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Information, Technology and Information Worker Productivity

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We study the fine-grained relationships among information flows, IT use, and individual information-worker produc- tivity, by analyzing work at a midsize executive recruiting firm. We analyze both project-level and individual-level performance using: (1) direct observation of over 125,000 e-mail messages over a period of 10 months by individual workers (2) detailed accounting data on revenues, compensation, project completion rates, and team membership for over 1300 projects spanning 5 years, and (3) survey data on a matched set of the same workers' IT skills, IT use and in- formation sharing. These detailed data permit us to econometrically evaluate a multistage model of production and in- teraction activities at the firm, and to analyze the relationships among communications flows, key technologies, work practices, and output. We find that (a) the structure and size of workers' communication networks are highly correlated with their performance; (b) IT use is strongly correlated with productivity but mainly by allowing multitasking rather than by speeding up work; (c) productivity is greatest for small amounts of multitasking but beyond an optimum, mul- titasking is associated with declining project completion rates and revenue generation; and (d) asynchronous informa- tion seeking such as email and database use promotes multitasking while synchronous information seeking over the phone shows a negative correlation. Overall, these data show statistically significant relationships among social net- works, technology use, completed projects, and revenues for project-based information workers. Results are consistent with simple production models of queuing and multitasking and these methods can be replicated in other settings, sug- gesting new frontiers for bridging the research on social networks and IT value.

Key words: Social Networks, Productivity, Information Worker, IT, Multitasking, Production Function

Introduction

Information workers now account for as much as 70% of the U.S. labor force and contribute over 60% of the total value added in the U.S. economy (Apte & Nath 2004). Ironically, as more and more workers focus on processing information, researchers have less and less information about how these workers create value. Unlike bushels of wheat or tons of steel, the inputs and real output of most informa- tion workers is difficult to measure. Yet, as the information content of work increases, the role of infor- mation flows in information intensive work becomes increasingly central to our understanding of the per- formance of individuals, groups and organizations.

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Efficient access to useful information should promote information worker productivity by facili- tating faster, higher quality decision making. If information access influences productivity, its distribution and diffusion patterns should in turn correlate with the relative productivity of information workers. In the information age, new technologies, new ways of working, and an increasing availability of information could significantly affect productivity and specifically the productivity of information workers. Studies of IT-productivity demonstrate a strong positive relationship across distinct measures (Bharadwaj et. al.
1999, Brynjolfsson & Hitt 2000, Aral & Weill 2007) at the country (e.g. Dewan & Kraemer 2000), indus- try (e.g. Jorgenson & Stiroh 2000), and firm (e.g. Brynjolfsson & Hitt 1996) levels. Yet, we lack a micro- level understanding of how IT and information influence productivity. While a handful of micro-level studies of IT and productivity have been conducted in recent years (e.g. Ichniowski, Shaw & Pernushi 1997, Barua, Kreibel & Mukhopadhyay 1994, Mukhopadhyay, Surendra & Srinivasan 1997, McAfee 2002), most focus on manufacturing industries and measure physical goods output, leaving a number of important questions unanswered. The mechanisms by which IT and information affect productivity are not well understood and the output and production functions for information workers such as managers, consultants, researchers, marketers, lawyers and accountants remain poorly modeled and measured. Ironi-cally, IT may be especially important for the productivity of information workers because it enables them to search for, retrieve, analyze and store information (a key input into their decisions and activities), and enables new forms of work organization and communication that are increasingly asynchronous, geo-graphically dispersed and sustained over longer periods of the day (Hinds & Kiesler 2002).

Information workers gain access to information through both social and technological means. Ac- cordingly, we bridge two literatures – social networks and IT value – to understand how social and tech- nological access to information correlates with information worker productivity. We explore a new fron-tier for IT productivity research by opening the black box of the firm using detailed project-level data at the level of individual information workers to shed light on the intermediate mechanisms that explain per- formance. By studying a single industry in depth, Ichniowski, Shaw and Prennushi (1997) were able to specify a production function for blue collar workers, and then to measure the effects of particular tech- nologies and work practices on productivity. We undertake an analogous strategy for comprehending in- formation work: secure individual and project-level data for information workers and map their behaviors to project output. We focus on executive recruiters, or "head hunters," whose project output is precisely measurable. Accounting records provide detailed data on individual and project-level revenues, the num- ber of projects individuals and teams complete, precise start and stop dates, the number of concurrent pro- jects, and individual share-weighted effort. With company and employee cooperation, we also monitored email usage to analyze the flow of information through the firm's social network, conducted field inter- views, gathered survey data, and collected independent third party evidence of project difficulty. This mi- cro data allows us to match individual level behaviors to individual and project level results.

Our variables measure the use of IT, not merely its presence, and include direct, message-level observation of communications volume, the size and structure of email contact networks, professed abil- ity to use database technology, and relative time spent on various information seeking tasks. When com- bined with interviews and visits, these data enabled us to specify and estimate several equations relating social network structure, technology, skill, worker characteristics, task completion and revenue genera- tion. Narrowly focusing on one industry allowed us to precisely define the white collar production proc- ess, and our concentrated data collection from one firm eliminates many sources of heterogeneity that confound productivity estimation at more aggregate levels of analysis.

Our results demonstrate that information flows and IT use do in fact predict significantly higher levels of economic productivity. Richer communications structure predicts greater multitasking and pro- ductivity, and heavier database users generate more revenue for the firm per unit time. However, our analyses at the project level, designed to unpack the processes driving performance, also reveal some counterintuitive results. We find that individuals occupying central brokerage positions in the firm's com-
munication network, who arguably have more structurally efficient access to novel information, are not necessarily more efficient per project. Instead, their higher levels of productivity result from higher ca- pacities to multitask across simultaneous projects. Employees who use databases more also conduct more work simultaneously and finish projects faster, demonstrating that technology use not only speeds work, it enables new ways of working that can make workers more productive. Together, our results reveal a substantial program of correspondence among information, technology and output, and motivate new questions regarding the tradeoffs between multitasking and the speed of work, and how information af- fects intermediate production processes in white collar work.

1. Theory and Literature

Information Flows, Social Network Structure and Information Worker

Productivity

Access to information should promote information worker productivity by (a) supporting higher quality decisions, (b) facilitating the development of managerial skills and (c) enabling more effective political maneuverability. Information and reductions in uncertainty improve resource allocations and decision making and reduce delay costs by increasing the accuracy of mental mappings from actions to expected consequences (Cyert & March 1963, Marschak & Radner 1972, Galbraith 1973). Our context aligns well with the classic decision-theoretic interpretation of the value of information: improved infor- mation about the executive candidate pool and about job opportunities improves the fit between candi- dates and clients' requirements, increasing the frequency of matches and reducing time wasted interview- ing unsuitable candidates. Precise information also tempers risk aversion, enabling recruiters to make ap- propriate decisions faster (Arrow 1962, Stiglitz 2000). Reductions in uncertainty help recruiters place the right candidates in front of the right clients quickly, increasing the likelihood of concluding searches faster and in turn increasing the job completion rate and the revenues earned by the firm. Sharing proce- dural information or know-how can also improve employees' handling of recurrent search problems (Szu- lanski 1996) and recruiters report learning to deal with difficult professional situations through peer communication.

Access to information also enables skill development by increasing familiarity and facility with different topics, improving individuals' absorptive capacity and strengthening communication. As peopleare exposed to new ideas and information they develop the ability to absorb new concepts enabling more effective knowledge transfer (Cohen & Levinthal 1990, Simon 1991) and increasing the likelihood that others will share information with them as they share more intellectual common ground (Clark 1996, Cramton 2001, Reagans & McEvily 2003). As absorptive capacity is developed, individuals are better able to communicate ideas across a broader range of topics and to a broader audience, strengthening per- suasion and the ability to generate support from subject matter experts in accomplishing managerial goals (Rodan & Galunic 2004). Access to information can also create autonomy (Simmel 1922 (1955), Burgel- man 1991, Burt 1992) and enable political maneuverability (Padgett & Ansell 1993), helping individuals gain access to resources they need to do their jobs efficiently (Rodan & Galunic 2004).

In our setting, employees seek and access information socially through colleagues and contacts, and technologically by searching databases, intranets and public information available online. The struc- ture of social information acquisition is instantiated in communication networks that connect employees. Two of the most important network characteristics theorized to drive performance by providing access to information are structural diversity (the existence of 'structural holes' in a communication network, Burt 1992) and short path lengths to different parts of the network (high 'betweenness centrality'; e.g. Freeman 1979, Hansen 2002). While social network research has studied these concepts through survey based self reports, none has linked information flowing in email networks to productivity – an important lens onto how information flows affect the performance of information workers.[1]

Actors with structurally diverse social networks (networks rich in structural holes that link them to unconnected network neighborhoods) derive 'information benefits' from network structure because they are more likely to receive non- redundant information through network contacts (Burt 1992). As in- formation in local network neighborhoods tends to be redundant, structurally diverse contacts provide
channels through which novel information flows to individuals from distinct pools of social activity (Granovetter 1973). Access to non-redundant information facilitates early promotion (Burt 1992), greater career mobility (Podolny & Baron 1997), adaptation to change (Gargiulo & Benassi 2000), and R&D productivity (Reagans & Zuckerman 2001). In social networks, the economic value of information stems from its uneven distribution across actors. Individuals solve problems and find opportunities by tapping distinct information pools in diverse network neighborhoods to which their structurally diverse channels provide access. Actors with access to these diverse pools "benefit from disparities in the level and value of particular knowledge held by different groups…" (Hargadon & Sutton 1997: 717). Redundant informa- tion is less valuable because many actors are aware of it at the same time, reducing opportunities associ- ated with its use. Structural redundancy is also inefficient because actors incur costs to maintaining re- dundant contacts while receiving no new information from them (Burt 1992). Qualitative studies show that executive recruiters fill "brokerage positions" between clients and candidates and rely heavily on
non-redundant information flows to complete their work effectively (Finlay & Coverdill 2000). Recruit- ing teams with novel information about newly available candidates or positions can fill diverse client re- quirements more quickly and accurately. We therefore expect that *individuals and teams with uncon- strained (or diverse) communication networks are more productive.* (Hypothesis 1a)

While network diversity provides novel information from different local network neighborhoods, being along the shortest network paths to the greatest number of potential contacts may also increase ac- cess to information. Business units with shorter path lengths to other units, those with high betweenness centrality (Freeman 1979), finish projects faster (Hansen 2002). There are two broad information search benefits to higher betweenness centrality. First, longer path lengths increase the likelihood and severity of distortion as information is passed from individual to individual in a network (March & Simon 1958, Huber 1982, Hansen 2002). When information about the candidate pool or impending layoffs at a source firm are passed from recruiter to recruiter, there are an increasing number of chances for misunderstand- ing, vagueness, filtering or even deliberate withholding and falsification (Huber & Daft 1987). The poten- tial for garbling

increases in proportion to the social distance traversed by messages, in this case the num-
ber of people along the message path. A common anecdotal example of this phenomenon is the telephone game, in which messages become distorted as they are passed along a chain of contacts. Second, when information is vague or imprecise teams must take time to verify its accuracy and relevance, and obtain complementary information to enable effective decision making (Hansen 2002). For example, when a recruiter receives second hand information about a potential candidate, they must verify the candidate's prior experience and leadership potential in order to qualify them as a possible match for a given position. In contrast, short path lengths provide direct information with less distortion, and reduce search costs as- sociated with verification. Recruiters can request clarification directly from the message source rather than wasting time tracking down the source or establishing where the information was garbled. Without knowing the origins of distortions, teams may search for extended periods of time and in a costly manner to collect and verify the information they need to make high quality decisions. We therefore expect that *individuals and teams located on the shortest path lengths to other individuals in the firms' communica- tion network are more productive*. (Hypothesis 1b)

IT Use, IT Skills and Information Worker Productivity

Information workers also gather, process and analyze information by technological means. In- formation contained in databases, document repositories and Intranets are frequently used to conduct due diligence and aid decision making. In our context recruiters use the Executive Search System (ESS) and external proprietary databases to conduct research essential to their information processing and decision making tasks. These systems also provide decision support with value added information sorting, extrac- tion and summarization tools that enable more efficient and effective search and analysis. A well estab-
lished literature in Information Systems examines the antecedents of IT acceptance and use in organiza- tions (e.g. Davis 1989, Straub et. al. 1995, Szajna 1996, Taylor & Todd 1995, Doll and Torkzadeh 1998, Venkatesh & Davis 2000), and a handful of studies advocate systems use as the "missing link" between IT investments and performance improvements (e.g. Lucas & Spitler 1999, Devaraj & Kohli 2003). These studies argue that "[s]ystems-use is a pivotal construct in the system-to-value chain," (Doll and Torkzadeh 1998) implying that differences in IT use are correlated with productivity, performance and
creation. Goodhue & Thompson (1995) contend that this link is especially pronounced in contexts where the technology (its design and function) "fits" employees' task requirements well. We examine the use of the Executive Search System (ESS) and external proprietary databases, both of which are designed specifically to support recruiters' information seeking and decision making needs. We therefore expect that: Individuals and teams who use the ESS and external proprietary databases more are more produc- tive. (Hypothesis 2a)

Task-technology fit depends not only on the match between technology and its application, but also on the skills of the individuals using the technology (Goodhue & Thompson 1995). A strong empiri- cal relationship between IT use and skill at the worker (Kreuger 1993), firm (Dunne, Haltiwanger & Troske 1997), and industry (Autor, Katz & Kreuger 1998) levels, demonstrates that firms with significant amounts of IT capital tend to hire more skilled workers. A handful of firm level studies also demonstrate that the co-presence of IT and highly skilled labor improves productivity and performance (Breshnahan, Brynjolfsson & Hitt 2002, Aral & Weill 2007). Although most individual level studies of the impact of IT use on productivity and performance do not evaluate the relative IT skills of workers (e.g. Lucas & Spitler 1999, Devaraj & Kohli 2003), there are good reasons to believe that IT skills and IT use should be corre- lated and that stronger IT skills should contribute to the productivity of information workers. Information intensive work is generally supported by "data analysis skills" which complement IT to improve produc- tivity (Bresnahan, Brynjolfsson & Hitt 2002) and firms whose employees have stronger IT skills perform better on average (Aral & Weill 2007). We therefore expect that: Individuals and teams with stronger IT skills are more productive. (Hypothesis 2b)

Intermediate Mechanisms: Multitasking & the Speed of Work

Recruiters earn revenue by filling client positions rather than billing hourly and real output is therefore generated by completing projects. As recruiters complete more projects per unit time, they gen- erate more real output per unit time. If we consider recruiters to be managing queued projects, the faster they complete each project and take on more work the more projects they will complete and the more real
output they will produce per unit time. We therefore expect that: *Workers who finish projects faster are more productive as measured by overall project completion rate and revenue generation.* (Hypothesis 3)

Project-level multitasking – the act of taking on multiple simultaneous projects in parallel – al- lows recruiters to accomplish more work by utilizing lulls in one project to accomplish tasks related to other projects. As is typical in project based work, there are periods of downtime during projects when recruiters wait to have phone calls returned or interviews scheduled. The non-continuous nature of project based work is naturally suited to parallel processing across multiple simultaneous projects. Multitasking creates efficiency in information worker production by smoothing labor hours over projects with bursty work requirements. We therefore expect that: *Workers who take on more simultaneous projects are more productive as measured by overall project completion rate and revenue generation.* (Hypothesis 4a)

However, taking on multiple simultaneous projects is costly. As more projects are attempted in parallel, recruiters face longer delays in getting back to the activities of a particular project while cycling through activities related to other projects. These delays may preclude timeliness or force recruiters to skip lower priority

activities that could help fill positions. When employees juggle too many projects, work gets backed up and productivity suffers. The situation is analogous to congestion and throughput processes for queued tasks. For example, the throughput of cars on a highway increases as more cars join traffic, but is reduced by congestion after a certain level of traffic is exceeded. Multitasking is associated with short-term and long-term cognitive switching costs that reduce reaction times and task completion rates, and increase error rates in experimental settings (e.g. Rubenstein et. al. 2001). Overlapping activi- ties create confusion and associative competition, and responses are substantially slower and more error- prone with frequent task switching (Gilbert & Shallice 2002, Monsell 2003). Our interviews corroborate this story. As the CIO of the firm put it "Everyone can only deal with so many balls in the air. When someone gets 'too far in,' [takes on too many projects] they lose touch. They can't tell one project from another." If this is the case, then a fundamental trade-off is likely to exist between workload and effi- ciency, such that multitasking beyond a certain point reduces productivity. We therefore expect that:

There are diminishing marginal productivity returns to project based multitasking and that multitasking beyond an optimal level reduces productivity. (Hypothesis 4b)

Network position and IT use and skill should in turn correlate with multitasking and the speed of work. Multitasking allows recruiters to smooth labor hours over projects with bursty work requirements. Periods of downtime during projects create interstitial spaces during which work on other projects can be accomplished. Asynchronous communication and information seeking technologies should complement the efficient use of these project lulls by allowing recruiters to seek information and expertise without the constraints of coordinating the availability of information sources. We therefore hypothesize that: *The use of asynchronous communication and information seeking technologies – Email and Database – is posi- tively associated with multitasking, while the use of synchronous communications methods – Phone and Face-to-Face communication – is negatively associated with multitasking.* (Hypothesis 5a)

Favorable network positions (e.g. unconstrained networks with high betweenness) enable more effective social information gathering by increasing access to non-redundant information and reducing garbling, noise and costly verification and search behaviors. Recruiters who are well positioned to gather information are likely to make better decisions during the search process and to conclude searches more quickly. In other work which analyzes the content of the email data, we find that recruiters with greater access to novel information and those employees who are more likely to receive diffusion of news and information in email and to receive such information sooner than others in the firm's network are indeed more productive (Aral, Brynjolfsson & Van Alstyne 2007, Aral & Van Alstyne 2007). We therefore ex- pect that: *Individuals and teams with unconstrained communication networks finish projects faster* (Hy- pothesis 6a), and that: *Individuals and teams located on the shortest path lengths to other individuals in the firms' communication network finish projects faster*. (Hypothesis 6b)

2. The Research Setting and the Role of Information and Technology

We studied a medium-sized executive recruiting firm over five years, with fourteen regional of- fices throughout the United States. The employees occupy three basic positions – partner, consultant and researcher – and conduct their 'executive searches' in teams. Our interviews indicate that the contract execution process is relatively standard: A partner secures a contract with a client and assembles a project team (team size mean = 1.9, min = 1, max = 5). The team then establishes a universe of potential candi- dates including those in similar positions at other firms and those drawn from the firm's internal database. These candidates are vetted on the basis of perceived quality, their match with the job description and other factors. After conducting initial due diligence, the team chooses a subset of candidates for internal interviews, approximately six of whom are forwarded to the client along with a formal report of the team's due diligence. The team then facilitates the client's interviews with each candidate, and the client, if satisfied with the pool, makes offers to one or more candidates. A contract is considered complete when a candidate accepts an offer. The period from client signature to candidate signature defines project duration.

The core of executive recruiters' work involves retrieving and understanding clients' require- ments and matching candidates to those requirements.2 This matching process is information-intensive and requires assembling, analyzing, and making decisions based on information gathered from various sources including team members, other firm employees, contacts outside the firm, and data on potential candidates in the internal proprietary database, external proprietary databases, and public sources of in- formation. Recruiters earn revenue by filling vacancies, rather than billing hourly. The speed with which vacancies are filled is therefore an important intermediate measure of productivity. Contract completion implies that the search team has met the client's minimum thresholds of candidate fit and quality, and given controls for differences across contracts (e.g. job type, location), project duration (in addition to real dollar output value) can be interpreted as a quality controlled measure of team and worker productivity.

Interviews with the CIO and other employees indicate that the firm uses IT in essentially two ways: 1) as a communication vehicle (e.g. phone, voicemail, and email) and 2) as a central repository of information and knowledge about ongoing projects, potential candidates and internal task coordination. Both of these functions facilitate the information exchanges teams require to systematically assemble, analyze, codify and share knowledge about candidates and clients. The firm pays to use external data- bases and has its own proprietary Executive Search System (ESS), built from an off-the-shelf relational database. The ESS provides a repository of information on current and past projects, the firm's own em- ployees (e.g. contact information, areas of expertise, work history and current assignments), clients, and potential candidates (e.g. resumes, prior due diligence,

and notes or "work ups" on their previous jobs); and also helps employees coordinate and manage dependencies across projects. For example, when searching for potential candidates, employees must honor contractual obligations that prevent them from poaching employees of previous clients for one year. The ESS maintains an up-to-date record of candi- dates that are 'frozen' due to prior client obligations and employees use this information to coordinate contractual obligations across projects and to reduce time spent interviewing ineligible candidates.

3. Model Specification

A Production Model of Revenue and Project Output for Executive Recruiting

A decade ago, moving from aggregate data to more fine grained data at the firm level helped re-solve the 'IT productivity paradox.' Explorations at the firm level, however, are still constrained by the granularity of the data and can only explain *whether* IT increases productivity, not *how* IT increases pro- ductivity. Our data allow us to construct a detailed model of the production process of executive recruit- ers, and to test the impact of IT and information flows on intermediate process metrics and final output measures. We conduct both individual-level and project-level analyses that examine the specific mecha- nisms through which IT and information affect the production process.

We apply a traditional microeconomic production function framework to the production process of information workers in which employees use information based inputs to produce information based products and services. Like much of the work that estimates the productivity effects of IT capital (e.g. Hitt & Brynjolfsson 1995, Brynjolfsson & Hitt 1996, Dewan & Min 1997, Jorgenson & Stiroh 2000), we be- gin with a generalized production function describing output (Q) as a function of ordinary capital (K), capital (C) and labor (L):

$$Q_{it} = f_1(C_{it}, K_{it}, L_{it}). \quad [1]$$

The Cobb Douglas production function is the most common and widely validated functional form used to estimate the productivity effects of IT capital at the firm level. It has the appealing property that the coef-ficients can be directly interpreted as output elasticities (Hitt & Brynjolfsson 1995):

$$Q_{it} = C_{it}^{\beta_1} K_{it}^{\beta_2} L_{it}^{\beta_3}. \quad [2]$$

By taking logarithms and adding an error term, this function produces a reduced form equation that can be estimated using firm level data where β_1, β_2 and β_3 are parameters to be estimated:

$$\log Q_{it} = \alpha_{it} + \beta_1 \log C_{it} + \beta_2 \log K_{it} + \beta_3 \log L_{it} + \varepsilon_{it}. \quad [3]$$

We adapt this framework to reflect the production function of individual information workers in the con- text of executive recruiting by modifying both the unit of analysis and the definition of inputs.

Since recruiters generate revenue by completing projects (rather than billing hourly) and are as- signed to projects with varying levels of individual effort share per project, we define real output (Q) as the revenues generated by each recruiter and conceptualize completed projects (P) as the primary driver of revenues such that $Q_{it} = f_2(P_{it})$. Individual workers use the accumulated capital of the firm to execute tasks. Investments in ordinary capital (K) (e.g. property and equipment, buildings, offices, desks and meeting rooms) and IT capital (C) (e.g. personal computers, phones, fax machines, copiers and projec- tors) are uniform across workers in that employees have equal access to them. We therefore conceptualize ordinary capital (K) and IT capital (C) as constant across employees and embodied in the constant term ofthe production function ( ). Instead of measuring IT capital, our input variables focus on access to in- formation and technology use. We include two new categories of inputs to the production function based on our hypotheses: IT use and skills (IT) and communication network structure (NS) (a proxy for access to information inputs).[3] The move away from measuring ordinary capital and computer capital to measur- ing IT use and skills and social network structure allows us to precisely estimate relationships among IT

[3] We include a series of control variables to account for traditional demographic and human capital variables (e.g. age, gender, level of education, industry experience and managerial level), job type, temporal variation and city characteristics., information access through social networks and output in information work settings using the re- duced form equation expressed in equation [4 However, this reduced form has two limitations. First, it may produce noisy measures of the relationships because several intermediate process steps separate using IT and accessing information from producing real output. Second, while these estimates uncover whether IT use and information access through social networks are associated with output, they cannot tell us how these factors are related. We therefore devel- oped our model further, using interviews and site visits as a guide, to sharpen our estimates and to exam- ine how IT is related to output through intermediate process mechanisms.

The labor term (L) in firm-level production functions typically describes the number of employ- ees or the wage adjusted cost of labor inputs. In white collar work settings, where workers do not bill hourly and in which labor is not compensated by the hour (as in our case), employees are given autonomyto choose when and how they work, rather than fulfilling a certain quota of hours worked per week. If weconsider white collar workers to be managing queued tasks, each with distinct start and stop points, we can measure the relationship between IT, information flows, and intermediate measures of output. In par- ticular, data on project multitasking and start and stop times over the sample period index the rate at which projects are completed. In our production model, employees work on projects whose number and duration determine total dollar "bookings" (contracts landed) and "billings" (contracts executed) revenue. The production function therefore characterizes output as a multiplicative function of the number of si- multaneous projects (MT_{it}) and project duration (D_{it}), as specified in equations [5] and [6].

These specifications are derived from models of queued task execution in services work (e.g. Adler et. al.1995, Hopp et. al. 2007) and from models of parallel and overlapping queued task processing (e.g. Krishnan et. al. 1997) from the engineering and operations management literatures, which specify the execution of queued tasks as a multiplicative function of load (e.g. multitasking) and speed (e.g. duration).

Finally, we relate IT use and skills and network structure to the intermediate mechanisms that describe the production process. We relate the hypothesized inputs to multitasking through the following linear additive specification which resembles those of Ichniowski, Shaw & Prennushi (1997). Increment to R^2, PE and Box-Cox tests indicate this additive form is preferred to a multiplicative Cobb-Douglas specification in equations

To test whether IT, information flows and the level of multitasking are related to project duration (*D*), we develop a parsimonious model of project completion rate $R(t)$. As the dataset contains right censored data,[4] OLS estimation can produce biased and inconsistent results of rate analyses (Tuma & Hannan 1984). We therefore use a hazard rate model of the likelihood of a project completing on a given day, conditional on it not having been completed earlier. We employ the Cox proportional hazards model in equation [8] to estimate relationships among IT use, information flows and the completion rate:

Independent Variable Construction

Social Network Structure. To measure information flows we constructed variables for both the amount of email sent and received and the network structure of email traffic at both the individual and team levels. Since teams at our research site are small (two recruiters per team on average) we focus on the global network structure of teams' external contacts, rather than their internal structure which is typically dyadic. Measures of the level of email traffic count the total number of emails sent and received, network size (the number of contacts), and in-degree and out-degree centrality, which measure the message frequency weighted number of contacts.7 We also measure the two aspects of network structure hypothesized to influence information access: betweenness centrality and network diversity.

4. Statistical Specifications

We estimated Equation 4 using a random effects specification on monthly panels of email networks, revenues and survey data on ESS Use and ESS Skill. We employed random effects to recover parameter estimates of important cross sectional variables (e.g. education, organizational position, industry experience, ESS Use and ESS Skill). We replicated random effects analyses using an OLS specification on annual data in 2002, the year in which the survey was conducted.

We then tested relationships between revenues, completed projects, multitasking and project duration using Feasible Generalized Least Squares (FGLS), fixed effects and random effects specifications at the daily level. As daily panel estimates displayed serial correlation based on Durbin-Watson tests and heteroskedasticity based on Breush-Pagan tests, we model FGLS specifications using within-panel corrections for both heteroskedasticity and auto-correlation, with autocorrelation in the error diminishing uniformly over time: $\varepsilon_t = \rho\varepsilon_{t-1} + u_t$. We conducted Hausman tests of the efficiency and consistency of random effects specifications in daily analyses and all tests revealed the random effects specifications to be efficient and consistent. We then examined OLS estimates of the relationships between independent variables and multitasking at the project-level with a variable indexing right censored data, and employed a Maximum Likelihood specification to test the Cox proportional hazards model of project completion rate. We report standard errors according to the White correction (White 1980), and as project analyses may cluster on groups of project team members, we report robust standard errors clustered by project team in project-level analyses.[15] More detail regarding statistical specifications is reported in Appendix D.

5. Results

We first took a more traditional approach and examined the relationship between IT and revenues directly and evaluated a popular conception of how IT may improve productivity – by increasing the pace of work – by estimating the reduced form Equation 4. While we expected these estimates, which ignore the intermediate process steps hypothesized in the production function, to exhibit greater noise, we did indeed find evidence of positive and statistically significant correlations among IT, network position and individual revenues. A one standard deviation increase in betweenness centrality in the email network is associated with approximately $76,000 greater revenue output per year controlling for human capital, demographic variables and use of the ESS system. A one standard deviation increase in network diversity is associated with approximately $83,000 greater annual revenue output (see Model 1, Table 3).

Table 2: Panel Data Descriptive Statistics

	Monthly Data													
	All Employees					**Partners**					**Consultants**			
Variable	**Obs.**	**Mean**	**SD**	**Min**	**Max**	**Obs.**	**Mean**	**SD**	**Min**	**Max**	**Obs.**	**Mean**	**SD**	**Min**
Age	522	42.36	10.94	24	67	162	50.5	5.70	40	63	216	43.67	9.87	27
Gender (1=male)	657	.56	.50	0	1	234	.65	.48	0	1	279	.52	.50	0
Industry Ex-perience	522	12.52	9.52	1	39	162	21.72	7.85	9	39	216	11.25	7.47	1
Education	522	17.66	1.33	15	21	162	18.5	1.02	17	21	216	17.29	1.21	15
Total Emails	563	145.69	110.16	0	592	224	125.52	81.71	1	391	215	119.94	90.10	1
Sent Emails	563	80.31	59.67	0	342	224	57.20	44.09	0	242	215	57.06	44.70	0
Received Emails	563	69.09	56.16	0	253	224	71.73	44.84	0	232	215	66.26	49.19	0
In Degree	563	79.99	70.38	0	445	224	66.90	49.57	0	230	215	61.11	49.71	0
Out Degree	563	79.99	61.21	0	344	224	70.25	42.05	0	202	215	64.67	49.67	0
Network Size	563	16.81	8.79	1	58	224	17.92	6.92	1	35	215	14.33	7.05	1
Betweenness Centrality	563	59.20	73.75	0	895.3	224	55.98	50.08	0	279.85	215	41.58	51.11	0
Network Diversity	563	.71	.17	0	.91	224	.75	.14	0	.91	215	.69	.18	0
ESS Use	531	28.71	20.52	0	75	180	24.45	19.35	0	75	207	28.52	23.03	0
ESS Skill	531	6.23	1.65	2.52	9.32	171	5.44	1.57	2.52	8.32	216	6.20	1.64	3.27
Revenues	630	20962	18843	0	80808	234	28462	17121	0	80808	261	22284	17931	0
Completed Projects	630	.39	.36	0	1.69	234	.49	.32	0	1.69	261	.45	.36	0
Multitasking	630	5.84	5.20	0	24.96	234	8.79	5.10	0	24.96	261	5.38	4.13	0
Ave. Project Duration	630	225.23	165.77	0	921.04	234	309.44	146.71	0	921.04	261	235.48	134.13	0
	Daily Data													
Completed Projects	104982	.017	.017	0	.84	44286	.020	.016	0	.839	37537	.020	.018	0
Revenues	100815	694.82	690.24	0	3353.35	44286	901.69	664.67	0	3205.53	35564	812.78	689.23	0
Multitasking	104983	6.55	5.51	0	28	44286	9.07	5.24	0	28	37537	6.61	4.68	0
Share-Weighted Multitasking	104983	3.36	2.91	0	14.25	44286	4.16	2.54	0	14.25	37537	4.02	2.95	0
Ave. Project Duration	107658	212.01	158.55	0	1218.75	44775	280.24	143.98	0	1218.75	39724	222.98	129.33	0

These results are corroborated by the panel data estimates which show corresponding increases of $3,400 and $1,900 in revenue output per month (see Model 2). A one unit increase in ESS Skill is associated with approximately $26,000 greater annual revenue output and $2,700 greater revenue output in monthly panel data estimates. However, to our surprise, we also found that our IT and information flow variables were not correlated with reductions in project duration, but instead were correlated with longer project duration on average (in some specifications these results were even statistically significant). While IT seemed to help individual workers bring more revenue to the firm, it was not simply speeding up their work.

6. Discussion and Conclusion

To date, most important advances in assessing IT business value were achieved through the use of more sophisticated econometric methods or more comprehensive firm-level and plant-level data. In con- trast, our research seeks to open two new frontiers: (1) objective measures of information flows through social networks, and (2) detailed task-level evidence of information worker output. This approach pro- vides a higher resolution microscope with which to study organizational phenomena, revealing finer grained relationships than would be possible with any amount of firm, industry, or country-level data.

Three contributions result from this approach. First, we show that information work can, in fact, be measured with great precision. We identified a context with objective performance metrics, built tools to directly observe behaviors and information flows in email, and gathered independent data on project quality controls. Our analyses of these data produce precise estimates of the productivity of information workers and reveal underlying production and interaction relationships. While information work has often defied measurement in the past, we found it remarkably quantifiable in this setting.

Second, when we apply social network analysis to our email data, we find that position and flow are critically important. Recruiters with diverse social networks and high betweenness centrality generate more revenue than their peers. Betweenness centrality and network diversity also show positive associa- tions with ability to multitask, as do in-degree, out-degree, and network size. Among information work- ers, it pays to be a communications broker. Peripheral employees outside the communication flow work on fewer projects per unit time. The total volume of communication is also statistically significant as is network constraint, demonstrating that constrained networks and redundant contacts correspond to less multitasking. An implication of these results for managers is that untangling social networks through stra-tegic job rotation could lead to more efficient multitasking. We also find that richer information flows alone do not necessarily increase the speed with which individuals complete projects. Central information brokers boost their productivity by multitasking more effectively rather than by working faster.

Finally, we build and validate multitasking and hazard rate models of project completions at both individual and team levels. These models highlight intermediate production processes and directly ex- plore the association between using technology, juggling more tasks, and the ability to complete tasks faster. We find that individual differences in IT use behaviors correspond with differences in perform- ance. On average, workers using more asynchronous email and database tools handle substantially more projects simultaneously. In contrast, traditional synchronous communication modes such as phone calls correlate with less multitasking. Further, there were speed implications. People who multitasked heavily benefited from also using the ESS heavily to speed their work, enabling them to complete more projects per unit time, although the benefits of multitasking decreased after a point. These results, together with the survey data, imply that targeted ESS training could improve speed and thus firm performance.

In sum, we find substantial correspondence among information, technology, and output in this setting. It is not just having IT but how one uses it that predicts differences in performance. In particular, our approach demonstrates how email flows reveal how social network structures affect business per- formance. Tools and techniques developed during this research can be readily applied to other project- level information work involving email and databases including sales, consulting, law, medicine, software development, banking, insurance, and architecture, among others. This portends a substantial improve- ment in our

understanding of the relationships among information flows, technology, and value creation.

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