test the key knowledge hierarchic predictions from both task and ICT perspectives. Second, the study provides descriptive evidence of the sectoral variation in hierarchical forms, an interesting issue itself. Third, middle and corporate manager spans are explored separately across industries. Hence non-pyramidal hierarchies can be analyzed. Since different factors shape middle and corporate manager spans, this is of first-order importance.

Four sets of findings emerge. They reconcile with the knowledge hierarchic view of organizations, albeit with caveats. First, hierarchies are not monotone with respect to ICT nor tasks. Better communication technology [henceforth CT] decreases middle manager but increases corporate manager spans. One standard deviation increase in CT use reduce the average number of middle manager subordinates by 2.13 but increases corporate spans by 1.88. Second, provided that ERPs decrease information costs progressively more along the hierarchy, IT seems to induce managerial problem solving and hence decrease spans. Third, hierarchies are not invariant to tasks. Tacit knowledge narrows

O*NET to construct industry tasks to study the effects of computerization.

[4]The data covers 287 4-digit NAICS industries. Federal and state-level public administration are omitted.

[flattens] the bottom [middle] hierarchy. Technical/physical tasks narrow hierarchies which typically reflects the decentralization of decision making authority. Cognitive tasks increase spans in the bottom hierarchy. In short, the findings testify to strong non-linearities in hierarchical outcomes. Finally, the key insight is this: tasks shape the middle and bottom but not much the top hierarchies. Hence only the organization down the middle management reflects the nature of the industry.

Encouragingly many of the findings are robust to exogenous variation. An IV specification produces qualitatively similar results as the OLS models. Moreover, most findings are invariant to sector fixed effects. Other robustness checks with sub-samples and corrections for minor coding issues fail to invalidate the findings.

This paper is organized as follows. Section (2) discusses ICT, tasks and organization. Section (3) describes the data and (4) provides an empirical investigation. Section (5) presents and (6) discusses the results. Section (7) concludes. Data descriptions, tables and figures are in the Appendix.

2 Background

Without much doubt the advances in ICT have fundamentally changed organizational fabrics. The literature has identified multiple channels by which organizations are transformed. Delegation, decentralization and the make–buy decision are but a few of the themes reshaped by ICT. Technological development and various other forces have also changed industry tasks [Autor et al., 2003]. A very brief summary of the literature and theoretical frameworks pertaining to these themes is given below.

2.1 ICT and organization

One early contribution to the discourse pertaining to IT and organization is Leavitt & Whisler [1958]. Long before the personal computer revolution of the 1980s it claimed that IT would result in 'recentralization' of management and the obliteration of the middle manager layers. Their decision making tasks would be left to mathematical and statistical models. Although decision support systems are extensively implemented, organizations still employ cadres of middle managers. A later attempt to assess the impact of IT is provided in Brynjolfsson et al. [1994]. With caveats it confirms that IT decreases firm sizes. It suggests that theoretically IT would decrease [increase] firm sizes if the ratio of internal to external coordination costs were increased [decreased] – this corresponds to the make–buy decision. The 1990s empirical evidence thus suggests that IT lowered external coordination costs and made buying relatively more attractive. Brynjolfsson et al. also finds support that IT has induced labor substitution, namely automation. They conclude that IT facilitates 'decoupling' of vertically integrated firms to smaller interacting entities. Pinsonneault & Kraemer [1997] emphasizes the interplay between IT, decision authority and organizational outcomes. It documents that IT either expands or contracts the middle manager layer, depending on the [de]centralization of the decision authority. Hence the implications of IT is very contingent on other organizational characteristics.

Garicano [2000] and Garicano & Rossi-Hansberg [2006] managed to isolate the distinct effects of communication and information technologies on organizations at theoretical level. In these models better communication technology generally results in higher spans and decentralization. Since managers are time constrained, better CT allows them to supervise larger teams due to lower time-cost of helping. An improvement in information technology among managers leads to lower spans and centralization. Managers face lower costs to acquire information which shifts decision making up along the hierarchy. As said, the one key contribution of the knowledge hierarchic view is to distinguish between communication and information technology. However, while this distinction is clear theoretically, empirically the demarcation is vastly more obscure.

In empirical work information technology is typically proxied with ERPs and/or CAD/CAMs. The former comprise of interconnected databases which link together business units, processes, customers and suppliers. Hence ERP facilitates information transmission both internally and externally. Although ERP lowers information acquisition costs beyond doubt, its implications on communication costs could be substantial. Bloom et al. [2009] surveys managers on ERP use, and finds partial support that they facilitate information acquisition over communication. However, the distinction is not clear-cut. As Yusuf et al. [2004] points out, ERP allows for rapid sharing of information across departments, and the systems then also reduce communication costs. Hence the notion that ERP systems only lower information costs is empirically unclear. CAD/CAMs are postulated to reduce information acquisition costs at the worker level. Bloom et al. [2009] uses ERP and CAD/CAM usage to proxy for information acquisition technology among plant managers and workers, respectively. It finds empirical support for the idea that better IT widens spans of control among both plant managers and CEOs. Communication technology in Bloom et al. [2009] is proxied with the use of corporate intranets. They allow for faster information transmission since problems can be codified and sent with ease. Empirical findings suggest that better CT increases the centralization of authority but also widen spans among plant managers and CEOs. These largely match the predictions in the knowledge hierarchic literature.

Technology apparently matters but there are caveats as the analysis of managerial work patterns in Mintzberg [1990] demonstrates. First, managers prefer oral communication – telephone and meetings – over other means. The study documents that 78% of chief executives' time is spent on verbal communication. Second, Management Information Systems[5] are seldom used. Although this evidence precede the ascent of electronic communication and modern ERPs, it suggests that technology-mediated communication and information acquisition have not supplanted traditional conducts.

2.2 Tasks and organization

Theories of the organization of production typically employ concepts which relate to tasks. In Garicano [2000] and Garicano & Rossi-Hansberg [2006] their role is very visible. Given that organizations largely exist to process various activities, it is no coincidence that tasks are deemed important. Indeed it would be surprising if the activities did not have any effect on hierarchical forms.

[5] MIS is a precursor to ERP.

The knowledge hierarchic literature models tasks very explicitly by incorporating a measure of problem complexity, $F[z]$. It governs the distribution of tasks the hierarchy faces, and yields some unambiguous predictions [Garicano, 2000]. An increase in complexity shifts problem solving from workers to managers, and concurrently managerial spans also decline. The logic is the following: as workers must consult their managers more frequently, due to time constraints lower spans must ensue. Managers simply can't lead as many subordinates as before.

Reconciling the theoretical predictions within empirical contexts is admittedly hard. There is simply no direct way to operationalize task complexity. Moreover, although a unidimensional task measure is appropriate for theoretical purposes, it would not suffice in empirical setting – placing industries along a single continuum would not make much sense. Hence the industry task taxonomy of this study has four dimensions: tacit knowledge, cognitive, physical/technical and interaction. In terms of parsimony, it probably represents a lower bound. It should be noted that the industry task taxonomy here can at best serve as an approximation: considerable amount of interpretation is needed to align the empirical findings within the knowledge hierarchical framework.

Industry tasks are utilized in economic research. For example, Autor et al. [2003] uses a five-dimensional task structure at industry- and occupational-level to study the effects of computerization.[6] Although the study does not revolve around organizational forms, conceptually the task methodology employed here borrows from that study. The key motivation for employing tasks is to reduce the dimensionality of industries and supersede the 'explanations' based on industry fixed effects. Tasks are interpretable and with caveats reconcilable with theoretical frameworks.

It should be noted that the nexus between tasks and hierarchies have been studied empirically outside economics. In fact quite many industry taxonomies originate from the 1960s management literature. As they represent a different research tradition, a short recap of the salient taxonomies and findings is presented.

An early investigation to the organizational impact of tasks is Woodward [1965]. It documents relationships between technological complexity and structural parameters such as lengths of command, spans of control and personnel ratios.[7] It shows that routine-based mass production is associated with higher and non-routine small-scale production with lower managerial spans. Although subsequent literature has criticized the findings, the study is important for two reasons. First, it refuted the classical management notion of a single, optimal structural form. Second, it showed how organization hierarchies stem from a complex mesh of processes, tasks and technology.

Other contributions are Hickson et al. [1969] and Hull & Collins [1987]. These studies test the hypothesis that operations technology and hierarchical structure interplay. The notion of operations technology in Hickson et al. [1969] embeds concepts such as automation, interdependencies of workflow segments, specificity of operations and production continuity. It finds partial support that

[6] The tasks are non-routine analytic, non-routine interactive, non-routine manual, routine cognitive and routine manual. They are constructed using Dictionary of Occupational Titles, the predecessor of O*NET.

[7] The Woodward technology scale is pinned on its level of mechanization: small batch and unit technology, large batch and mass production and continuous process production.

operations technology affects organization structure. Hull & Collins [1987] extends Woodward's typology with knowledge complexity. It clearly demonstrates the criticality of tasks shaping managerial spans. Analysis of traditional batch and mass production [low knowledge complexity] and technical batch and process production [high knowledge complexity] indicates substantially higher spans in the former [15.22 and 14.23] than the latter [8.69 and 8.83] group. In short, industry tasks seem to unambiguously interplay with organizational forms.

3 Data

This study utilizes two sets of data: Occupational Employment Statistics and O*NET.[8] The overarching idea is to construct industry task and technology measures by combining the OES and O*NET data. Since the latter contains detailed data on work activities and technologies used in different occupations, industry-specific measures of these can be obtained. Industries comprise of four tasks. They provide a rich yet sufficiently parsimonious account of the activities undertaken in different industries. O*NET is also used to calculate ICT utilization across industries.

The OES sample period spans from 2002 to 2010.[9] The years from 2002 to 2007 are used as instruments, from 2008 to 2010 as outcome variables.[10] Regarding O*NET, the latest 2010 version [O*NET 16.0 database] is used. After aggregation at the 4-digit NAICS level, the sample size measures 287 per year and 861 total observations. The sample contains all industries except the public sector. Descriptive statistics at the 2-digit NAICS level are given in Table (2).[11]

3.1 Organization data

OES contains data on employment and wages by 4-digit NAICS industries and 7-digit SOC occupations.[12] The detailed occupational coding allows the identification of workers, middle and corporate managers. By knowing the employments of these groups within industries, it is possible to estimate the spans for middle and corporate managers for each industry.

[Insert Figure (1) approximately here]

Corporate managers consist of chief executives and general and operations managers. The former typically lead whole enterprises, while the latter manage individual business units/areas or establishments. Middle managers consist of

[8] The 'Occupational Employment and Wage Estimates' data is published by Bureau of Labor Statistics. OES is collected at establishment-level, and has been utilized extensively in the literature. O*NET contains detailed occupation data, and has been used, for example, to construct measures of task inputs [Autor et al., 2003].

[9] Prior years' industry coding is based on Standard Industrial Classification [SIC]. Although conversion between SIC and NAICS is possible, it would introduce many complications.

[10] The OLS sample consist of years 2008 to 2010 although 2002 to 2010 could have been used. However, qualitatively the findings are similar with both periods. For easier comparison with the IV estimates, the shorter period is adopted.

[11] Henceforth the 2-digit NAICS industries are denoted as 'sectors', and they bundle together similar 4-digit NAICS industries.

[12] SOC and NAICS stand for Standard Occupational Classification and North American Industry Classification System, respectively.

functional managers and first-line supervisors. They report to corporate managers. Workers comprise of all other occupations, and have reporting lines to middle managers.[13]

The span of corporate managers is calculated as the ratio of middle managers to corporate managers. Correspondingly, the span of middle managers is the ratio of workers to middle managers. Despite the rather aggregated data, the figures presented for the sectors in Table (2) are very consistent with micro-level evidence [Rajan & Wulf, 2006; Smeets & Warzynski, 2008]. Furthermore, as documented in Garvin & Levesque [2008] the gaps in spans between managers at different levels of hierarchy vary considerably. Corroborating with the evidence here, its comparison of major U.S. enterprises shows that average spans are higher lower down the hierarchical ladder. These non-pyramidal structures are also apparent in Figure (1), which depicts the organization hierarchies across the main U.S. sectors. As can be seen, the flatness varies considerably.

It is worth noting that the middle manager category is not entirely unproblematic: aggregating together functional managers and first-line supervisors yields heterogeneity within the group. In some organizations the former could locate slightly higher in the hierarchy. Yet even in these cases their subordinates comprise of workers and hence substantial measurement errors in spans are unlikely.

The three-layer setup is adequate for two reasons. First, Caliendo et al. [2012] documents that the average number of layers in French manufacturing organizations is 2.5 and Colombo & Delmastro [1999] that the vast majority of Italian metalworking plants have three or four layers. Second, as Statistics of U.S. Businesses [SUSB] data shows, the average number of employees per establishment in 2009 U.S. is 15.4.[14] As Table 3 shows, enterprises with 1500 to 1999 employees have the highest employees per establishment ratio of 56.3, and those with over 10000 employees have 46.8. Hence the three-layer hierarchy here should represent a typical U.S. firm reasonably well. Moreover, industries with particularly large firms do not introduce problems since their establishments are not larger than mid-sized firms'.[15]

It is worth reminding that hybrid organizations are quite common [Daft et al., 2010]. They combine functional, divisional and/or horizontal structures within a single organization. The imposition here of a strictly vertical hierarchy is admittedly somewhat restrictive. Nevertheless, it is necessary in order to accommodate the vast array of industries in the OES.

3.2 Task and technology data

O*NET contains detailed information of over 900 SOC occupations. This study uses two of its databases: Detailed Work Activities [DWAs] and Tools and Technology [T2]. The former provides information of 41 different activities performed across occupations, and is used to construct the industry tasks. The latter provides information of the tools and technologies typically used in different occupations. By aggregating over occupations within an industry it is possible to obtain utilization indices of technologies such as ERP. The approach

[13]Detailed SOC codes and titles are provided in the Appendix.

[14]Source: U.S. Census Bureau.

[15]If CEOs were separated from other corporate managers, the number of layers here were four. However, spans within the corporate management are beyond the scope of this study.

here hinges on the idea that occupations use different 'bundles of tasks and technologies' to produce – in essence they represent the factors of production. Industries then employ occupations to yield an optimizing set of tasks and technologies to produce.

Four industry tasks depict industries: tacit knowledge, cognitive, physical/technical and interaction. This particular set is chosen for three reasons. First, given the wide range of different industries a lower dimensionality could attribute to functionally different industries highly similar task contents. Two-dimensional tasks would roughly reduce to complex–noncomplex and service–manufacturing continua. As the operating and business models differ considerable even within sectors like retail, services and manufacturing, the two-dimensional approach would provide very reductive. Second, the four tasks here are of such generality that reflection to literature is possible. Third, the tasks map directly to the O*NET Content Model. For the same reason Principal Component Analysis [PCA] is omitted. Although PCA would be suitable for the dimensionality reduction from the 41 original DWAs, the strictly O*NET-based taxonomy is preferred for transparency and clarity reasons.

Without going into details, the construction of tasks goes as follows.[16] The DWAs of each occupation are mapped to the O*NET Content Model to obtain for each four tasks of varying intensity. These tasks describe the nature of the occupation, and include four dimensions: tacit knowledge, cognitive, physical/technical and interaction. Details of these are presented in Table (1). Industry tasks are composed by aggregating over occupations and weighting with employment shares. As a result each industry is represented by four tasks and they represent the different activities undertaken by different occupations in the industry. Table (2) presents tasks by sector and they are briefly explained below.

Tacit knowledge: This captures the activities pertaining to information input: identification, monitoring, inspection and estimation. To large extent these relate to the observation of physical objects, namely structures, materials, equipment and such. High tacit knowledge occupations include machinists, retail salespersons and inspectors. Low tacit knowledge occupations include secretaries, clerks and analysts. Tacit knowledge tasks are high in manufacturing and construction industries, and low in finance and education services.

Cognitive: This captures the activities pertaining to data processing and decision making: processing information, scheduling, planning and problem solving. These tasks typify many high skilled professions. High cognitive task occupations include engineers, psychologist and doctors. Low cognitive task occupations include assemblers, dishwashers and nannies. Cognitive tasks are high in professional services and information industries, and low in warehousing and food services.

Physical/technical: This captures the activities pertaining to manual and technical work: handling and moving objects, operating vehicles and using technical devices. These tasks typify many industrial occupations. High physical/technical task occupations include maintenance workers, mechanists and welders. Low physical/technical task occupations include analysts, HR specialists and educators. Physical/technical tasks are high in construction and mining industries, and low in finance and educational services.

[16] Details for data construction are provided in the Data Appendix.

Interaction: This captures the activities pertaining to communication, coordination and administration: interpersonal communication, conflict resolution, consultation and staffing. High interaction task occupations include secretaries, scientists and psychologists. Low interaction task occupations include sorters, masons and metal workers. Interaction tasks are high in educational services and health care, and low in manufacturing and transportation industries.

[Insert Table (2) approximately here]

The O*NET T2 database contains information on various technologies typically used in occupations. The proxy for communication technology is 'Electronic mail software' and for information technology 'Enterprise resource planning ERP software'. Technology indices are constructed similarly as tasks. Hence for each industry are obtained measures of CT and IT use by aggregating the utilization of these technologies in different occupations. Put simply, the ICT measures capture the proportion of employees using that particular technology in an industry. Both technologies evidence substantial variation between industries. For example, as Table (2) documents only 13% employees in 'Construction' but 61% in 'Finance and Insurance' use an ERP. Regarding CT, in 'Educational Services' 84% but in 'Accommodation and Food Services' only 21% use electronic mail. The utilization rates largely match expected patterns.

The clear advantage of this approach is that the whole organization is represented. This stands in contrast to approaches which reduce ICT use to a binary variable: the approach here does not just indicate whether technologies are used but capture the magnitude of ICT utilization across industries. This is important since as Harris & Lentz [2006] documents enterprises with ERPs use them in unequal proportions even within an industry. By counting the proportion of employees typically using particular technologies, the approach here can at least partially alleviate the problems inherent in less granular methods.

In short, the major advantage of O*NET is that it allows for a parsimonious industry task taxonomy. Moreover, the tasks are derived from a rich array of occupations, providing an unparalleled representation of shop floor activities at the industry-level. Some caveats are apparent, however. First, the plausibility of approach hinge on the dictum that 'organizations are what they do'. Inter-industry task trade is rampant, a fact completely ignored here. Second, articulating occupational tasks is as much art as science. Any errors replicate themselves in the industry-level measures. Third, since some occupations are absent from the T2 data the ICT measures are not perfect. The between-industry technology use might also vary within an occupation. Yet even with these minor reservations the approach seems solid.

4 Empirical strategy

The empirical strategy is based on two model specifications. The baseline use the Ordinary Least Squares [OLS] approach. Middle and corporate manager spans are regressed on a set of ICT, human capital and task variables. Industry fixed effects are used as a robustness check and to control for unobserved sectoral variation. For various reasons the ICT variables might be endogenous. An Instrumental Variables [IV] approach is employed to saturate the model with exogenous variation.

4.1 Baseline model

The baseline specification to estimate the determinants of organizational outcomes takes the form

$$S_{it} = \alpha + \mathbf{X}_{it}\beta + \gamma ERP_{it} + \eta EMAIL_{it} + \delta HC_{it} + J_t + \epsilon_{it} \quad (1)$$

where S and $\mathbf{X}$ are the span of control and tasks, respectively. HC controls for education, J_t are time fixed effects and ϵ_{it} is the error term. Industry and year are denoted by i and t. Since both the middle and corporate manager spans are estimated, the dependent variable S takes two forms accordingly. Furthermore, in middle manager regressions the human capital variable HC includes workers', in corporate manager regressions the middle managers' education level. This equation is estimated using OLS, and the parameters of interest are β, γ and η.

Unobserved time-invariant industry effect would imply an error term of the form $\epsilon_{it} = a_i + \varepsilon_{it}$. To parcel out this between-industry variation in management practices a specification of Equation (1) with industry FEs is estimated. However, with a short panel [$T = 3$] the loss to the degree's of freedom from estimating [$N = 287$] industry-specific parameters at 4-digit NAICS level is considerable. Hence the industry FEs are reduced to sectoral level which still leaves 23 sector parameters to be estimated. This cancels out the variation between sectors yet unobserved within-variation could still be present.

The effects of tasks are captured by β. As can be observed from Table (2), there is substantial between-industry variation in tasks reflecting the diverse activities taking place across industries. In some sense the tasks and industry FEs substitute each other. Unlike the industry FEs, tasks allow hierarchies to be pinned down on real activities. However, industry FEs serve an important purpose: by parcelling out the unobserved sectoral variation, it becomes possible to test the robustness of tasks in a within-sector context.

The effect of communication technology is captured by η. Higher share of email use is postulated to reduce communication costs. However, the O*NET T2 database would allow for many alternative CT measures: valid proxies could include 'Mobile phones', 'Videoconferencing systems' or 'Internet browser software'. Due to the high correlation between different CTs and email's ubiquity, it is selected.

The effect of information technology is captured by γ. Higher share of ERP use is postulated to reduce information costs. Again alternative IT measures are available: valid proxies could include 'Data base user interface and query software', 'Customer relationship management CRM software' or 'Human resources HRIS software'. ERP has few advantages over the alternatives. First, it is less industry-specific than CRM, for example. Second, ERP lowers information costs across the organization and not just in certain functions like does HRIS. Third, ERP subsumes and hence implies many other corporate information systems.

In this study ERP proxies information technology across organizations. This contrasts with Bloom et al. [2009] which uses CAD/CAM and ERP for workers and middle managers, respectively. Few reasons for the current specification are apparent. First, save ERP many IT systems are industry-specific. While CAD/CAM systems are used in manufacturing, they are likely less prevalent in the health care sector. Second, inspection of the O*NET T2 data reveals that ERPs are frequently used in management but also in worker occupations. Clerks, technicians and cooks are just a few of the many occupations utilizing

ERPs today. Hence the inclusion of ERP in middle manager and corporate manager regressions. The interpretation of the ERP coefficients depends on how it reduces information costs across the organization. If ERPs decrease information costs progressively more higher in the hierarchy as the survey results in Bloom et al. [2009] indicate, the expected sign of the coefficients are negative. For example, if ERPs empower middle managers compared to workers, more problem solving is expected to take place in the middle hierarchy. Due to middle managers' time constraint their spans are then correspondingly lower.

Both ICT variables are cardinal. Since they measure the share of employees using a particular technology, the ICT coefficients directly relate to changes in the utilization of the respective technologies. This study can hence avoid one typical shortcoming in empirical literature, namely that ICT variables are frequently dichotomous. Two measurement errors of binary ICT are apparent. First, no adjustment for the varying rate of utilization between industries can be made. Although Harris & Lentz [2006] shows that enterprises implement ERPs to varying degrees, due to data limitations the literature largely treats ERPs as binary decisions. Second, by 2012 the vast majority of [big] enterprises have implemented ERPs and communication networks. Correspondingly the empirical question should shift to the organizational outcomes of different utilization rates, not the use itself. In fact the binary approach runs the risk of attributing unobserved heterogeneity [legacy IT, culture, etc.] to ERP use. By resorting to utilization rates, the empirical setting here can avoid these problems.

Regarding human capital, worker and middle manager education levels within-industries are correlated at 0.50. Using an industry-average education level would not qualitatively change the results. It should be noted that the between-industry variation at the manager-level education is lower than at the worker-level.

4.2 Endogeneity

Organizational outcomes are potentially endogenous to ICT utilization. At least few reasons are apparent. First, large managerial spans could incentivize organizations to invest in ICT since it might ease monitor and control activities. Reverse causality would ensue. Second, increasing industry specialization could lead to more between-industry task-trade. This might reduce managerial spans – especially at the corporate manager level – but increase demand for ERPs which facilitate supplier integration across industry boundaries. Third, as Harris & Lentz [2006] points out, ERPs are used for process automation and headcount reduction. These could potentially reduce middle manager spans.[17]

If either $cov(ERP_{it}, \epsilon_{it}) \neq 0$ and/or $cov(EMAIL_{it}, \epsilon_{it}) \neq 0$ hold, the coefficient estimates are biased. To control for the potential endogeneity an IV approach is employed. One instrument is needed for each ICT variable: ERP is instrumented with industry volatility, EMAIL with industry complexity. The IV estimates are calculated using Two-Stages Least Squares [2SLS]. Robustness tests with first-stage statistics are presented in Table (8). The instruments are described below.

[17] Intuitively middle manager spans might not change. However, as each worker could handle more activities, the task-adjusted managerial burden might increase even though spans decrease.

Industry volatility: This instrument captures the within-industry fluctuation in employment between 2002 and 2007. It therefore intends to pin down the inherent [in]stability of the economic environment. Several factors motivate this instrument. First, ERPs make organizations nimbler and enable them to cope with uncertainty. Second, ERPs facilitate quicker adaptation and flexibility. Finally, ERPs ease corporate restructuring amid [de]growth periods. Theoretically ERP utilization should covary with industry volatility: the industries which experience high volatility should favor ERPs. As the F-statistics of 14.04 and 9.07 in Table (8) indicate, industry volatility satisfy instrument relevance. Moreover, the direct organizational impacts of employment changes between 2002 and 2007 should have subsided by 2008 since asymmetric organizational changes are not likely to persist for years. The exclusion restriction seems justified but there are two caveats. First, van Fleet & Bedeian [1977] hypothesize that stable environments favor large spans. Second, unionization might entail direct effects between volatility and managerial spans. If unions raise the costs of restructuring, volatile industries might have lower spans especially among middle managers since workers would become more expensive. In fact these industries should rely more on non-unionized middle managers as problem solvers. In short, the exclusion restriction is not without caveats.

Industry complexity: This instrument captures the number of individual SOCs within the 4-digit NAICS industry. It pins down the need to communicate across the organization. The motivation is clear: fragmentation in the organization of production almost mechanically increases the need for communication. Encouragingly in the data industry complexity is robustly associated with CT use. As the F-statistics of 30.72 and 16.07 in Table (8) indicate, industry complexity satisfy instrument relevance. Regarding the exclusion restriction, some caveats are apparent. First, industry complexity could reduce spans were the problems managers confront to increase in breadth. Namely, less time would be available for each subordinate. This would likely only apply for corporate managers due to their need to integrate. Second, increased complexity might hinder monitoring, and hence lower spans could ensue. Third, complexity could entail more autonomy to workers due to their information advantage. This might imply higher spans. As is clear, theory can guide the exclusion restriction only so far. Yet a strong prior to either direction is absent.

Instrumenting tasks is omitted for two reasons, the first practical and the second theoretical. First, since an IV strategy with two endogenous variables is already complicated, introducing more would make interpretation overly difficult. Second, the tasks capture the 'deep parameters' of the industry: the salient and largely immutable activities required for operation.[18] Exogeneity is thus established on the ground that managerial practices are unlikely to change the fundamental fabrics of industries in the medium-term. Still, admittedly in some cases this could prove optimistic. For example, heavy inherited middle management could design tasks to suit the legacy organization, an apparent reverse causality. To partially assess this question it is fruitful to explore the long-run dynamics of the tasks. The within-industry correlations of tasks between 2002 and 2010 are revealing: they range from 0.93 to 0.99, and suggest that industry activities change slowly. In short, industry tasks are unlikely to

[18]For example, no amount of management innovation can turn banking physically intensive or nursing an asocial activity.

transform quickly. Hence the exogeneity assumption.

4.3 Measurement issues

The feasibility of the task approach developed in this study critically hinges on three issues. First, do the tasks credibly represent the activities the organizations do? Namely, is the aggregation from occupations' DWAs to industry tasks feasible. Second, is O*NET data reliable and do the DWAs represent the true activities in different occupations? Third, are managerial responsibilities in OES reported correctly and consistently across industries?

Provided that an organization represents the work of all of its constituent parts, the aggregation to industry tasks is justified. Yet the approach only considers inputs which are directly employed by the industry. If an industry uses intermediate inputs extensively, the tasks do not illustrate the true activities required for production. In this case measurement error would occur and the coefficient estimates were biased.

O*NET does not differentiate the intensity of individual DWAs, only their presence in an occupation. Work activities are given equal weights irrespective of their true utilization. Moreover, although O*NET 2010 taxonomy identifies 2164 different DWAs, the coverage's completeness is difficult to assess. It is clear that the industry tasks approximate the real operational activities. However, the tasks shown in Table (2) are intuitive.

The OES identifies 801 7-digit SOCs which cover the vast majority of the occupational spectrum. Moreover, the classification of managerial responsibilities is approximate. Measurement errors can result for four reasons.

First, in skip-level reporting workers bypass middle managers and report directly to corporate management. The observed spans of middle and corporate managers would be upward and downward biased, respectively. Despite the industry-level aggregation, the average spans presented in Table (2) are very consistent with evidence from other sources [Rajan & Wulf, 2006; Smeets & Warzynski, 2008]. Furthermore, the observation of higher middle than corporate manager spans corroborates with other studies [Harris & Lentz, 2006]. Substantial measurement errors are hence unlikely.

Second, as indicated before, the three-layer setup typifies industries rather well. Although some industries could be composed of particularly large firms with multiple layers, as the SUSB data shows the average number of employees per establishment plateaus at around 50. In fact the size of establishment is not conditional on enterprise size in firms with above 1000 employees. Furthermore, conditional on context and definitions, the typical number of organization layers ranges from 2.5 to 4 [Colombo & Delmastro, 1999; Caliendo et al., 2012]. Hence the three-layer setup should characterize a typical U.S. organization quite robustly.

Third, the empirical setting here can not discern layers within layers. Exceptionally granular hierarchies could introduce measurement errors. For instance, if each layer – worker, middle and corporate manager – is composed of two hierarchical layers, the observed spans represent upper bounds and are overestimated. The regression coefficients would then be biased upwards. Yet simultaneously the vertical distance between adjacent layers would diminish and the manager–subordinate reporting relationship change qualitatively. Understandably the OES data does not contain direct information about the number of organization layers in industries. Nevertheless, in light of facts that the observed spans in Figure (1) match external evidence, and that the typical number of layers equals 2.5 to 4, the problem of within-layer reporting is likely minor.

Fourth, any glance at real organization charts reveal that corporate managers frequently have both direct and indirect reports. The former often comprise of business line managers, the latter of functional [e.g. finance, legal, HR] managers operating in a matrix. However, measurement errors originating from horizontal and/or matrix organizations should average out at industry-level.

5 Results

The key results concerning the middle and corporate managers spans are presented in Tables (4) and (5), respectively. Although they evidence similarities, there are also notable differences between middle and corporate manager coefficients. Organizational outcomes are sensitive to the layer in question, and no single narrative can encompass all circumstances. It is also noteworthy that in both contexts organizational outcomes are influenced by ICT and tasks yet the corporate manager spans are less influenced by the latter.

5.1 Middle manager span of control

As the OLS coefficients in Table (4) imply, middle managers spans are negatively associated with ICT use. Irrespective of the controls both ICT technologies decrease average middle manager spans. A standard deviation increase in ERP and EMAIL reduce spans by 1.05 and 1.85, respectively. Given that the middle manager spans average at 8.81, the effect of ICT is clear. More widespread ICT utilization seems to result in narrower organizations. Furthermore, the inclusion of tasks does not qualitatively change the findings regarding ICT. Judging from Column (1) alone one could infer that the unobserved between-industry variation causes low spans in knowledge-intensive sectors. ICT, then, would capture this variation resulting from unobserved industry characteristics. However, in light of Columns (2) and (3) this seems unlikely. The ICT coefficients remain similar in the presence of tasks w/wo sector FEs. Hence the negative relationship between ICT and tasks seems robust.

[Insert Table (4) approximately here]

Regarding CT, the results contrast with most theoretical predictions. Better CT should increase, not decrease spans [Garicano, 2000]. The theoretically predicted sign of IT hinges on the relative benefits of ERPs. The empirical findings here is consistent with the idea that ERPs empower middle managers relative to workers. Since the former solve problems, the spans are lower. By aligning with the knowledge hierarchy narrative this conclusion would be very attractive. However, it should be noted that ERP use among worker occupations is not unusual. Consequently the negative coefficient should be considered as the lower bound.

Tasks influence middle manager spans. Given the variety of operating models and hierarchical forms across industries, this is not surprising. It is encouraging, however, that the approach can pin down some common threads that govern managerial spans in very different industry environments.

Tacit knowledge tasks reduce middle manager spans. As Table (4) implies, the coefficients are negative in all specifications. One standard deviation increase in tacit knowledge reduces spans by 1.55. Although the coefficient is significant at .1% in Column (2), in Column (3) the significance is absent. Sector FEs capture some of the variation. However, quite confidently it can be stated that industries which utilize tacit knowledge have narrower bottom hierarchies.

Cognitive tasks increase middle manager spans only when sector FEs are present. This suggest that there is variation within the sectors how cognitive tasks influence spans, yet this variation is obscure in the between-industry setting in Column (2). With sector FEs the coefficients are significant at 5%. One standard deviation increase in cognitive tasks increase spans by .83. Cognitive tasks yield flatter bottom hierarchies but this is only apparent when sectors are controlled for.

Physical/technical tasks decrease middle manager spans irrespective of controls. One standard deviation increase in physical/technical tasks decrease spans by .86. The coefficient doubles with sector FEs which suggests that the variation within the sectors further accentuates the effect of physical/technical tasks. These findings are very robust and suggest that industries abundant with complex technical activities have relatively narrow bottom hierarchies. It could reflect barriers in within-hierarchy communication with the result that middle managers can only have a limited number of subordinates.

Interaction tasks unambiguously decrease middle manager spans. The significance is robust at .1% in all specifications. Activities pertaining to communication and coordination result in narrower organizations. The coefficients in Colums (2) and (3) imply that the effect is accentuated with industry FEs. This suggests that the negative association is even more pronounced within the sectors. There is substantial interplay between interaction and cognitive tasks. They are pairwise correlated at .63 but individually both are negatively correlated with middle manager spans. However, all other things equal only interaction tasks are associated with narrower hierarchies. As cognitive tasks have positive coefficients, taken together the findings suggest that organizational outcomes are shaped by tasks in a non-trivial manner.

The findings partially align with the predictions in knowledge hierarchic literature. The alignment of the IT findings depends on the relative utilization of ERPs within organizations. By narrowing hierarchies the CT coefficients contradict theory. As both tacit knowledge and physical/technical tasks decrease middle manager spans, narrow hierarchies seem to result when work needs considerable shop floor information and physical presence. These tasks should be relatively costly to communicate and/or be expensive to the middle managers to learn. Cognitive tasks flatten organizations. This aligns with the view that these tasks are particularly easy to transmit within hierarchies. Interaction tasks, on the other hand, lead to fewer subordinates among middle managers. To reconcile with the knowledge hierarchic view, communication of these tasks should be costly.

5.2 Corporate manager span of control

Unlike middle managers, corporate managers lead managers. They are hence somewhat distanced from the operational shop floor activities. Against this backdrop the observation here that the tasks play a much subdued role in shaping spans among corporate managers is intriguing. It could reflect the uniformity of managerial tasks across industries. Nevertheless, ICT continues to influence top hierarchies.

As the OLS coefficients in Table (5) imply, corporate managers spans are differentially affected by CT and IT. Higher utilization of ERPs decrease spans. One standard deviation increase in ERP use reduce spans by 2.58. However, better communication technology has the opposite effect. One standard deviation increase in EMAIL use rise spans by 1.55. Since corporate manager spans average at 6.98, ICT utilization has a considerable effect on organizational outcomes.

[Insert Table (5) approximately here]

With sector FEs the significance of EMAIL drops to 10%. Although the coefficient of CT is lower, better communication technology still yields higher managerial spans even within sectors. EMAIL ceases to be significant without ERP in Column (4). As CT and IT correlate at .57, in Column (4) EMAIL then captures some of the negative effect of ERP on spans. This highlights the importance to disentangle between different technologies.

Regarding theory, the CT coefficients are aligned with predictions: better communication technology increases corporate manager spans. As with the middle manager spans, the theoretical prediction for IT hinges on the relative benefits of ERPs. The finding here is consistent with ERPs reducing information costs more among corporate than middle managers. The survey results in Bloom et al. [2009] slightly support this notion. It would be tempting to interpret these results aligning with the knowledge hierarchical literature. Regarding communication technology, it seems justified. Yet the alignment of the IT findings critically hinge on the true utilization patterns of ERPs among middle and corporate managers.

The industry tasks shape corporate manager spans. Yet interestingly the corporate manager spans are much less influenced by industry activities than the middle manager spans. Without sector FEs in Column (2) only physical/technical tasks are significant at conventional levels. The coefficient of -.23 implies that one standard deviation increase in these tasks decreases average spans by .79. Physical/technical tasks therefore tend to compress the ranks of middle managers. However, this effect diminishes with sector FEs. After sectoral differences are controlled, physical/technical tasks do not appear to drive organizational outcomes. Comparison of Columns (2) and (3) reveals that with sector FEs tacit knowledge tasks increase spans. Yet this is apparent only after substantial amount of within-sector variation is controlled away.

In contrast to middle managers, the organizational outcomes at the top regarding ICT adhere to the knowledge hierarchic predictions. Yet tasks have a more subdued role at the top. This is an intriguing finding for few reasons. First, it suggests that top hierarchies owe much less to particular industry characteristics. Although middle manager and corporate manager spans vary almost equally between industries[19], it is interesting to observe the latter to be virtually invariant to industry tasks but very sensitive to ICT. Second, from vertical perspective hierarchies are non-linear within an industry. If different factors

[19]As Table (2) documents, the standard deviation of middle manager and corporate manager spans are 7.19 and 6.97, respectively.

drive spans disproportionately along hierarchies, no single theory is likely to be able to reconcile the spectra of outcomes. Top and middle hierarchies are clearly qualitatively dissimilar.

5.3 Robustness

Endogeneity in the OLS specifications can not be ruled out. Exogenous variation is needed to establish any causal patterns. The problem is especially acute with the ICT variables, and therefore two instruments are employed. In the IV specification CT is instrumented with industry complexity, IT with volatility. The estimates are calculated using 2SLS and presented for middle and corporate managers spans in Tables (6) and (7), respectively. Table (8) presents the first-stage regression results and other robustness statistics.

Regarding middle manager spans both ICT coefficients remain negative in the IV specification shown in Tables (6). In Column (1) their magnitudes increase only slightly compared to the OLS coefficients, but in Column (2) with the sector FEs the change is substantial. In short, the results obtained with IV specifications imply that information and communication technologies shape organizational outcomes by affecting middle manager spans of control.

The IV coefficients of ICT variables for corporate management spans are partly ambiguous. ERP coefficients retain their signs and increase in magnitudes compared to OLS. However, in Column (1) without sector FEs the coefficient of EMAIL is effectively zero but positive with FEs in Columns (2) and (3). This suggest that communication technology increases managerial spans only within sectors. It is worth noting that with OLS the sector FEs have the opposite effect. Hence it remains somewhat inconclusive whether the variation within sectors increase or decrease spans. Nevertheless, some relief can taken from the findings in Column (3). In this specification ERP is omitted but the EMAIL coefficient 13.81. There is some reason for encouragement, however. The OLS coefficients of IT and CT are opposite, but EMAIL and ERP have a pairwise correlation of .57. Endogeneity could only yield these results were the unobserved variable positively correlated with spans to covary positively with EMAIL and negatively with ERP. Although this is not impossible, the existence of such variable seems somewhat improbable. In short, the results obtained with IV specifications imply that information technology has a negative effect on corporate manager spans. This findings is robust across specifications. Communication technology has an ambiguous effect on corporate manager spans. The verdict thus remains inconclusive.

The task coefficients mostly retain their signs, magnitudes and significances in the IV specifications. Yet endogeneity of tasks can not be entirely ruled out. Despite considerable organizational inertia, industries' occupational and hence task structures change albeit gradually. Managerial outcomes could at least hypothetically influence these. Furthermore, when an industry re-optimizes its occupational structure to utilize more ICT, the equilibrium profile of tasks can change as well. However, due to the drastic development of ICT during the recent decade, it is believable that technologies provide the larger impetus for hierarchical change. Given the high correlation of tasks between 2002 and 2010, the industries are subject to substantial inertia.[20] Therefore the task approach

[20]Although the within-industry correlation in tasks between 2002 and 2010 ranges from

should capture some fairly immutable and exogenous variation between industries.

Measurement errors relating to the coding of managerial status can not be ruled out entirely. Even with completely accurate occupational coding, the imposed reporting relationships could be erroneous. For example, in 9 observations out of the 861 the corporate management spans are below one, in 18 above 25. Although the latter might not reflect any measurement or coding errors, subsamples with different lower and upper bounds are estimated. Encouragingly the results remain qualitatively similar.

6 Discussion

This study presents statistical relationships between tasks, technologies and managerial spans. At a stylized level the results here align with earlier research. First, hierarchies are non-pyramidal [Garvin & Levesque, 2008; Caliendo et al., 2012]. Second, ICT seems to matter [Smeets & Warzynski, 2008; Bloom et al., 2009]. Third, spans are contingent on industry tasks [Woodward, 1965; Hickson et al., 1969]. To the degree they are consistent with the knowledge hierarchic theories is discussed briefly below. First a short assessment of the approach is provided.

A key advantage of the approach is that it allows hierarchies to be pinned down on tasks. Hence by resorting to tasks the study can give some indication why industry structures look the way they do. With a unified measure of industry characteristics the purely descriptive narratives can be transcended. For example, the 'Metal, Machinery and Computer Manufacturing' sector has below average middle manager spans since the operations require tacit knowledge and physical/technical tasks, not because it represents manufacturing *per se*. These insights are already valuable since due to the parsimonious task structure the conclusions are quite general.

Yet unfortunately the explanations do not extend beyond tasks. Inferring why a specific task yields a particular organizational outcome is not feasible within the methodology here. Continuing the example above, the exact reason why tacit knowledge and physical/technical tasks narrow spans remains unknown. However, at a rudimentary level the findings can be contrasted on theoretical frameworks. For example, Garicano [2000] predicts that more complex production processes move problem solving up and hence reduce spans. To some extent the physical/technical tasks would be consistent with this as they are associated with complex manufacturing processes. Another key prediction of the model is that lower communication costs imply higher spans. Reconciling this with the positive coefficient of cognitive tasks requires that these tasks are particularly cheap to communicate: the work activities in Table (1) support this notion. This holds while communication technology is controlled for. It should be noted, however, that CT itself flattens [narrows] the middle [bottom] hierarchies. This could suggest of dissimilarities in problems originating at different levels of hierarchy.

Organizations use communication and coordination to reduce uncertainty, and the literature is quite unanimous in that high prevalence of communication

0.93 to 0.99, it should be noted that similar task and technology profiles can be attained with dissimilar occupational structures.

is associated with a high task variety [Daft & Lengel, 1986]. Since task variety increases complexity, reconciling with Garicano [2000] would then imply that communication and coordination tasks resulted in narrower spans. Encouragingly, the signs of interaction task coefficients are in the majority of specifications negative. The empirical finding of narrowing spans is hence aligned with theory. However, the case of tacit knowledge is less clear. It narrows bottom hierarchies yet theories yield limited guidance of the exact mechanism. One possible explanation relates to costly transmission of tacit information. Here the task comprises of acquisition and evaluation of information pertaining to mostly physical objects. By its very nature this kind of information is often hard to codify. Since codification is a necessary condition for low-cost communication, by the predictions in Garicano [2000] tacit knowledge should then narrow spans. In short, tacit knowledge tasks would be costly to communicate.

The IV estimates suggest that ICT and tasks shape hierarchies. At best these findings hint at causal relationships, but in truth this claim entail many caveats. Hierarchical outcomes are messy and any single narrative is unlikely to be able to reconcile the following facts. First, managerial spans have remained fairly constant for centuries [van Fleet & Bedeian, 1977]. This casts some doubt on the ICT–tasks explanations since both have experienced substantial long-term changes. Second, Japanese corporations have high spans and flat hierarchies. Indeed cultural differences might supersede any technological or task narratives. Third, as any firm-level data shows [see e.g. Smeets & Warzynski, 2008] managerial spans differ much more within firms than between. This is perplexing since due to similar corporate-wide systems, the within-firm variation in either quantity or quality of ICT should be negligible. Applying the task approach to firm-level data would be interesting since they could perhaps explain why different functions within firms have such dissimilar managerial spans.

7 Conclusions

This study seeks to explain why managerial spans evidence such dissimilarity across industries. In particular, the objective is to disentangle the effects of different tasks and technologies to hierarchical forms, and hence to empirically investigate the predictions in knowledge theoretic literature [Garicano, 2000; Garicano & Rossi-Hansberg, 2006]. By utilizing a sample of 287 U.S. industries the sectoral representation is comprehensive. Indeed the data contains the whole U.S. private sector. Rich organizational forms are attained by exploring both middle and corporate manager spans. Industry tasks are derived from O*NET, a rich database of detailed occupational data.

The key findings are as follows. First, ICT seems to shape hierarchies. Communication technology decreases the middle but increases the corporate manager spans. Hence industries that utilize CT have flat middle hierarchies. Information technology reduces spans and narrows organizations. This finding is consistent with the view that ERP facilitates problem solving on the top of hierarchy. With caveats the findings are robust to exogenous variation in ICT. Second, organizations are sensitive to tasks. Tacit knowledge narrows [flattens] the bottom [middle] hierarchy. Technical/physical tasks narrow hierarchies which typically implies centralization of decision making authority. Cognitive tasks lead to the flattening of the bottom hierarchy. The findings broadly align with the predictions in knowledge hierarchy literature [Garicano, 2000]. Third, the study provides descriptive evidence of the substantial sectoral variation in managerial spans of control in U.S. Importantly, it also reveals that non-pyramidal hierarchies are typical, if not the norm.

Reconciling the findings one key insight emerges: industry tasks shape the middle and bottom but not much the top hierarchies. Hence while spans in the corporate management are insular to operational activities, the organization down the middle management reflect the nature of the industry. Generally the results imply that managerial spans can not be attributed to any simplistic narrative – as the knowledge hierarchic view argues, both technology and industry tasks matter.

The investigation of hierarchical forms carry policy relevance. First, ICT spreads rapidly, and the era of 'Big data' and ubiquitous communication is near. Second, industry tasks change albeit gradually. Evidence in Autor et al. [2003] testify of a secular rise in cognitive tasks since the 1960s. These forces will already transform the hierarchical fabric of enterprises across the developed world. Furthermore, as Teece [1996] argues the formal structure of enterprises could even affect the rate of technical innovation. Given the stakes, hierarchies are clearly worth studying.

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A Data construction

This study makes extensive use of the OES and O*NET data. The former covers 1.2 million U.S. establishments and 62% of its employees and is hence very representative. The industry tasks are composed from the O*NET Detailed Work Activities [DWAs]. At first the tasks are constructed for each SOC occupation, and then aggregated to industry-level using employment statistics from the OES. Industry ICT measures are constructed similarly but use the O*NET Tools and Technology data. Education level is based on the O*NET Job Zones. The instruments variables – industry complexity and volatility – use OES data.

A.1 Organization data

Workers, middle and corporate managers: The Occupational Employment Statistics separates between 801 7-digit SOC occupations. By dividing the data based on the SOCs, different employee groups can be identified. These are presented below.

- Corporate managers
  - SOCs: 11-1011 and 11-1021
  - Titles: Chief executives, general and operations managers
- Middle managers
  - SOCs: 11-1031–11-9199, NN-1011, NN-1012, NN-1021, NN-1031 and NN-1099
  - Titles: Functional managers (e.g. financial, sales, production), First-line Supervisors/managers (e.g. production, office, transportation)
  - Notes: Middle managers comprise of functional managers and first-line supervisors. Since the latter are present among multiple disciplines, they span many SOC codes. Hence the prefix 'NN'. Irrespective of the discipline, all first-line supervisors are identifiable by the four last digits in SOC code.
- Workers
  - SOCs: All other SOC codes
  - Titles: All other SOC titles

As can be seen, middle managers comprise of functional managers with specific responsibilities [e.g. finance, sales, production] and first-line supervisors. The former manage workers in their respective functions, while the latter typically manage workers in their production line or equivalent. In the context of this paper the middle managers report to the corporate managers. Workers comprise the residual occupations. They report to middle managers. As is clear from the O*NET taxonomy, the workers category represents a diverse population from clerks to surgeons. It should be noted that certain professional occupations could have at least minor supervisory duties. For simplicity this possibility is abstracted away. The spans s for middle and corporate managers, respectively, are computed by

$$s_i^m = \frac{\sum_{j=1}^{n} E_{i,j}[1|j=l, 0|j \neq l]}{\sum_{j=1}^{n} E_{i,j}[1|j=m, 0|j \neq m]}, \; s_i^c = \frac{\sum_{j=1}^{n} E_{i,j}[1|j=m, 0|j \neq m]}{\sum_{j=1}^{n} E_{i,j}[1|j=c, 0|j \neq c]} \tag{2}$$

where i denotes the 4-digit NAICS industry and j the 7-digit SOC occupation. The number of SOCs within industry i equals n. Employee groups are denoted by $k \in \{l, m, c\}$ where l, m and c stand for the respective worker, middle and corporate manager SOCs. $E_{i,j}$ denotes the employment of occupation j in industry i. Put simply, the nominator counts the number of workers or middle managers in an industry. The denominator counts the number middle or corporate managers in an industry. The average span of the industry s_i^k is the ratio between these employments.

The three-level setup reflects the majority of organizations but obviously entails some caveats. First, senior professionals can have managerial responsibilities and/or directly report to corporate managers. Second, at this level of aggregation dotted-line responsibilities typical in matrix organizations are absent. Third, some first-line supervisors do not report to corporate managers. Finally, bundling together chief executives and general/operations managers is not unproblematic since they typically have reporting relationships in-between.

The data would allow for a five-level setup with four management layers. While non-linearities in organizational outcomes might speak for it, for practical reasons a setup with two manager layers is adopted. For example, subdividing middle managers to upper middle management and first-line supervisors could yield inconsistent data since the latter group can be absent in some industries. Separating middle managers would on average shift both middle manager and corporate manager spans down somewhat. Separating CEOs from corporate managers would be very straightforward but is omitted since significant amount of existing research already studies CEO spans. Despite these limitations the spans reported in Table (2) are very well aligned with the literature. Indeed the reported average spans of 8.81 and 6.98 for middle and corporate managers, respectively, are startlingly consistent with the findings reported at more micro-level studies [Rajan & Wulf, 2006; Smeets & Warzynski, 2008; Garvin & Levesque, 2008] and with historical evidence [van Fleet & Bedeian, 1977]. It is also noteworthy that substantial variation exists in spans across the sectors.

A.2 Task, ICT and human capital data

Occupational tasks: O*NET contains a matching table from the 2164 DWAs to Content Model's Occupational Requirements. This pins the multitude of DWAs to the 5-digit Content Model with 41 different elements. To reduce the dimensionality, these are aggregated to 3-digit level with four different elements. The 3-digit elements are obtained by counting the 5-digit elements within that particular group. The elements are presented in Table (1). The four tasks are: tacit knowledge, cognitive, physical/technical and interaction. Describing industries in just four dimensions amounts to a very tight set of controls. Admittedly some elements especially within the interaction tasks are slightly unrelated. For example, 'Coordinating, Developing, Managing, and Advising' and 'Administering' are functionally rather different tasks. However, through admittedly subjective introspection the four elements seem to yield a sufficient trade-off between granularity and compactness.

Industry tasks: These are obtained by aggregating the occupational tasks in a given industry for each year. Since OES disaggregates employment at 4-digit NAICS and 7-digit SOC levels, the industry tasks are simply calculated as employment-weighted averages. Each 4-digit NAICS industry is hence characterized by four task variables. These seek to provide a compact description of the various tasks undertaken in different industries. Paralleling the discussion above, the approach with four tasks seems fit at industry-level as well. The four industry tasks t are computed by

$$t_{i,k} = \sum_{j=1}^{n} T_j^k e_{i,j} \tag{3}$$

where i denotes the 4-digit NAICS industry, j the 7-digit SOC occupation and $k \in \{1, 2, 3, 4\}$ the respective task. The number of SOCs within industry i equals n. The number of task k in occupation j is denoted by T_j^k. Employment share of occupation j

in industry i is denoted by $e_{i,j}$. Put simply, industry tasks are computed by averaging over occupational tasks and weighing with the respective employment shares.

Industry ICT: The O*NET Tools and Technology data contains information on different technologies typically used in occupations. In T2 all tools and technologies are classified according to the United Nations Standard Products and Services Code [UNSPSC]. The highest level of classification is used here, namely UNSPSC Commodity Titles. Two particular items are utilized: 'Electronic mail software' and 'Enterprise resource planning ERP software'. Hence each occupation is characterized by two binary variables indicating the usage of these tools or technologies. Industry-level ICT intensities are aggregated as before. The resulting variables proxy for CT and IT usage within an industry. Put simply, the variables indicate the share of employees using a particular technology within the 4-digit NAICS industry. The O*NET 2010 T2 database includes 647 SOCs. Consequently the ICT intensities can not be calculated using full sample of OES SOCs. However, the 647 SOCs represent the vast majority of employee population in the OES data.

Industry education level: O*NET Job Zone data contains the typical education level in the occupation on a 1 to 5 scale. Industry-level education levels are obtained as before. Separate education levels are calculated for workers and middle managers. These are used as controls for human capital in the regressions.

A.3 Industry complexity and volatility data

Industry complexity: Complexity within a 4-digit NAICS industry is proxied by counting the number of different occupations within the industry in OES. For example, 'Seafood Product Preparation and Packaging' and 'Oil and Gas Extraction' have 72 and 159 SOCs, respectively. It is plausible that the measure reflects genuine business complexity since more lateral communication and coordination is required with more internal stakeholders. However, there is one technical caveat. If there are differences in the granularity of SOC classifications across occupations, then the complexity measures can be biased. Namely, some industries would appear complex because their occupations are more narrowly defined. This measure is used as an instrumental variable for CT.

Industry volatility: Volatility within a 4-digit NAICS industry is proxied by calculating the fluctuation in industry employment between 2002 and 2007 in OES. It is calculated as the relative standard deviation of employment in the period. The measure seeks to capture the inherent volatility of the industry and the corresponding organizational readjustment needs. There are two caveats. First, it only captures workforce adjustments at the extensive-margin – differences in labor employment. Hence the within-industry reorganization remains obscure. Second, the measure ignores non-employment volatility triggered by for example trade, offshoring or revenue changes. Indeed many other measures of industry volatility would equally well be justified. Use of the current one is partially dictated by data availability but one of its undisputed advantages is employment patterns' close correspondence to the question at hand. Industry volatility is used as an instrumental variable for IT.

B Tables and figures

Table 1: The task taxonomy of the O*NET Content Model

Task	*Subtask*	*Detailed Work Activity*
Tacit Knowledge		
	Information acquisition	Getting Information; Monitor Processes, Materials, or Surroundings
	Information evaluation	Identifying Objects, Actions, and Events; Inspecting Equipment, Structures, or Material; Estimating the Quantifiable Characteristics of Products, Events, or Information
Cognitive		
	Data processing	Judging the Qualities of Things, Services, or People; Processing Information; Evaluating Information to Determine Compliance with Standards; Analyzing Data or Information
	Reasoning and decision making	Making Decisions and Solving Problems; Thinking Creatively; Updating and Using Relevant Knowledge; Developing Objectives and Strategies; Scheduling Work and Activities; Organizing, Planning, and Prioritizing Work
Physical/Technical		
	Physical and manual activities	Performing General Physical Activities; Handling and Moving Objects; Controlling Machines and Processes; Operating Vehicles, Mechanized Devices, or Equipment
	Complex and technical activities	Interacting With Computers; Drafting, Laying Out, and Specifying Technical Devices, Parts, and Equipment; Repairing and Maintaining Mechanical Equipment; Repairing and Maintaining Electronic Equipment; Documenting/Recording Information
Interaction		
	Communication and interaction	Communicating and Interacting; Interpreting the Meaning of Information for Others; Communicating with Supervisors, Peers, or Subordinates; Communicating with Persons Outside Organization; Establishing and Maintaining Interpersonal Relationships; Assisting and Caring for Others Selling or Influencing Others; Resolving Conflicts and Negotiating with Others; Performing for or Working Directly with the Public
	Coordination and development	Coordinating the Work and Activities of Others; Developing and Building Teams; Training and Teaching Others; Guiding, Directing, and Motivating Subordinates; Coaching and Developing Others; Provide Consultation and Advice to Others
	Administration	Performing Administrative Activities; Staffing Organizational Units; Monitoring and Controlling Resources

Notes: these come directly from the O*NET Content Model Reference. The 4-digit subtasks to O*NET map as follows. 4.A.1.a: Information acquisition, 4.A.1.b: Information evaluation, 4.A.2.a: Data processing, 4.A.2.b: Reasoning and decision making, 4.A.3.a: Physical and manual activities, 4.A.3.b: Complex and technical activities, 4.A.4.a: Communication and interaction, 4.A.4.b: Coordination and development, 4.A.4.c: Administration. The tasks in *italics* correspond to 3-digit O*NET categories. The non-aggregated, 5-digit set of O*NET 'Detailed Work Activities' subdivides each 4-digit element to a total of 41 elements.

Figure 1: Average managerial span of control among middle and corporate managers. Workers represent corporate managers' indirect subordinates. Pooled OES data of U.S.

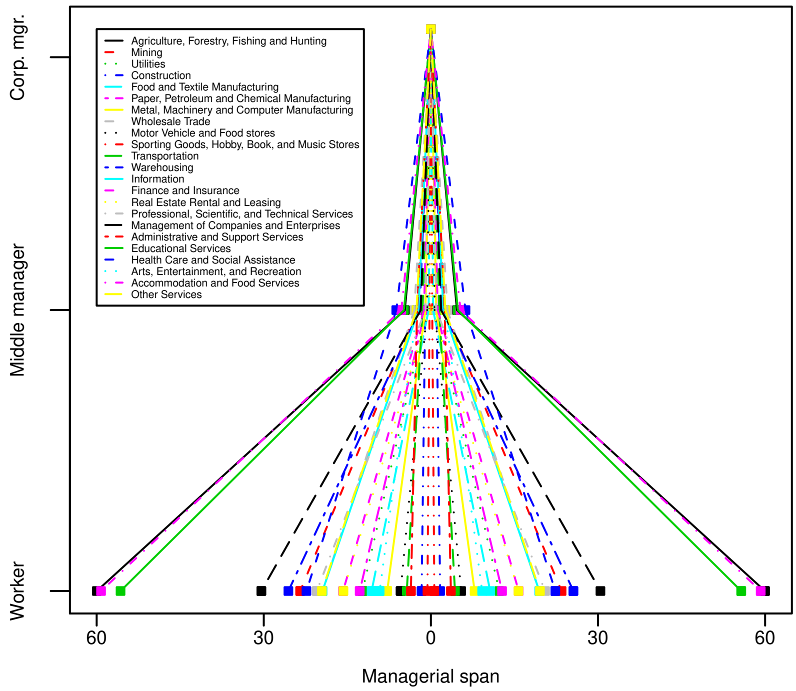

Table 2: Descriptive statistics by sector, U.S.

	Managerial spans		*ICT*		*Education*		*Industry*		*Industry tasks*			
Industry	*Middle manager*	*Corporate manager*	*ERP*	*Email*	*Worker*	*Middle manager*	*Business complexity*	*Business volatility*	*Tacit knowledge*	*Cognitive*	*Physical/ technical*	*Interaction*
Agriculture, Forestry, Fishing and Hunting	5.95	14.90	0.30	0.69	1.47	3.23	47.1	0.04	4.33	7.15	11.63	9.46
Mining	7.11	5.53	0.25	0.42	2.62	3.62	95.0	0.09	4.77	9.88	16.36	9.10
Utilities	6.71	4.90	0.35	0.64	2.78	3.67	129.0	0.03	5.48	9.75	16.11	10.29
Construction	8.60	5.52	0.13	0.37	2.60	3.68	113.1	0.06	5.71	8.03	22.25	7.78
Food and Textile Manufacturing	5.89	5.13	0.30	0.50	1.77	3.37	65.7	0.09	5.62	7.74	13.68	9.10
Paper, Petroleum and Chemical Manufacturing	7.47	5.53	0.27	0.52	2.19	3.52	96.0	0.04	5.74	8.72	13.69	8.08
Metal, Machinery and Computer Manufacturing	8.01	5.97	0.30	0.44	2.59	3.64	94.7	0.05	7.27	9.76	13.38	8.43
Wholesale Trade	9.60	2.82	0.48	0.60	1.95	3.60	105.3	0.03	3.93	10.19	9.59	12.49
Motor Vehicle and Food stores	11.00	6.69	0.19	0.17	1.72	3.20	68.4	0.03	4.26	10.87	9.00	12.21
Sporting Goods, Hobby, Book, and Music Stores	8.66	6.45	0.22	0.22	1.69	3.19	64.3	0.05	3.69	10.74	8.40	12.66
Transportation	15.43	4.54	0.25	0.34	2.20	3.44	56.6	0.05	4.85	8.11	13.15	8.83
Warehousing	10.15	20.43	0.26	0.32	1.67	3.34	78.7	0.05	3.67	6.73	13.16	8.77
Information	9.33	3.85	0.50	0.61	2.98	3.95	79.1	0.06	3.28	12.30	7.65	13.43
Finance and Insurance	5.04	6.33	0.61	0.75	2.97	4.00	77.8	0.05	2.16	12.46	4.27	13.60
Real Estate Rental and Leasing	7.03	4.69	0.29	0.54	1.97	3.64	92.5	0.04	3.47	10.51	10.81	13.78
Professional, Scientific, and Technical Services	8.58	7.28	0.38	0.78	3.25	4.16	167.6	0.05	4.44	17.23	6.92	14.84
Management of Companies and Enterprises	3.16	3.94	0.64	0.82	2.89	4.07	312.0	0.05	2.75	13.09	5.53	15.04
Administrative and Support Services	15.30	2.94	0.28	0.50	1.89	3.53	140.2	0.06	3.19	7.81	10.83	10.23
Educational Services	8.34	7.12	0.27	0.84	2.90	4.06	165.6	0.06	2.61	12.25	6.70	19.58
Health Care and Social Assistance	7.23	16.99	0.12	0.61	2.47	3.14	132.2	0.05	3.08	10.73	6.87	14.32
Arts, Entertainment, and Recreation	15.72	3.88	0.19	0.50	2.16	3.52	87.0	0.04	2.79	8.97	8.07	12.81
Accommodation and Food Services	9.64	11.64	0.07	0.21	1.38	3.32	80.2	0.03	3.47	5.66	9.53	8.77
Other Services	8.68	3.41	0.26	0.62	2.15	3.60	91.2	0.03	4.28	9.41	12.83	13.57
Average	8.81	6.98	0.30	0.52	2.27	3.59	106.06	0.05	4.64	9.78	11.26	11.02
Standard Deviation	7.19	6.97	0.17	0.22	0.58	0.39	48.74	0.037	1.93	3.31	5.06	3.45

Notes: corporate manager span denotes the number of middle managers per corporate manager. Middle manager span denotes the number of workers per middle manager. ICT measures show the share of employees using ERP and email. Education denotes the average level of education in industry on 1 to 5 scale. It is reported separately for workers and middle managers. Business complexity measures the number of different SOCs within an industry. Business volatility measures the relative standard deviation of employment between 2002 and 2007. It should be noted that these figures represent sectors [2-digit NAICS industries], and are unweighed averages of the 287 4-digit industries. The data is sourced from O*NET T2 and Job Zone databases, and OES. The figures are averages for 2008 to 2010.

Table 3: Employment at firm- and establishment-level, U.S.

Enterprise employment	*Firms*	*Establishments*	*Employment*	*Empl. per firm*	*Empl. per establishment*
0–4	3558708	3565433	5966190	1.7	1.7
5–9	1001313	1015178	6580830	6.6	6.5
10–19	610777	646145	8191289	13.4	12.7
20–99	495673	672753	19389940	39.1	28.8
100–499	83326	353510	16153254	193.9	45.7
500–749	5854	75842	3563852	608.8	47.0
750–999	2777	46266	2399250	864.0	51.9
1000–1499	2834	63813	3458407	1220.3	54.2
1500–1999	1446	44360	2497868	1727.4	56.3
2000–2499	916	38296	2043085	2230.4	53.3
2500–4999	1795	119458	6236581	3474.4	52.2
5000–9999	956	120976	6594104	6897.6	54.5
>10000	931	671435	31434976	33764.7	46.8
Total	5767306	7433465	114509626	19.9	15.4

Notes: The figures represent Statistics of U.S. Businesses [SUSB] data from the U.S. Census Bureau. All sectors are included and the data reflects 2009, the latest available.

Table 4: Middle manager spans, U.S.

OLS regressions of middle manager spans of control on ICT and tasks.

Variable	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
Constant	11.68***	20.05***	21.47***	22.92***	19.53***
	(0.96)	(1.59)	(2.68)	(2.65)	(2.65)
ERP	-6.93***	-6.23***	-7.57**		-10.76***
	(1.69)	(1.71)	(2.43)		(2.28)
EMAIL	-8.68***	-8.37***	-6.99***	-9.09***	
	(1.35)	(1.46)	(1.89)	(1.78)	
Worker education	1.68***	2.96***	3.31***	3.37***	2.84***
	(0.45)	(0.53)	(0.69)	(0.69)	(0.68)
Tacit Knowledge		-0.8***	-0.38	-0.49.	-0.19
		(0.19)	(0.26)	(0.26)	(0.26)
Cognitive		0.04	0.25*	0.25*	0.25*
		(0.12)	(0.12)	(0.12)	(0.12)
Physical/Technical		-0.17*	-0.34***	-0.34***	-0.38***
		(0.07)	(0.09)	(0.09)	(0.09)
Interaction		-0.57***	-1.04***	-1.24***	-1.21***
		(0.12)	(0.18)	(0.17)	(0.17)
Year FEs	Yes	Yes	Yes	Yes	Yes
Sector FEs	No	No	Yes	Yes	Yes
Observations	861	861	861	861	861
R^2	0.12	0.17	0.32	0.31	0.31

Notes: Standard deviations in parentheses. *** significant at .1%, ** at 1%, * at 5% and . at 10%. All models are estimated using OLS. The sector FEs represent the 23 2-digit NAICS industries. The data covers years 2008 to 2010.

Table 5: Corporate manager spans, U.S.

OLS regressions of corporate manager spans of control on ICT and tasks.

Variable	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
Constant	16.09***	18.53***	15.24***	17.76***	14.54***
	(2.19)	(2.84)	(3.47)	(3.49)	(3.45)
ERP	-13.39***	-15.35***	-12.34***		-10.99***
	(1.68)	(1.72)	(2.36)		(2.23)
EMAIL	7.61***	7.01***	3.47.	0.14	
	(1.31)	(1.51)	(1.96)	(1.89)	
MM education	-2.71***	-3.15***	-0.66	-0.72	-0.07
	(0.68)	(0.8)	(0.86)	(0.87)	(0.79)
Tacit Knowledge		0.27	0.53*	0.37	0.48*
		(0.19)	(0.24)	(0.24)	(0.23)
Cognitive		0.21.	-0.12	-0.1	-0.15
		(0.12)	(0.13)	(0.13)	(0.13)
Physical/Technical		-0.23**	-0.1	-0.11	-0.08
		(0.07)	(0.09)	(0.09)	(0.09)
Interaction		-0.07	0.29	-0.03	0.41*
		(0.13)	(0.18)	(0.18)	(0.17)
Year FEs	Yes	Yes	Yes	Yes	Yes
Sector FEs	No	No	Yes	Yes	Yes
Observations	861	861	861	861	861
R^2	0.10	0.14	0.32	0.29	0.31

Notes: Standard deviations in parentheses. *** significant at .1%, ** at 1%, * at 5% and . at 10%. All models are estimated using OLS. The sector FEs represent the 23 2-digit NAICS industries. The data covers years 2008 to 2010.

Table 6: Robustness check: middle manager spans, U.S.

IV regressions of middle manager spans of control on ICT and tasks.

Variable	*(1)*	*(2)*	*(3)*	*(4)*
Constant	19.7***	26.48***	19.79***	20.81***
	(1.7)	(5.05)	(1.7)	(1.64)
ERP	-8.49	-15.96		-8.91
	(12.02)	(24.76)		(12.21)
EMAIL	-13.31.	-35.05*	-9.76	
	(7.78)	(14.57)	(7.04)	
Worker education	3.62**	5.4***	2.9**	2.09**
	(1.28)	(1.38)	(0.97)	(0.68)
Tacit Knowledge	-0.79***	-0.95*	-0.88***	-0.75**
	(0.23)	(0.46)	(0.19)	(0.24)
Cognitive	0.05	0.24.	-0.03	0.09
	(0.16)	(0.14)	(0.12)	(0.17)
Physical/Technical	-0.18.	-0.12	-0.14*	-0.2*
	(0.09)	(0.17)	(0.07)	(0.1)
Interaction	-0.4	0.44	-0.58*	-0.81***
	(0.33)	(1.22)	(0.25)	(0.16)
Year FEs	Yes	Yes	Yes	Yes
Sector Fes	No	Yes	No	No
Observations	861	861	861	861

Notes: Standard deviations in parentheses. *** significant at .1%, ** at 1%, * at 5% and . at 10%. IV models are are calculated using 2SLS. The instruments for EMAIL and ERP are business complexity and volatility, respectively. The sector FEs represent the 23 2-digit NAICS industries. The data covers years 2008 to 2010.

Table 7: Robustness check: corporate manager spans, U.S.

IV regressions of corporate manager spans of control on ICT and tasks.

Variable	*(1)*	*(2)*	*(3)*	*(4)*
Constant	4.59	3.12	30.4***	6.1
	(9.54)	(9.53)	(6.91)	(5.65)
ERP	-31.07**	-63.32**		-31.64**
	(10.88)	(22.36)		(11.67)
EMAIL	-2.19	11.77	13.81.	
	(8.05)	(17.89)	(7.89)	
MM education	1.7	0.6	-7.31***	1.22
	(3.22)	(3.76)	(2.2)	(1.97)
Tacit Knowledge	0.6*	1.17**	-0.04	0.59*
	(0.29)	(0.42)	(0.21)	(0.28)
Cognitive	0.1	-0.25	0.29.	0.13
	(0.17)	(0.27)	(0.17)	(0.13)
Physical/Technical	-0.33**	-0.01	-0.14.	-0.33**
	(0.1)	(0.16)	(0.07)	(0.11)
Interaction	0.52	1.88	-0.56	0.44*
	(0.43)	(1.26)	(0.35)	(0.2)
Year FEs	Yes	Yes	Yes	Yes
Sector Fes	No	Yes	No	No
Observations	861	861	861	861

Notes: Standard deviations in parentheses. *** significant at .1%, ** at 1%, * at 5% and . at 10%. IV models are are calculated using 2SLS. The instruments for EMAIL and ERP are business complexity and volatility, respectively. The sector FEs represent the 23 2-digit NAICS industries. The data covers years 2008 to 2010.

Table 8: IV robustness tests

First-stage regressions of endogenous variables on instruments.

	Dependent variable			
Variable	*ERP*	*ERP*	*EMAIL*	*EMAIL*
Constant	0.02	0.02	-0.09*	-0.1*
	(0.04)	(0.04)	(0.04)	(0.04)
Industry volatility	0.51***	0.45**		0.19
	(0.14)	(0.14)		(0.16)
Industry complexity		0*	0.001***	0.001***
		(0)	(0)	(0)
Controls				
Tasks	Yes	Yes	Yes	Yes
Worker education	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Industry FEs	No	No	No	No
F-statistic	14.04	9.07	30.72	16.07
Observations	681	681	681	681
R^2	0.24	0.25	0.41	0.41

Notes: Standard deviations in parentheses. *** significant at .1%, ** at 1%, * at 5% and . at 10%. All models are estimated using OLS. The columns show regressions of endogenous variables on the respective instrument[s] and controls. The F-statistics indicate the comparison to restricted models where the instruments are excluded. Robustness checks show that the F-statistics are not substantially lower with 2-digit NAICS industry FEs.