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Assessing the Impact of Communication Cost on Worker Productivity: An Individual Level Examination of the Productivity Paradox

by

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Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Fuqua School of Business in the Graduate School of Duke University

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ABSTRACT

(Business – Management)

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Abstract

Most corporations believe that adding computers to their organizations make individuals more productive. However, documenting increases in productivity remains elusive. This paper attempts to explain the resulting “productivity paradox” in terms of communication costs at the individuals level. The basic notion is as follows: Computer networks increase the amount of communication between organizational members by reducing communication costs. Increased communication generates an increase in the number of tasks organizational members are asked to perform. Individuals then become overworked and attempt to perform their own work using fairly simple cognitive rule, termed production systems. Simple production systems are, in general, less accurate. Reduced accuracy causes work to be redone, thereby decreasing the productivity of the individual. Two experiments were conducted to examine the role of communication cost on productivity. Results of the experiments show that, in general, communication cost does affect accuracy and number of attempts required to complete a task. Further, cost operationalized as either monetary or social costs have similar effects on productivity.

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At Duke, I must thank my committee chair, Gerry DeSanctis. I tell everyone that she is the best. And she is. I could not imagine anyone more supportive on every level. Thanks to my other committee members, Chip Heath, Daniel Gigone, Rich Burton, and Karen Cook for their comments and advice.

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I would like to thank my friends in the Duke University Behavioral Lab, Kristin, Jonathan, Gal, and Marlene. The place should have been called the Misbehavioral Lab. It was a great intellectual environment and a lot of fun. I am going to miss the camaraderie. Finally, I would like to thank my girlfriend, Virginia Fay. She has been a constant source of love, joy, support and better sentence structure.

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Chapter 1

Introduction

The most fundamental question when upgrading an organization's information infrastructure is, "Will this expenditure be worth the increase in productivity?" High level managers and industry observers have found a fundamental disconnect between the amount of money spent on information technologies (IT) and the expected productivity gains (Roach, 1991; Grover, Teng, Segars, & Fiedler, 1998; Pinsonneault & Rivard, 1998; See Brynjolfsson & Yang, 1996, for an excellent literature review). Jorgenson & Stiroh (1995), for example, found that while increases in worker productivity had decreased to about .5 percent per anum, capital expenditures of computer related products increased by 12 percent per year. Much of the literature indicates that productivity and capital expenditures on computers are not closely correlated.

The lack of a direct correlation between corporate spending on information technology and productivity has been termed the "productivity paradox" (Roach, 1987). The productivity paradox has been examined by a number of researchers, but the causal mechanism remains largely unresolved. This phenomena was first observed by Steven Roach (1987, 1991, 1992). Roach noted that while IT was increasingly ubiquitous in the service sector, productivity remained flat. This finding has been generalized to a number of other sectors, including manufacturing.

The resulting productivity paradox has led researchers to focus on the possibility that productivity was simply being incorrectly measured, or that the expenditures on information technology were too small, relative to other capital investments (Griliches, 1995; Brynjoslfsson & Hitt, 1996, 1998, Baily & Gordon, 1988). Recently, attention has shifted to developing a more macro-level contingency theory argument. Contingency theorists have identified a number of situations where investment in information technologies does increase productivity. Brynjolfsson and Hitt (1998), for example, have found that information technology impacts productivity only when they occur concomitantly with changes in other business investment. Other research (Brynjolfsson & Hitt, 1995, 1996) has shown that productivity is affected by IT expenditures, but that such effects occur only at the firm level, not at the macro-level of the nations economy. Nonetheless, the productivity paradox and its causes are still hotly debated.

Most current research has examined macro-level phenomena. While this approach is starting to bear fruit, I suggest that part of the explanation of the productivity paradox can be found at the individual level of analysis. In order to build on the current understanding of the productivity paradox, I stress cognitive factors and information processing. I then couple these cognitive factors with notions of organizational information processing, productivity, and communication cost.

In this paper, I propose one possible explanation for unrealized productivity gains - an explanation grounded in the cost of information at the level of the individual. While lowered communication costs increases the ability of organizations to share knowledge and take advantage of division of labor, it may have unintended, individual level consequences. My thesis is that communication cost plays two critical roles in the use of information: communication cost affects both how information is acquired and how information is processed. These themes are more fully developed below.

First, as communication costs decrease, individuals will be more likely to ask others for information. To the extent that information is cheap to obtain, individuals will tend to increase their consumption of information. Lower communication costs will then increase the amount of information organizational members must provide, thereby increasing their amount of work. In this case, decreasing communication costs might actually increase the amount of work that each individual must accomplished. Information technologies are implemented to increase organizational efficiencies. In this scenario, the organization must perform more work, not less. In this way, investments in IT can actually decrease productivity.

Second, the relatively cheap access to information reduces the incentive for individuals to think carefully about information currently in their possession. Thus, the amount of effort individuals invest in analyzing a given piece of data decreases. In this case, individuals are substituting information for information processing. To the extent that the individuals require more information and spend time more processing the information, productivity is reduced.

I argue that cost of communication may have a profound impact on how individuals utilize information technologies and in turn, impacts productivity. I hope to provide partial answers to three questions: 1) Does reduction of communication costs have a negative or positive influence on productivity? 2) What are the processes by which communication costs affect productivity? and 3) Are these processes sensitive to the types of communication costs imposed?

The paper takes the following format. First, I summarize some of the relevant literature, including research on the productivity paradox, communication costs, productivity, and organizational and individual information processing. Second, I discuss the theoretical models of information processing, and productivity used in the dissertation and make a series of propositions based on these models. Third, I discuss specific hypotheses and develop an experiment used to test the hypotheses in a hierarchical organizational form. Fourth, I discuss an experiment used to test the hypotheses in a flat organizational form. Fifth, I discuss some implications of this work for organizations and some possible boundary conditions. Finally, I summarize the paper's contribution to the management literature.

Chapter 2

Literature review

In this section, I introduce some of the literature that I will draw on for theory development. This section is motivated by the notion that the productivity paradox can, in part, be explained at the individual level using psychological constructs. Most of my theory relies on cognitive constructs and related research into human information processing and problem solving. The literature review section provides a general overview of this research and ties the literature to the theory presented in the next chapter. Each of the core constructs mentioned during the dissertation is presented in italics. Operationalizations of these constructs are capitalized.

This chapter takes three parts. First, I discuss cognition and information processing at the individual level. Second, I discuss the effect of communication costs and increasing the amount of information processing requirements, or information overload, on individual level information processing. Third, I discuss information processing at the organizational level.

Cognition and individual information processing

Business disciplines such as organizational information processing (Jin & Levitt, 1996) and organizational cognition (Walsh, 1995 for a review) have found it helpful to adapt information processing theories from cognitive psychology. Information processing theories are based on the notion that the human mind is a device similar to a computer. When presented with some input stimuli or situation (e.g., identify a color, alphabetize a list, value a company), the mind executes a given set of operations or actions. Put in an organizational context, these inputs can be thought of as tasks required of individuals in an organization. The resulting output may be either some internal state (i.e., emotive, thinking, problem solving) or some external behavior (i.e., walking). Once again, in an organizational context, the outputs may be thought of as completed tasks. Information processing provides a useful perspective in understanding how individuals perform their tasks and their resultant productivity.

The information processing paradigm emerged from research on how individuals develop skills and acquire knowledge (Broadbent, 1958). Information processing research assumes that mental operations can be broken down into discrete tasks that can be executed sequentially. Researchers in this paradigm develop models that specify the mental operations individuals use when performing a task and their order of execution (J. Anderson, 1983; Newell & Simon, 1972; Schank & Abelson, 1977). This perspective allows researchers to specify the processes individuals use when engaged in work and to derive individual and organizational level predictions from these processes.

Two of the early information processing theorists, Newell & Simon (1972), broke down the individual's cognitive processes into small discrete mental operations termed elementary information processes (EIPs). EIPs are a specific set of instructions that can be used to solve a problem such as basic arithmetic (addition, subtraction) or logical operators (and, or, equals). Individuals simply string together EIPs to form complex "production rules." These production rules represent the knowledge individuals use to perform tasks; they represent how individuals work. Thus, productivity is a direct function of production rule selection.

Interestingly, individuals do not always select the "best" production systems for a task. Instead, production rule selection has been shown to be contingent on a number of environmental factors (Payne, Bettman, & Johnson, 1993)[1]. In particular, individuals will vary the complexity of their production systems based on factors such as opportunity costs and complexity of the initial problem. In cases where opportunity costs are high or problems are complex, individuals select simple production rules as a way to conserve cognitive effort. In turn, *production rule complexity* has been shown to affect the accuracy of individuals involved in decision tasks (Payne, Bettman, & Johnson, 1993). In general, less complexity leads to less accurate decision making and problem solving.

It is clear that individuals respond to environmental factors and these factors affect production rule selection. Understanding the role of these environmental factors in production rule selection is critical in understanding the impact of environmental factors on productivity.

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[1] Payne, Bettman & Johnson use the term decision rules to denote what cognitive psychologists call production rules. The terms are isomorphic.

One of the primary reasons organizations adopt IT is to control information or communication costs. In the next section, I discuss information/communication cost as an environmental factor. I then discuss one consequence of decreased communication cost; information overload.

Information overload and Communication costs

Managers often cite reduction of communication costs as the main reason for IT implementations. They believe that reduced communication costs will lead to increased knowledge sharing. Thus, more communication is better. Research on information overload, however, contends that individuals can be overwhelmed by information. Information overload may lead to information processing problems. This problem of information overload maybe exacerbated by reducing communication costs; as communication costs decrease, amount of communication increases, leading to an increase in information processing demands. Unfortunately, individuals' information processing capabilities are limited by human cognitive abilities. In this section, I review some of the literature on communication costs and information overload.

Cost of information has been an active area of interest for both practitioners and theorists. In terms of IT, one of the primary reasons given for the introduction of organization wide information systems (e.g., email, WWW access, SAP) is that they offer managers a method of manipulating communication costs (Marschank & Radner, 1972; Radner, 1992, 1993; Van Zandt, 1990; Radner & Van Zandt, 1992). Further, researchers in a number of fields, including organizational theory, decision making, and economics, have shown that costs for information affect the way individuals process and acquire information (Payne, Bettman, & Johnson, 1993; Gregan-Paxton & Roedder John, 1995; Bolton & Dewatripont, 1994).

Organizational theorists have also been concerned with the cost of communication and its affect on centrality. The basic argument is as communication costs decrease, knowledge sharing becomes easier. Thus, the advantages of a decentralized organizational structure decrease as central control becomes feasible (Malone & Crowston, 1994; Brynjolfsson et al., 1989; Hagstrom, 1991). Information technology implementations have been shown to lead to flatter, less hierarchical organizational structures. It is not clear, however, that organizations with fewer operational layers are less centralized. Bolton & Dewatripont (1994) note that a reduction in layers allows for larger spans of control and may actually indicate a more centralized firm.

While macro level organizational theorists and economists have been concerned with the role of communication costs in organizational design, psychologists have examined the role of monitized costs on individual decision making (Gilliland, Schmitt, & Wood, 1993; Gregan-Paxton & Roedder John, 1995; Payne, Bettman and Johnson, 1993). Researchers have concluded that higher information costs leads to selection of simpler production systems. The logic goes as follows: when faced with costs for information, individuals attempt to minimize the amount of information required to make a decision. In order to minimize costs, they select production systems that do not require large quantities of information and thus, are simpler to execute. Payne, et. al. (1993), show that selection of simple production systems leads to less accurate choices. To summarize, when individuals must pay for information, they tend to use simpler and less accurate production systems (e.g., decision rules) when making a decision.

Most of the psychological research on communication or information costs involves participants exchanging some currency for data. These costs have taken a variety of forms, including money (Payne, Bettman, & Johnson, 1993) and candy (Gregan-Paxton & Roedder John, 1995). In an attempt to minimize costs, participants select production systems that minimize *information demands*. Thus, charging for information can influence production rule selection. When information is expensive, individuals select production systems that minimize data requirements. The literature has little to say regarding the effect of cheap information. It is possible that costless information will lead individuals to select production systems that are inefficient in their use of data. I explore this possibility more fully in the next chapter.

While communication costs affect individual's demands for information, there is literature that speaks to the effect of too much information on problem solving and decision making. Much of the recent work in this area is of the positive bent, examining how to reduce information overload by aggregation or filtering (Berghel, 1997; Pransky, 1995). Marketing behaviorists have examined the effect of information overload on consumers, but their results are equivocal and hotly debated (Jacoby, 1984; Malholtra, 1984; Keller & Staelin, 1989; Meyer & Johnson, 1989).

Psychological research has shown that individuals memory is biased under conditions of information overload (Bargh, 1986). Recall performance has also been shown to be worse under conditions of overload (Peavler, 1974). Although Payne (1993) and his colleagues do not explicitly discuss the case of information overload, they find that as the amount of information available to decision-makers increases, individuals select simpler, less accurate, production systems.

Organizational information processing.

Organizational information processing research treats organizations as aggregations of individual information processors. Organizational information processing is derived from the work of Simon (1955) and more recently, Galbraith (1973, 1977) and Nadler & Tushman (1988). These authors explain organizational design decisions in terms of the information processing requirements of the organization based on competitive environments.

Galbraith (1973, 1977), for example, argues that organizations have a number of mechanisms at their disposal to facilitate information processing. These mechanisms include use of fixed, procedural rules (i.e., bureaucracy), organizational form, and goal setting. These tools allow the organization to manipulate the level of attention individuals need to give to information processing tasks and can be used to control attentional resources within the organization. Whereas Galbraith primarily focuses on the role of organizational structure on information processing, I am interested in the role of information technologies, their ability to reduce communication costs on organizational information processing, and the subsequent impact on individual productivity.

Other research on information processing has expanded its applications to team structures (Jin & Levitt, 1994) and use of personal vs. formal ties in information handling (Gilly, Stevenson, & Yale, 1991). Of the information processing frameworks that I have examined, perhaps Jin and Levitt (1994) provide the most cogent model of the processes. I present a summary of their model below.

The Jin and Levitt (1994) model views the individual in the organization as a decision-maker who gathers information, processes it, and comes to some conclusion (see Dukerich, Milliken, & Cowan, 1990, for another inbox-outbox type of model). Organizations are simply collections of these individuals. Other individuals, either inside or outside the organization, place tasks in the decision-maker's inbox. The decision-maker then probabilistically selects an item from the inbox to work on. Selection of an item is determined by length of time in the inbox as well as some task characteristics2. An individual stops working on an item when the task is completed, or when there is some kind of dependency that requires the decision-maker to pause. Information flows

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2 Jin and Levitt (1993) assume that selection is a function of priority and amount of time a task has spent in the inbox. This assumption, while based on empirical data, is not necessary for my theory and subsequent predictions.

along communication links that connect individuals in the organization. I treat their model as my primary touchstone for development of my own model of organization information processing.

The next chapter develops the theoretical underpinnings of the rest of the dissertation. Specifically, I develop an information processing and productivity model. A series of propositions are then derived from the models that are then tested in subsequent chapters.

Chapter 3

Theory

In this section, I develop models for both information processing and productivity. I then show how cost affects productivity at both the individual and group levels.

Information processing for the individual and the organization

Conceptually, the information-processing model is fairly straightforward. As presented in Figure 1, each individual in the organization has both an inbox and outbox. Items in the inbox represent the *information demands* from members of the organization. As with the Jin & Levitt model (1994), individuals select tasks from their inbox based on priority of the task and length of time spent in the inbox. Each task leads individuals toward a desired goal state and form the basic information processing routines used for organizational operation.

[Insert Figure 1 Here]

If individuals know how to perform the task selected, they do so. In the event individuals do not know how to do the task, they pause. They may then ask for instruction on the task by placing an information demand in the inbox of an individual with whom they have a communication link, or by trying to solve the problem themselves. Individuals ask for help based on a cost/benefit calculation. The greater the difference between costs and benefits, the more likely the individual will generate an information demand. If the first person approached does not respond to the information demand, the individual will repeat the process of link selection with the next least expensive link. This set of actions continues until either the individual receives an answer or costs are perceived as greater than the benefits. When the costs are larger than the benefits, the individual attempts to solve the problem themselves without making *information demands* on organizational members.

Assuming communication does take place, the receiver of the information requested begins the process of answering the request by putting it into her inbox, thereby increasing her available work. The process of answering the request then repeats from the point of selecting the task. That is, in order for the request to be fulfilled, the new individual must select the request from the inbox, decide that the benefits are greater than the costs, provide the information, and send information back to the organizational member who generated the information demand. Once a task is completed, it is placed in the outbox where it no longer consumes attention of the individual information processor.

Productivity

As noted, my main construct of interest is productivity. Rather than focus on productivity for a given economic sector or company, I examine productivity of *individuals* engaged in logic tasks. Such tasks are common in the economy and cut across all sectors.

Productivity has been traditionally defined as an end product: the amount of resources needed as input to produce a given level of output. The lower the level of inputs for a given level of output, the higher the productivity. This definition treats all output as equal with quantity being the determinant of productivity and masks the underlying factors that contribute to productivity. To the extent that productivity is driven by other factors, the simple input/output model makes the job of evaluating productivity more difficult.

I would like to suggest a slightly different productivity framework. In this framework, raw material and the amount of time needed to transform the raw material to a unit of output are added to the input side of the equation. In terms of measure output, a unit of output is gauged at a given level of quality. Thus, productivity is a function of three factors, 1)the amount of time and 2)materials needed to obtain one unit of output at a 3)given level of quality. I now expand on each of the three elements of productivity as they apply to logic tasks.

Inputs to logic tasks include time spent processing information and the actual information used to solve the task. Both *task time* and data are critical resources for logic tasks. The output is some kind of conclusion that solves the problem. The first input to the productivity model is the time spent processing the information. Processing time is a function of the production systems individuals use for the task. More complex production systems take longer to execute and, holding all else equal, reduce productivity[1]. I refer to the time spent processing information as *task time*. Note that *task time* is italicized. Throughout the rest of the dissertation, I shall italicize constructs but capitalize variables that operationalize the constructs.

The second input of productivity is information. In some sense, information is the raw material of logical tasks. Unfortunately, gathering information is never costless. For students, gathering information might require such costs as spending time in the library; for employees, trading favors; for employers, simply paying for data. In any case, data acquisition has an associated cost. The more data required for a task, the higher the cost. At the organizational context, asking for information impacts the productivity of two individuals. As discussed, the person asking for the data must spend time gathering the data. The productivity of the person sending the data is also affected; the respondent must spend resources answering the information demand. In general, the more information required, the less productive the individual. I refer to the amount of information requested by an individual as *information demands*.

The third component of productivity is the quality of completed tasks. In a logic problem, individuals can make multiple attempts to solve the task. The higher the quality level of the output, the fewer attempts it will take to solve the logic problem. Holding all else equal, higher quality leads to increased productivity. I refer to quality as *task accuracy*.

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1 As *task time* decreases, the number of tasks finished in a given amount of time increases.

To summarize, productivity has three related, but distinct components: *task time*, *information demands*, *and task accuracy*. In order to be productive, an individual or organization must be fast, able to minimize their information needs, and be accurate.

Productivity Model

In this section, I expand the productivity model to include task, cognitive, and organizational factors. Recall that the model of individual level information processing assumes that individuals use production systems, rules that dictate how an individual will perform a task. This assumption has consequences for productivity. Research by Payne, Bettman, & Johnson (1993) and others (See also Gilliland, Schmitt, & Wood, 1993) has shown that, in general, more complex production systems2 are more accurate. Complex production systems can take an increased number of factors into account when making a decision, thereby increasing the likelihood of an appropriate response.

Accuracy is primarily determined by the selection of complex production systems. However, more complex production systems take longer to execute. The more complex the production system, the fewer the number of tasks that can be executed in a given time frame. Payne and his colleagues have shown that individuals are sensitive to this tradeoff and will select complex rules when they need accurate results and simple rules when speed is paramount. In terms of productivity, increasing accuracy requires an increase in *task time*.

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2 Researchers in this area tend to use the term decision rules to indicate the production systems that individuals use to solve a decision problem. In this context, the terms are isomorphic.

This notion, that there is a tradeoff made between accuracy and task speed, is critical. The purpose of this dissertation is to examine the impact of costs of information on productivity. Figure 2 illustrates how cost and cognitive factors affect productivity. Each element of the model and its effect on productivity are discussed below.

[Insert Figure 2 Here]

I start the discussion from the cost box on the left-hand side of the productivity model. Cost of information has been shown to increase the complexity production rules selected for a given task (Payne, Bettman & Johnson, Gregan-Paxton & Roedder John, 1995). Individuals attempt to minimize these costs by selecting production systems that make efficient use of information already in their possession. This leads to the first proposition:

P1: Communication Cost is directly proportional to production rule complexity.

Production rule complexity affects *task time*, *task accuracy* and *information demands*. In terms of *task time*, the number of EIPs required to implement a production system is positively and closely correlated with implementation time. More complex production systems (those with a larger number of EIPs) have been shown to take longer to execute (Payne, Bettman, & Johnson, 1993). Thus, as *production rule complexity* increases, the amount of time required to execute the production system, or *task time*, should increase. Proposition two reflects the relationship between *production rule complexity* and *task time*:

P2: Production rule complexity is directly proportional to task time.

Production rule complexity has also been shown to be positively related to *task accuracy* (Payne, Bettman, & Johnson, 1993). More complex production systems can take an increased number of factors into account, thereby making more accurate choices. As costs increase *production rule complexity*, *task accuracy* should also increase. Proposition 3 makes the link between *production rule complexity* and *task accuracy* explicit.

P3: Production rule complexity is directly proportional to task accuracy.

Communication costs place a "tax" on acquisition of new information. One method of reducing the total cost of communication is for individuals to use information already in their possession more intelligently. More efficient use of existing information should lead to fewer *information demands*.

P4: Production rule complexity is inversely proportional to internal information demands.

The *information demands* of the organization also impact individual level productivity. As organizational members demand information, the amount of information supplied by a given organizational member increases. Every time information is supplied, the individual is interrupted while performing a task. Interruptions can have a profound effect on problem solving by removing important items from short term memory, thereby reducing an individuals information processing capacity.   Interruptions make it difficult to keep items in short-term memory. It can be shown that complex production systems make fairly intensive use of short-term memory. By contrast, simple production systems need relatively little short-term memory. Thus, as individuals must supply more information and interruptions increase, effective use of short-term memory becomes more difficult. As a consequence, *production rule complexity* should decrease. Proposition five formalizes the relationship between information supplied and *production rule complexity*.

P5: External information demands is inversely proportional to production rule complexity.

The final component of the model links the number of external *information demands* with *task time*. Each increase in *external information demands* cause individuals pause their current task and, at the very least, force the individual to make a decision whether they want to interrupt their current task and attend to the interruption. Making this decision takes time, increasing the *task time* for the individual's primary task. The effect of external task demands on *task time* increases if individuals decide to fully attend the interrupting task. Thus, as the number of interruptions increases, total *task time* increases.

Note that the number of interruptions has two competing effects on *task time*. First, interruptions lead to simpler production systems, decreasing the amount of time it takes to finish a task. Second, as individuals are interrupted, they must make decisions regarding attention and may perform two tasks at once, increasing the *task time* for the primary task. To simplify the argument, I only note that supplying information has two countervailing influences on *task time*; I make no predictions regarding the effect of information supplied on *task time*.

Two examples illustrating the productivity model might be helpful. In the first example, let us assume that communication costs are increasing. While it is tempting to think of costs in terms of money, the theory treats costs more generally. That is, costs can take a variety of forms: a few possible "currencies" include money, time (the old saw, time is money comes to mind), and social costs (i.e., fear of sanction). The direct effect of increasing communication costs would be for individuals to increase their production system complexity and use information more efficiently. In turn, *task time* and *task accuracy* should increase, while internal *information demands* decrease. While the task gets accomplished with less information and more accuracy, the time needed to perform the task increases. In terms of productivity, less information and increased accuracy is good for productivity. On the other hand, increased *task time* negatively impacts productivity.

In the second example, assume that organizational members have increased their demand for information. As information processing capacity decreases and *production rule complexity* goes down, *task time* should decrease. On the other hand, an increase in external *information demands* requires time to be attended to and perhaps worked on. The theory makes no clear prediction about the role of interruptions on *task time*. The theory is more developed in terms of *task accuracy* and task quantity. As external *information demands* increase, *production rule complexity* decreases. As *production rule complexity* decreases, *task accuracy* goes down while internal *information demands* increase. In terms of productivity, both *task accuracy* and *information demands* are predicted to be negatively effected by an increase in information supplied.

Chapter 4

Experiment 1

Introduction

The first experiment examines the effect of monetized communication costs and organizational *information demands* in a hierarchical organization. This chapter proceeds in five parts. I first sketch out the experimental task. Second, I operationalize the constructs and generate hypotheses that map onto the core propositions presented in the previous chapter. Third, I discuss an experimental design and manipulation used to test the effects of monetized costs. Fourth, I present the results from the experiment. Finally, I discuss the results.

Experimental Task

Game

The basic experimental task is based on the board game Mastermind^tm^. Mastermind^tm^ is a game of logic for two players. In the original game, one person selects a sequence of colored pegs and the other person has to guess the sequence. The game starts with one individual, termed the Master, selecting a series of 4 colored pegs. There are 4 colors to choose from: red, orange, yellow, and green[1]. The other individual, called the Mind, has up to eight chances to guess the exact sequence of the pegs. After each guess, the Master then compares the mind's guess to the correct peg sequence and provides feedback. The feedback indicates how many of the Mind's pegs match in terms of color and position of the correct sequence. Feedback is given by use of colored pegs. Providing a black peg indicates that a peg is the correct color and location. A white peg is used when a peg is the correct color, but in the wrong position.. It is important to note that the feedback does not indicate which of the colored pegs are correct. Instead, feedback only provides information regarding the quantity of correct pegs. The Mind must deduce the correct sequence over repeated guesses.

An example follows: Figure 3a shows a blank Mastermind[tm] board. Figure 3b shows the sequence of pegs selected by the Master, the initial guess by the Mind, and the resulting "correctness" of the guess. In this case, the Mind guessed yellow-red-red-yellow and got the color of one of the pegs, a red, correct. The second guess (figure 3c), yellow-yellow-yellow-yellow, is a simple attempt by the player to figure out which of the colors is correct. Since none of the pegs in the correct sequence were selected, none of the indicator pegs are used.

[1] Early on, it was clear that some of the experimental participants were marginally color-blind and mentioned that they had a difficult time distinguishing between yellow and green. In order to minimize the chance of color blindness affecting the ability of players to identify the colors, green was changed to blue. This change seemed to resolve any difficulties as no participant had problems with the task due to color blindness.

[Figures 3a-3f here]

In the third attempt (Figure 3d), the Mind guesses some of the other colors in the sequence while attempting to correctly locate the one red that she knows is in the Master's sequence. The Mind guessed red-orange-orange-orange. Two of the pegs are in the right position, the red and one of the oranges. Note that from the Mind's perspective, she does not know which orange is correct, only that one of the three is in the correct place.

By the fourth sequence (Figure 3e), the Mind assumes that the red is correct. In the first guess, one of the pegs was the correct color and with the second guess, she knew it was one of the reds. In the third guess, she correctly got the position of the red peg. If it had been wrong, she would have received a white feedback peg instead of a black one. She decides to start all subsequent attempts with a red peg. The sequence guessed in this round (Figure 3e) is red-green-green-orange. In addition to the black peg result from guessing the first peg color, she gets a black peg for one of the greens (although she does not know to which of the remaining pegs it refers) and two white pegs indicating that the other colors are correct. At this point, she knows the colors of the correct sequence, but not the position of each color.

In an attempt to find out which color was correct, the Mind exchanges the third peg, a green, with the fourth peg, an orange. The fifth guess, Figure 3f, shows the change. The Mind still has two pegs in the correct position, and the other two colors are correct. Finally, in Figure 3g the Mind moves the orange peg over another slot and exchanges it with the green in the second position. All of the Mind's pegs now match the Master's selected sequence and the game is over. In this case, the Mind as won the game. If the Mind had not guessed correctly by the eighth guess, the Master would have won.

Organizational Design

The first experiment grouped three individuals together in a hierarchical organizational structure. Two players were at the lowest part of the structure and charged with being the Mind in repeated trials of Mastermind[tm]. They are referred to throughout this chapter as players one and two. The third player is the Master to the first two players and is herself playing a game as the Mind. In addition, there is a fourth actor, the computer, acting as the Master for player three. A graphical representation of the organization and the tasks performed by each player is shown in Figure 4. Note that only player three, indicated in the middle of the figure, plays the role of both Master and Mind. Rather than refer to players by Master and Mind, I will use the labels provided on Figure 4, Players one, two and three.

[Insert Figure 4 here]

There are several differences between the experimental task and the original Mastermind[tm] game. First, rather than have the Masters select the sequence, the order and color of the pegs was randomly generated. This randomization was only done once for the experiment. Thus, the peg sequences for a given player number were the same across experimental groups. Further, the order of the peg sequences was consistent across experimental groups. Second, the number of guesses in each game will not be limited to eight; instead, Minds will be allowed to make as many guesses as they wish[2].

The experimental organization will be asked to play 10 games. Participants will be paid according to the speed with which they complete this task. The incentive structure provides encouragement for individuals to do the work efficiently and accurately. In contrast to the single player version of the game, where the individual is only concerned with accuracy, the group version of the game requires players to play quickly *and* correctly.

Measures and operationalized hypotheses

This section serves two purposes. First, it describes testable hypotheses that map onto the constructs in the core propositions. Second, it operationalizes the variables used to test the hypotheses.

The first core proposition addresses the effect of cost on *production rule complexity*. Proposition 1 states that higher cost leads to selection of more complex production systems. Unfortunately, *production rule complexity* is an unobserved variable. One of the persistent problems in cognitive research is that there are no direct measures for measuring the complexity of individual production systems. Researchers

[2] If the experimental task limited the number of guesses per game to eight, any measure of the number of guesses , a key measure discussed later, would have restricted variance. By allowing participants an infinite number of guesses, the variance is no longer restricted.

have developed two indirect methods, verbal protocols and use of timing data, to infer production rule selection. Verbal protocols, while providing rich data, are difficult to code and analyze. In addition, the researcher makes the assumption that participants can accurately verbalize what they are thinking and that the data collection process does not affect the execution of the task (see Ericsson and Simon, 1984 for a detailed examination of process tracing).

Timing measures, while not as rich as verbal protocols, provide a simple and unobtrusive measure of production system complexity. Timing data measures how long individuals spend on tasks. As individuals select increasingly complex production systems, the time it takes to execute the production systems increases (Payne, Bettman, & Johnson, 1993). Proposition two makes the link between *production rule complexity* and *task time*. In order to measure the complexity of the production systems, the average amount of time between the Mind receiving feedback and the making a guess is recorded. Complex production systems should take longer to execute, and increase *task time*. Thus, *task time* increases with communication costs.

Average Time per Guess is used to operationalize *task time*. Average Time per Guess is simply the average amount of time it take a participant to make a guess for a given trial and is a within subject factor.

H1: Task time increases with communication costs.

Core proposition three states that *production rule complexity* is proportionally related to *task accuracy*. As noted, *production rule complexity* is an unobserved variable but its effect can be observed through other constructs, such as *task accuracy*. To the extent that *task accuracy* is increased by *production rule complexity*, *task accuracy* should increase. *Task accuracy* is operationalized as the average number of feedback pegs per trial, termed Guess Accuracy.

In terms of specific hypotheses, Cost is predicted to lead to an increase in *production rule complexity*. Thus, Guess Accuracy should increase with cost. H2 can be stated as follows:

H2: Guess Accuracy should increase with cost.

Core proposition four states that *production rule complexity* is inversely proportional to Internal *Information demands*. As *production rule complexity* increases, individuals are predicted to require less information as they use their existing information more efficiently. The Number of Guesses per game serves as a direct measure of Internal *Information demands*. Hypothesis three predicts that increasing cost will decrease *information demands*. H3 can be formally stated as follows:

H3: Communication costs decreases Number of Guesses.

The first three hypotheses addressed the effect of cost on *task time*, *task accuracy* and Number of Guesses. The next two hypotheses predict the relationship of external *information demands* on *task accuracy* and Number of Guesses. Note that I make no predictions regarding the effect of external *information demands* on *task time*. External *information demands* has both a positive and negative influence on *task time*. No clear predictions are possible.

External *information demands* reflect the number of times an individual is interrupted by another organizational member wanting feedback. This variable is referred to as Feedback Demand. Core proposition five states that external *information demands* are inversely proportional to *production rule complexity*. As noted earlier, *production rule complexity* is proportionally related to *task accuracy*. Thus:

H4: Feedback Demands will decrease Guess Accuracy.

The last hypothesis predicts the relationship between external and internal *information demands*. Specifically, as external *information demands* increase, internal information demands should also increase. Once again, internal *information demands* are operationalized as number of guesses per game.

H5: Feedback Demands increases Number of Guesses.

Experiment 1

Design

Experiment one was designed to test hypotheses one through five. This section describes the experimental procedure. Each experimental session required three individuals, termed a group. Participants were recruited from two different undergraduate classes on the campus of a prestigious southeastern university. Participants were asked to organize a group of three people and arrange a time that the whole group could come to the lab. Participants who organized a group received five dollars for their trouble. A total of 14 groups were collected for the experiment.

Each group was assigned an experimental manipulation, either low or high cost. Every time the Mind made a guess, she was, in effect, initiating a communication. She asked the Master if she got the correct sequence, and if not, to provide feedback as to how close the guess is to the correct sequence. The method used to manipulate costs was by simply charging Minds to communicate with the Masters.

Participants in both the high and low cost groups were given a $15 budget for purchase of time and information. In the high cost manipulation, five cents was deducted from a participant's budget after each guess. The 15 dollar budget corresponds to 300 guesses3. In terms of time cost, as the average experiment time went above 45 minutes, each member of the group had 50 cents removed from their budget. Participants in the low cost group received feedback for free.

Individuals within the group were also randomly assigned to roles. Roles correspond to task assignment illustrated in Figure 4; they could have been either Minds or Master/ Minds. The factors in the experiment are Cost, Role, and Trial Number.

Participants were each shown to a small room with a computer. No communication between the players was possible, except through the guesses made in the

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3 Although pre-testing shows that no individual has taken more than 26 guesses to deduce a single sequence, the average number of guesses is 6.7. Given this rate, the average number of guesses for the entire experiment is 70, costing the participant $3.50.

game. Players are first asked to answer a short demographic questionnaire. This questionnaire provides some potential control variables, including demographics and need for cognition (Cacioppo, Petty, & Kao, 1984).

Each participant is then shown a computerized tutorial of Mastermind[tm] and a demonstration of the software, but not asked to play. This minimizes the ability of the participant to develop specific production systems until they actually play the game. Just before the game begins, participants are informed how their payoffs are determined (i.e., by the groups average amount of time to complete the experiment and, for participants in the high cost condition, the number of guesses they make during the game).

Participants are then given access to the game, instructed that that they must complete 10 games and left alone. After finishing their last game, all participants are given a short series of questions concerning how they felt about the task. These questions were designed to be covariates for the analysis. A list of these questions can be found in Appendix A. Once these questions are answered, the study ends. Participants are then paid in accordance with their task performance, and given a debriefing statement.

Results for Experiment 1

Tables 1 shows the means of the dependant measures broken out by cost. Hypothesis one states that an increase in communication costs will lead to an increase in Average Time per Guess. That is, when faced with higher communication costs, individuals will use increasingly complex production systems as a way of minimizing those costs. Complex production systems take longer to implement, thereby increasing Average Time per Guess.

[Insert Table 1 Here]

In terms of the ANOVA analysis, the level of analysis is at the group level. Table 2 shows the results of the analysis. Cost significantly predicted Average Time per Guess. Individuals in the Low Cost condition spent 20.14 seconds per guess while those in the High Cost conditions took 28.7 seconds. The difference between the two conditions is significant ($F_{(1,36)}=11.62$, $p=0.0016$). The evidence shows that higher costs lead to more time spent per guess and is consistent with the theory; H1 is supported. Both Trial Number and Role by Trial interaction were also significant ($F_{(9,323)}=8.46$, $p=0.0001$, $F_{(18,323)}=2.46$, $p=0.0004$, respectively). As trials progressed, subjects tend to get faster and more accurate. Thus, the main effect for trial on guess time can be interpreted as a simple learning effect; they learned to implement decision rules faster. As noted, Role is confounded with the peg sequences. Thus, any interaction including Role is not really interpretable.

[Insert Table 2 Here]

Ideally, each of the analyses would perform joint tests of Communication Cost and Feedback Demands on the dependant variable. Such an analysis greatly reduces the sample size and is not practical. Player three was the only one of the three organizational member faced with varying Feedback demands. In order to run the analysis, players one and two must be excluded from the analysis; their level of Feedback Demands is zero and is perfectly collinear with their roles. Testing the joint effect of Cost and Feedback Demands reduces the sample size to one third of the total subjects and limits the results to Player 3. The first ANOVA tests for the effect of cost on the full sample. The second ANOVA includes both Cost and Feedback Demands with the reduced sample.

Hypothesis 2 predicts that increasing Communication Cost will increase Guess Accuracy. The Analysis of Variance is presented in Table 3. Individuals in the high cost condition were more accurate than those in the low cost conditions ($\bar{x}_{low} = 2.52$ vs. $\bar{x}_{high} = 2.62$ correct pegs per guess). The difference between the groups was not a significant ($F_{(1,36)}=1.29$, $p=0.2631$). H2 was not supported. Trial was a significant predictor of Guess Accuracy ($F_{(9.324)}=9.93$, $p=0.0001$), with individuals accuracy increasing as the trials progressed. Trial by Role was significant ($F_{(18,324)}=5.88$, $p=0.0023$), but not theoretically meaningful.

[Insert Table 3 Here]

Hypothesis 4 predicts that increased Feedback Demands will lead to decreased Guess Accuracy. The Analysis of Variance is presented in Table 4. Given the small sample size, experimental power is reduced accordingly.

The ANOVA results show that Feedback Demands was not a significant predictor of Guess Accuracy ($F_{(1,106)}=1.45$, $p=0.2313$). H4 was not supported. Only Trial Number was significant ($F_{(9,106)}$=6.79, p=0.0001), with participants Guess Accuracy increasing with Trial Number.

[Insert Table 4 Here]

Hypothesis 3 predicts that Communication Costs and Number of Guesses are inversely related. The Analysis of Variance s presented in Table 5. As predicted, Cost was a significant predictor of Number of Guesses ($F_{(1,320)}$=7.26, p=0.0106). H3 was supported. Individuals in the High Cost condition made 2 fewer guesses than individuals in the Low Cost condition ($\bar{x}_{low} = 9.17$ vs. $\bar{x}_{high} = 7.17$ guesses). Both Trial and Trial by Role were significant ($F_{(9,324)}$=1.99, p=0.0397, and $F_{(18,324)}$=2.72, p=0.0002, respectively).

[Insert Table 5 Here]

Hypothesis 5 predicts that an increase in Feedback Demands will increase Number of Guesses. Once again, testing effects of Feedback Demands omits Players 1 and 2, leading to a fairly small sample. The Analysis of Variance is presented in Table 6. As predicted, the effect of Feedback Demands was highly significant ($F_{(1,106)}$=98.95, p=0.0001). The regression estimate indicates that a one unit increase in Feedback Demands increases the Number of Guesses by 0.51. H5 is supported. The interaction of Feedback Demands and Cost was significant ($F_{(1,102)}$=9.13, p=0.0031); the regression estimate shows that for individuals in the high cost condition, a one-unit increase in Feedback Demands increases Number of Guesses by .015.

[Insert Table 6 Here]

Discussion

Of the five hypotheses, three were supported. The results show that both Communication Cost and Feedback Demands significantly impacted Average Time per Guess and Number of Guesses. It seems that individuals in the high cost conditions were thinking harder and requiring fewer guesses to finish the task. Subjects in the High Cost condition were more accurate than those in the low cost condition, but these differences were small and not significant. In terms of productivity, increasing communication costs had a mixed effect. Less information was required, but *task time* was increased. Accuracy was unaffected.

As predicted by the theory, increasing Feedback Demands had the effect of increasing the amount of information individuals needed to finish the game. The theory made no predictions regarding the relationship between Feedback Demands and Guess Time. This relationship, while not predicted by theory, is interesting in the context of productivity. If Feedback Demands increases both Guess Time and Number of Guesses, its impact of productivity would be clearly negative. In fact, Feedback Demands significantly increase Guess Time by 1.93 seconds per demand ($F_{(1,102)}$=270.43, p=0.0001). This result indicates that the direct effect of Feedback Demands on Guess Time was stronger than the indirect effect through *production rule complexity*. The analysis of variance is presented in Table 7. It seems as though increasing Feedback

Demands reduced productivity by leading to both increased task time and increased Number of Guesses.

[Insert Table 7 Here]

Neither of the hypotheses relating to Guess Accuracy were supported. One problem is that Guess Accuracy has limited variance; it ranges from 0 to 4. The restricted variance of Guess Accuracy makes hypothesis testing difficult. In terms of productivity, neither communication cost nor external demands for information had any impact. The next chapter examines the effect of Communication Costs in a "Flat" organization; where information flow is not restricted.

Chapter 5

Experiment 2

Introduction

In response to rapidly changing environments, many real world organizations have been transitioning from hierarchical to flat organizational forms. One of the espoused benefits of flat organizations is that information can be distributed faster and more broadly, allowing organizations to make faster decisions and take better advantage of organizational knowledge. In order to facilitate information flow, flat organizations have increasingly been using information technologies to minimize the cost of information distribution.

Increased information flow is only one element that changes when organizations adopt "flat" forms. Other, less intended changes, also occur. For example, the types of interpersonal relationships between individuals in the organization may shift as different organizational forms are adopted. Additionally, organizational form influences the amount of cognitive effort required in managing information flow. Each of these themes are more fully developed below.

In terms of interpersonal relations, individuals in hierarchical organizations are more likely to be in superior-subordinate relationships. By contrast, a flat organization tends to put people in peer-peer relationships. In superior-subordinate, individuals are expected to ask questions. The "social cost" of asking a question is low. By contrast, individuals in the peer-peer relationships are equals. There is no expectation that they will need to exchange information. They might do so based on norms of reciprocity, but the relationship does not explicitly entail fulfillment of information requests. Answering a question is more in the nature of a favor and the cost of asking a question is increased. I would argue that the social cost of asking for information is higher for individuals when the relationship is peer-peer. Further, that individuals will treat social costs in the same way individuals in the first experiment treated monetary costs.

Organizational form also influences the cost of managing information flow. In hierarchical organizations, the cost of deciding who receives information and is responsible for asking questions is well defined. These organizations have well defined paths for information. By restricting individuals can acquire information, the cognitive costs for making information acquisition decisions are low. By contrast, flat organizations remove those restrictions in information flow. In order to request information, individuals in flat organizations must decide *who* to ask. This "who" decision increase the amount of cognitive effort required to gather information. In effect, the "cognitive cost" is increased in a flat organization.

In order to assess the effects of social and cognitive costs, a second experiment was run using a "flat" organizational form. The goal of the second experiment was twofold. First, to the extent that each of the factors react similarly in the two experiments, the theory gains generalizability across organizational forms. Second, by combining and comparing the datasets from both experiments, the effects of social and cognitive costs can be evaluated.

This chapter proceeds in five parts. First, I discuss the hypotheses for the experiment. Second, I explain how the design of the Experiment 2 differs from that of Experiment 1. Third, I explain the results of the second experiment. Fourth, I present the results from the combined analysis. Finally, I discuss the implications of the combined experiment.

Hypotheses

In general, the communication cost hypotheses generated for the hierarchical organization used in Experiment 1 should hold for the flat organization used in Experiment 2. Communication Cost should increase Average Guess Time and Guess Accuracy while decreasing Number of Guesses. Feedback Demands should increase Number of Guesses while decreasing Guess Accuracy.

In terms of the effect of organizational design, I have already speculated that individuals in flat organizations incur higher social and cognitive costs when communicating with organizational members. Both types of costs were minimized in the first experiment in that the participants were isolated from the consequences of making bad guesses. The organizational structure was a hierarchy; each Player could submit guesses to one other actor (Player 3) and that actor was obligated to respond. In the second experiment, each Player can submit a guess to either (but not both) of the other two Players. The second experiment utilizes an organizational design with the participants in the role of peers. As peers, individuals must be more concerned with how they treat their colleagues. At the most basic level, the relationship is reciprocal. Peers can choose to not provide timely feedback or to be less thoughtful in their guesses, in response to such behavior by others. Further, individuals in flat organizations has the option to communicate with two sources of feedback. The flat organization condition increases the cognitive demands of individuals by requiring them to select a source for feedback. The fundamental point social and cognitive cost of communication are higher for an organization of peers that for individuals in a hierarchical organization. Rather than refer to both cognitive and social cost, individuals in the flat organization will simply be called the "High Social Cost" condition.

As with monetary costs, individuals faced with higher social cost respond similarly to those faced with higher monetary costs. That is, they will select more complex decision rules, spend more time on tasks, be more accurate, and make fewer guesses. The hypotheses regarding social cost and organizational design are more formally stated below:

H7: Average Time per Guess will be higher for individuals in the flat organization.

H8: Guess Accuracy will be higher for individuals in the flat organization.

H9: Number of Guesses will be lower for individuals in the flat organization.

The next section discusses the design of the second experiment.

Design

The second experiment is very similar to the first experiment. The only difference between the two experiments is that the organizational design differed. Figure 5 shows the organizational design for the second experiment.

[Insert Figure 5 Here]

There is one important consequence of changing the organizational structure to a flat design: the computer no longer provides feedback to Player 3. Instead, feedback to Player Three is provided by the other members of the organization. While this design maximizes social costs by allowing other Players to be punitive, it also changes the amount of feedback that organizational members can be expected to deliver. The amount of feedback that Players One and Two provide is raised, from none to some, while the amount of feedback that Player Three must provide decreases, from all to some. In addition, the total amount of feedback that the organization must provide increases as the computer is no longer used to answer Player Three's requests.

Once again, half of the groups in this experiment were charged in monetary costs for guessing a peg sequence. In terms of predictions for this experiment, I expect that individuals in both groups will react very similarly to individuals in the High Cost condition in Experiment One.

Results for experiment 2

The results for H1 were very similar to the first experiment. Table 8 presents the means of the dependant variables broken out by Communication Cost. In the first experiment, the effect of Feedback Demands and Communication Cost were tested separately. Recall that Players 1 and 2 were excluded from the joint Cost/Feedback Demands analysis; they did not have any external Feedback Demands. In this experiment, all individuals could be asked to provide feedback and are included in the analysis. Thus, it was possible to test simultaneously test the effect of Communication Cost and Feedback Demands.

The ANOVA testing hypothesis one is presented in Table 9. Average Time per Guess was significantly predicted by Communication Cost ($F_{(1,30)}$= 5.87, p=0.0216). As predicted, individuals in the High Communication Cost condition spent 9.78 more seconds making a guess than individuals in the Low Communication Cost condition ($\bar{x}_{low} = 26.42$ vs. $\bar{x}_{high} = 36.20$ seconds). Feedback Demands were also a significant predictor of Average Time per Guess ($F_{(1,349)}$=196.23, p=0.0001). Each unit increase in Feedback Demands increased Average Time per Guess by 2.22 seconds. Hypothesis One was supported for both hierarchical and flat organizations. Further, in a flat organization, productivity was negatively impacted by an increase in external Feedback Demands.

[Insert Table 8 Here]

[Insert Table 9 Here]

The interaction between Cost and Feedback Demands was significant ($F_{(1,330)}$= 5.46,p=0.0201). The regression estimate indicates that the effect of Feedback Demands on those in the high Communication Cost condition is reduced by -.85 seconds per unit. Trial and Feedback Demands by Trial were also significant ($F_{(9,330)}$=5.03, p=0.0001 and $F_{(9,330)}$=2.72, p=0.0045, respectively).

Hypothesis Two predicted that Guess Accuracy would increase with Communication Cost. Hypothesis Four predicted that Guess Accuracy would decrease with Feedback Demands. The ANOVA designed to test the two hypotheses is presented in Table 10.

[Insert Table 10 Here]

In the previous experiment, neither Cost nor Feedback Demands predicted Guess Accuracy. Individuals in the High Communication Cost condition were more accurate ($\bar{x}_{low} = 2.69$ vs. $\bar{x}_{high} = 2.73$), but the differences between the two groups were small and not significant ($F_{(1,30)}$=.36, p=0.5549). Feedback Demands was a marginal predictor of Guess Accuracy ($F_{(1,358)}$=3.51, p=0.0618). Counter to theory, each additional request for feedback increased accuracy by .0.0034 pegs. The effect was very small and I assume it is spurious. Trial Number was significant ($F_{(9,330)}$=8.07, p=0.0001) with Guess Accuracy decreasing by .006 pegs per trial. Feedback Demands by Role and Feedback Demands by Trial Number were significant ($F_{(2,330)}$=3.24, p=0.0404 and $F_{(9,330)}$=4.29, p=0.0001, respectively). Finally, the Trial Number by Role interaction was significant ($F_{(9,330)}$=5.02, p=0.0001).

In the first experiment, Number of Guesses significantly decreased with cost and significantly increased with Feedback Demands. In the second experiment cost had no effect on Number of Guesses ($F_{(1,39)}$=.52, p=0.4769). As predicted, Feedback Demands was a strong predictor of Number of Guesses ($F_{(1,358)}$=420.26, p=0.0001). Each additional request for feedback increased the Number of Guesses required to finish a game by 0.43 guesses. The interaction of Feedback Demands and Cost was significant ($F_{(1,358)}$=11.68, p=0.0007). Each request for feedback for individuals in the high cost condition had an additional effect of subtracting .17 from the Number of Guesses required to finish the trial. Table 11 shows the results of the analysis.

[Table 11]

Discussion for Experiment 2

The results for Experiment 2 were mixed. While Cost significantly affected Average Time per Guess, it had no impact on either Guess Accuracy or Number of Guesses. Monetary cost did not seem to have effect in flat organizations. A possible explanation is that flattening the organization imposed such a high level of social cost that the monetary cost manipulation ran into a floor effect. The social cost component of the flat organization forced both the high and low monetary-cost groups to think carefully about the task, so carefully in fact, that there is little room for improvement. The data, however, indicates that decreasing communication costs in a flat organization does not necessarily have any effect on *task time*, *task accuracy*, or number of guesses. Feedback Demands had little effect on the dependant measures. Of the three variables of interest, only Number of Guesses was affected by Feedback Demands. In terms of productivity, reducing communication costs in a flat organization has minimal impact on productivity. The next section examines the effect of social cost on productivity.

Results for Social Cost

This section combines the data sets from Experiment One and Two in order to assess the effects of social cost on *task time*, task quality, and task quantity. A dummy variable was constructed for the combined data sets to indicate whether a subject was in the hierarchical (low social cost) or flat organization (high social cost). As with experiment 1, simultaneous tests of Communication Costs and Feedback Demands were limited to data for Player 3, dramatically reducing the sample size. I ran two separate analyses for each dependant variable. The first analysis excludes Feedback Demands and uses the full data set. The second analysis includes Feedback Demands, but only uses one third of the data.

Table 12 presents the results for Average Time per Guess. The first analysis of variance controls for Communication and Social Cost. As predicted, Social Cost significantly affected Average Time per Guess ($F_{(1,69)}$=8.92, p=0.0039). The Social Cost manipulation increased Average Time per Guess by 7.20 seconds ($\bar{x}_{low} = 24.11$ vs. $\bar{x}_{high} = 31.31$ seconds). Cost was significant ($F_{(1,69)}$=13.74, p=0.0004) with Average Time per Guess being 1.29 seconds higher for individuals in the High Cost condition ($\bar{x}_{low} = 23.28$ vs. $\bar{x}_{high} = 32.76$ seconds). Trial Number was also significant ($F_{(9,621)}$=17.35, p=0.0001), with individuals taking less time per trial as the experiment progressed.

[Insert Table 12 Here]

The second ANOVA simultaneously tests for Communication Cost, Social Cost and Feedback Demands. Once again, only the results for individuals assigned as Player 3 are included in the analysis. Social Cost was not significant ($F_{(1,22)}$=1.74,p=0.2004). I suspect that the lack of a significant result is a function of the reduced sample size and not controlling for Feedback Demands. Both Cost and Feedback Demands were significant ($F_{(1,22)}$=5.74, p=0.0255, and $F_{(1,458)}$=68.93, p=0.0001, respectively). In terms of Feedback Demands, each request for feedback increased the Average Time per Guess by 1.81 seconds. Table 13 shows the results of the analysis. Hypothesis 7 was not fully supported.

[Insert Table 13 Here]

The next two ANOVAs assess the role of Social Cost on Guess Accuracy. The first ANOVA does not include Feedback Demands. Social cost was a significant predictor of Guess Accuracy ($F_{(1,71)}$=8.66, p=.0044). Individuals in the high social cost condition had higher Guess Accuracy of .09 pegs per trial ($\bar{x}_{low} = 2.60$ vs. $\bar{x}_{high} = 2.69$ pegs). As with previous tests on Guess Accuracy, Communication Cost was not significant. Trial Number was significant, with participants increasing in accuracy by trial ($F_{(1,621)}$=16.92, p=0.0001). Trial Number by Role was also significant ($F_{(9,621)}$=5.46, p=0.0001). Table 14 presents the results.

[Insert Table 14 Here]

When controlling for Feedback Demands, Social Costs was significant ($F_{(1,22)}$=8.68, p=0.0075). Guess Accuracy was .16 pegs higher for individuals in the high Social Cost condition ($\bar{x}_{low} = 2.45$ vs. $\bar{x}_{high} = 2.61$ pegs). Trial Number was also a significant predictor ($F_{(9.206)}$=6.81, p=0.0001) with accuracy increasing as subjects completed more trials. In both the full and reduced sample, increasing Social Cost significantly increased Guess Accuracy. H8 is supported. Table 15 presents the results.

[Insert Table 15 Here]

In the final two analyses of variance, the effect of Social Costs on Number of Guesses was assessed. Once again, the first ANOVA does not control for Feedback Demands, but uses the full sample. The results for this ANOVA are shown in Table 16. Social Cost was a marginally significant predictor of Number of Guesses ($F_{(1,69)}$=2.88, p=.0944). As predicted, individuals in the High Social Cost manipulation made .91 fewer guesses than individuals in the Low Social Cost manipulation ($\bar{x}_{low} = 7.24$ vs. $\bar{x}_{high} = 6.51$ guesses). Communication Cost was significant ($F_{(1,71)}$=5.51, p=0.0217). Individuals in the High Communication Cost condition made 1.3 fewer guesses than individuals in the Low Communication Cost condition ($\bar{x}_{low} = 7.57$ vs. $\bar{x}_{high} = 6.27$ guesses). The Trial Number by Role and the Communication Costs by Trial by Role interaction were also significant ($F_{(18,621)}$=2.59, p=0.0003 and $F_{(18,621)}$=2.15, p=0.0038, respectively).

[Insert Table 16 Here]

The second ANOVA controls for Feedback Demands and is presented in Table 17. Social Cost was significant ($F_{(1,206)}$=7.68, p=0.0111) with individuals in the High Social Cost manipulation needing 2.02 fewer guesses than individuals in the Low Social Cost condition. Individuals in the High Communication Cost condition required 1.39 fewer guesses than those in the Low Communication Cost condition, but the differences between the groups was not significant ($F_{(1,22)}$=2.30, p=0.1440). The level of Feedback Demands was highly significant ($F_{(1,206)}$=210.85, p=0.0001). Each one-unit increase in Feedback Demands caused a .69 guess increase in Number of Guesses. Finally, Trial

Number was significant ($F_{(9,206)}$=1.98, p=0.0427). In both the full and restricted samples, Social Costs were significant. Hypothesis 9 was supported using both the full and reduced sample.

[Insert Table 17 Here]

Discussion for Social Costs

The results for the social cost manipulation were generally in line with theory. In five of the six analyses, social costs were significant to the .1 level. In four of the six analyses, the results were significant to the .05 level. Using the full sample, Social Costs increased Average and Time per Guess and Accuracy. Although the effect was marginal, Social Costs also reduced the Number of Guesses. As predicted by the theory, social costs had countervailing impacts on productivity. Not surprisingly, the effects of Communication Cost and Feedback Demands on the dependant measures were duplicated in using the combined datasets. In the next chapter, I discuss the implications of this research for organizational theorists.

Chapter 6

Conclusion

Intro

This section contains six parts. First, I summarize the results of the two experiments. Second, I discuss the contributions of this research to the literature. Third, I discuss the contributions of this research to organizational designers. Fourth, I discuss the limitations of this research. Fifth, I highlight some opportunities for future research. Finally, I conclude with some general remarks.

Summary

The results of the two experiments are fairly consistent with regard to the effects of monetized communication costs on *task time*. In every test, increasing communication costs had the effect of increasing guess time. Holding all else equal, increasing costs negatively impacts productivity by increasing the amount of time individuals spend on a task.

The results for the other two dependant measures, Guess Accuracy and Number of Guesses are somewhat more equivocal. Monetized costs had no clear effect on Guess Accuracy. In no case was the effect of Communication Cost a significant predictor of Guess Accuracy.

However, in each of the experiments, Guess Number was lower for individuals in the High Communication Cost conditions. The ANOVA results show that Guess Number was significantly predicted by Communication Cost in three of the five analyses. Further, arguably the most general test, the results of the combined analysis of both experiments and using the full sample, shows that monetized Communication Costs had a significant effect on Guess Number. I conclude that Communication Cost does have a significant effect on Number of Guesses. Thus, productivity is *increased* as Communication Costs are increased.

Social costs significantly predicted Average Time per Guess but only when not controlling for *Information demands*. Average Time per Guess, controlling for Information Demand, was not significant. It is likely that this result was due to the reduced the sample used when controlling for *Information demands* and subsequent reduction of power.

Social cost also significantly affected accuracy. Unlike Average Time per Guess, Social Cost was a significant predictor of accuracy regardless of controlling for *Information demands*. Interestingly, monetized Communication Costs had no effect on accuracy. Social Costs do seem to increase productivity with respect to increased accuracy.

While Social Costs affect accuracy, Communication Costs do not. It is not clear why the type of the cost matters in regard to accuracy. It may be that different kinds of costs bring different factors to mind when engaged in production rule selection.

When not controlling for *Information demands*, the effect of Social Cost on Guess Number was marginally significant. Social Costs were significant when controlling for communication costs. It seems reasonable to say that, in terms of the amount of information requested, social costs did effect productivity.

Finally, Feedback Demand was predicted to effect only Guess Accuracy and Number of Guesses. While Guess Accuracy was not affected, the Number of Guesses was significantly lower for individuals with higher levels of Feedback Demands. This was in keeping with theoretical predictions. While I did not make hypotheses regarding the effect of Feedback Demands on Average Time per Guess, in a positive sense, this result is interesting. As Feedback Demands increased, the Average Time per Guess increased significantly. Thus, increasing Feedback Demands *always* had a negative impact on productivity.

Both social and monetized costs have been shown to affect components of productivity. The impact of social and monetized costs varied, but both types of cost can be used to manipulate productivity. Further, the demands of other organizational members for information have been shown to negatively impact productivity. In the next section, I discuss the contributions of this paper to the literature.

General Discussion

This paper makes several contributions to the management literature. First, it contains an individual level explanation of the productivity paradox. To date, most research has focused on the aggregate level and pays relatively little attention to the individual. While researchers are making progress in developing contingency theory arguments, understanding the effects of IT implementation at the individual level will enable better system and organizational design.

Second, the theory presented explicitly links information processing to productivity, and does so in a way consistent with current, and well-tested, psychological and sociological theory. Further, the models of information processing and productivity are very explicit. The models make clear predictions about the effects of communication costs on both accuracy and quantity of tasks performed that seem to be confirmed by this experiment, at least in the pre-testing.

Third, I have argued that that individual level productivity should be thought of as containing three components: inputs required, accuracy, and quantity of tasks performed. Without such a conceptualization, the traditional single, summary measure of productivity may be confounded as individual's tradeoff accuracy and quantity. By disentangling the two constructs of effort and accuracy, it becomes possible to suggest remedies to flat or decreased productivity.

Fourth, the paper develops an experimental method that allows measurement of productivity and its components in a conceptually clear manner. The ability to disentangle quantity and accuracy, as well as providing experimenter control, makes productivity paradox research a more basic undertaking. Hopefully, this method will provide researchers a platform to conduct other, individual level investigations.

Implications

This research has several implications for organizational designers. First, the introduction of computer networks, providing cell phones organization wide, or even moving offices closer together, might not have a positive impact on productivity. When making changes in the organization, it is helpful to think about what component of productivity you are interested in affecting. For example, when trying to decrease the amount of information needed to perform a task, decreasing monetized costs (i.e., reducing the cost of a phone call) should be considered with some trepidation. The research shows that individuals faced with low monetized costs will draw conclusions from the data faster, but that they will require more information to complete the task. If tasks require high degrees of accuracy, hierarchical organizations that minimize the ability of individuals to sanction will have a negative impact on *task accuracy*. Environments requiring high *task accuracy* are better served with flat organizations where individuals can sanction each other. If organizational designers are looking to maximize accuracy and number of inputs, but are unconcerned with *task time*, a flat organization with monetized communication costs would be most effective.

As these examples show, manipulation of communication costs should be done knowing that productivity increases require tradeoffs. It is difficult to increase accuracy and decrease *task time* by flattening the organization. Similarly, decreasing monetized costs will tend to decrease the amount of information used by individuals but at the price of increasing *task time*.

Perhaps the most useful piece of advice that comes out of this research is that increased communication decreases the productivity of the person charged with providing feedback. Who does this affect most? I would venture that hierarchical organizations are most vulnerable to this effect. To the extent that options for feedback are limited and individuals are expected to ask questions of their superiors, communication costs are low. As this research has shown, low communication costs affect components of productivity.

Limitations

There were several limitations of the experimental method and theory. On the theory side, I ignore a clear boundary condition, the effect of very high communication costs on productivity. Further, it is not clear how generalizable the theory is across different types of communication costs or tasks. On the experimental side, combining the two experiments is somewhat problematic. Further, the accuracy measure does not fulfill the regression assumptions. These issues are discussed below.

The first boundary condition not addressed by the theory is the presence of very high communication costs. While both experiments have shown that decreasing communication costs have a detrimental effect on some component of productivity, I would caution against making communication costs too high. While I do not address this possibility in the dissertation, I would argue that very high communication costs lead to sub-optimal results as individuals do not engage in enough communication. As data gets "expensive", individuals would select production systems that require very little data. At the extreme, individuals would attempt to solve tasks without any data, perhaps by random guessing. Clearly, such behavior is counter-productive.

A second boundary condition might exist in terms of the types of task affected by communication costs. Both experiments used a task that required both inductive and deductive logic to solve. Other tasks might not be so dependant on logic, thereby making decision rule selection less critical in deciding task performance. To the extent that tasks are routine, communication costs will likely have little effect on productivity.

One of the more interesting findings was that participants reacted to different types of costs in a different fashion. Monetized costs seem to affect the amount of information demanded while social costs had a greater impact on accuracy. The theory makes no distinction on types of cost and it is not clear why participants should select different production rules as a function of cost type.

In addition to boundary conditions of the theory, there are some elements of the experimental design that could increase experimental control. Primarily, the current design does not give the experimenter control over response times or *information demands* placed on participants. The current approach is appealing in that the theory is tested in real groups, a modified approach could increase experimental control. In order to increase control, participants could be placed "virtual" groups where they are told they are playing the game with each other, but would in fact be playing with the computer. The computer could then ask for feedback and respond to participants requests for feedback in a controlled fashion. Such a modified experiment would increase the level of experimental control and allow the experimenter to vary response times and *information demands* place on participants.

There were also several problems with the combined analysis of Experiments One and Two. First, the amount of information processed at the organizational level was higher for those in Experiment Two. Thus, a confound exists between the two experimental groups. However, I don't consider this confound particularly troublesome. At the individual level, *Information demands* was varied and, in some analyses, controlled for. In general, controlling for *information demands* had little impact on hypothesis testing for either monetized or social communication costs.

A second problem is that the subjects for the two experiments were recruited from different subject pools. The first set of subjects were recruited from two undergraduate business classes. Subjects for the second experiment were recruited from the entire school and two large chemistry classes. It is possible that one group of subjects were more analytical, thereby leading to a confound between the social cost variable and subject pools. In order to assess the analytical skills of the two experimental groups, I examined both math and verbal SAT scores. In fact, there were no significant difference in either the math or verbal SAT scores between the two experimental groups. The two groups scored were within twenty points of each other on both measures.

The final limitation I wish to discuss has to do with construction of the accuracy measure. Guess Accuracy was constructed by averaging the number of feedback pegs an individual received over the course of a game of mastermind. As such, the measure is bounded by 0 and 4. In fact, no player had a Guess Accuracy less than 1.28. This measure suffers from restricted range and limiting the variance. One of the regression assumptions is that the dependant variable must be "quantitative, continuous, and unbounded" (Berry, 1993, pg. 12). Clearly, Guess Accuracy does not meet this assumption. Violation of this assumption leads to inefficient and possibly biased estimators. Restricting the variance tends to underestimate the effect of costs on accuracy. It is likely that costs significantly impacts accuracy, but that the restricted variance limits my ability to test hypotheses regarding accuracy.

Future Research

I think that the two experiments have provided reasonable support for the theory, but additional theory testing is desirable. Future research should probably adopt the "participant-computer" experimental design, proposed above, in order to increase experimental control. It is likely that such a design would increase the sensitivity of hypothesis testing. Two extensions to the current research are suggested below.

It is possible that putting people into groups adds some level of perceived social cost to the experiment. The results presented might understate the real effects of communication costs. The first extension would have individuals simply play Master Mind against the computer. Participants would be informed that they were playing with a computer. This experiment would then serve as a baseline to which other studies could be compared. All following studies would then tell individuals they were part of an experimental group.

The second extension examines the differential effects of monetized and social costs on productivity. I think that the most interesting puzzle to come out of this research involves the difference in subjects responses to the different types of costs. It is clear that a more complete theory would explain the effects of different types of cost on productivity. At this stage, however, the properties of cost that effect production rule selection are still unknown. Rather than extend this research into other types of cost, I think it is more important to determine the properties of cost that individuals consider when making production rule selections. Perhaps the best way to proceed would be to replicate both experiments one and two while having subjects provide think aloud protocols. These protocols could then be analyzed, hopefully revealing how individuals select production systems based on different types of cost.

Final Thoughts

The basic notion, that lower communication costs force a tradeoff between time, quantity of inputs, and accuracy, is a simple, yet powerful, explanation of the productivity paradox. It is only part of the answer, but I suspect, an important one. Further, I would argue that one must be careful in raising communication costs, as their value might be perceived as less than their benefit, even in cases where this is objectively not the case (this prediction falls out of prospect theory by Tversky & Kahneman, 1982; See also Thaler & Sheffrin, 1988). Either way, organizational inefficiencies result.

In the end, what does this research say to organizational designers? It is clear that that by themselves, very low levels of communication costs may have a large and negative impact on organizational productivity. I suspect building in mild communication costs into information technology implementations would increase both *task accuracy* and organizational efficiency.

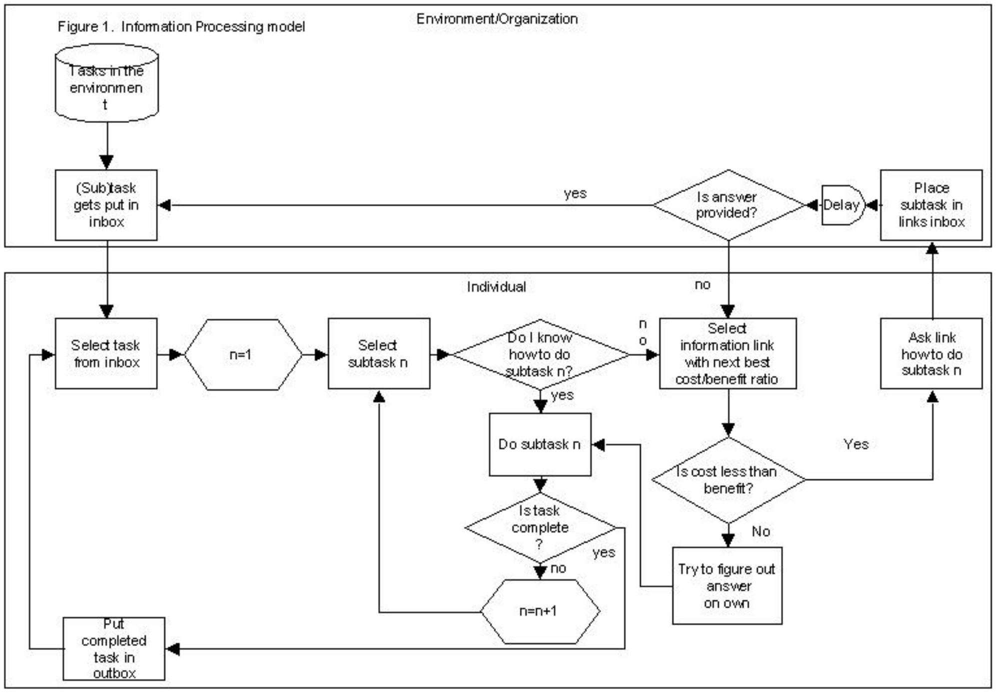
Figure 1. Information Processing model
Environment/Organization
Tasks in the environmen t
(Sub)task gets put in inbox
yes
Is answer provided?
Delay
Place subtask in links inbox
Individual
no
Select task from inbox
n=1
Select subtask n
Do I know howto do subtask n?
n o
Select information link with next best cost/benefit ratio
Ask link howto do subtask n
yes
Do subtask n
Yes
Is cost less than benefit?
Is task complete ?
No
yes
no
Try to figure out answer on own
n=n+1
Put completed task in outbox

Figure 2. Productivity Model

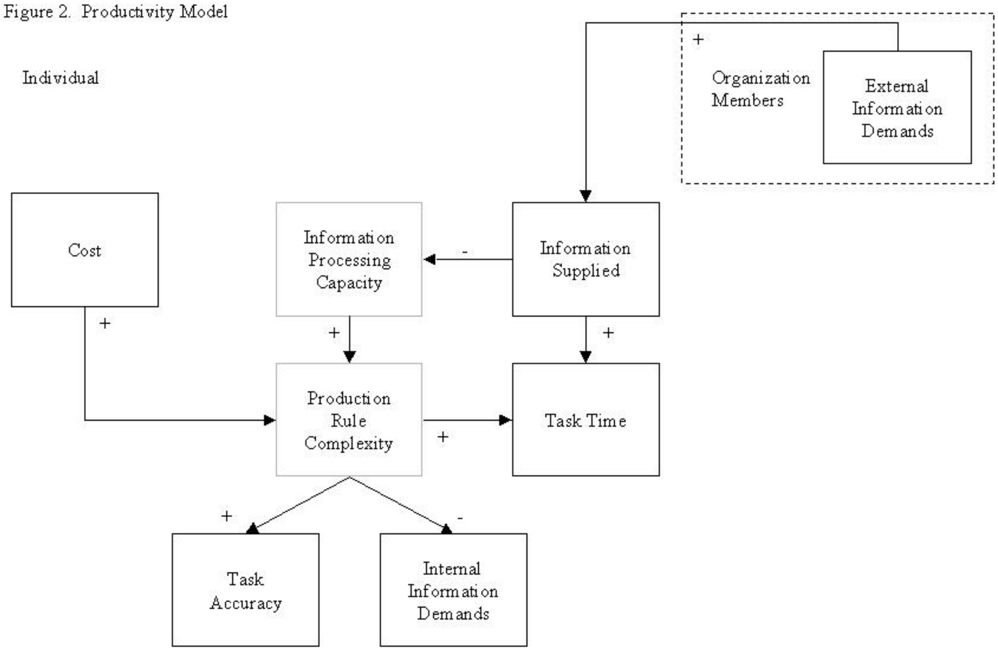

Figure 3a. Blank Mastermind board

Figure 3b. First Round

Figure 3c. Second Guess

Figure 3d. Third Guess

Figure 3e. Fourth Guess

Figure3f. Fifth Guess

Figure 3g . Sixth Guess

Table 1. Experiment 1 – Means by Cost (Sdt. Dev)			
		Variables	
	Average Time per Guess	Guess Accuracy	Number of Guesses
Low Cost	20.14 secs. (10.34)	2.52 pegs (0.54)	8.47 guesses (6.13)
High Cost	28.7 secs. (19.45)	2.62 pegs (0.52)	6.0 guesses (3.19)

Table 2. Experiment 1 – Guess Time				
Variable	df	F	P	
Communication Cost	1	15.38	0.0020	***
Role	2	1.24	0.3077	
Communication Cost by Role	2	0.01	0.9900	
Trial Number	9	7.81	0.0001	***
Communication Cost by Trial Number	9	1.08	0.3849	
Role by Trial Number	18	2.85	0.0002	***
Communication Cost by Role by Trial Number	18	0.78	0.7278	

* p< 0.10, ** p<.05, *** p<.01

Table 3. Experiment 1 - Guess Accuracy				
Variable	df	F	P	
Communication Cost	1	1.27	0.2818	
Role	2	1.23	0.3114	
Communication Cost by Role	2	0.32	0.7283	
Trial Number	9	9.31	0.0001	***
Communication Cost by Trial Number	9	0.50	0.8709	
Role by Trial Number	18	6.08	0.0001	***
Communication Cost by Role by Trial Number	18	0.98	0.4837	

* p< 0.10, ** p<.05, *** p<.01

Table 4. Experiment 1 - Guess Accuracy Controlling for Feedback Demands				
Variable	df	F	P	
Feedback Demands	1	0.33	0.5740	
Communication Cost	1	1.17	0.3040	
Feedback Demands by Communication Cost	1	0.03	0.8696	
Trial Number	9	7.14	0.0001	***
Communication Cost by Trial Number	9	9	0.4494	

* p< 0.10, ** p<.05, *** p<.01

Table 5. Experiment 1 - Number of Guesses				
Variable	df	F	P	
Communication Cost	1	8.48	0.0130	**
Role	2	1.01	0.3806	
Communication Cost by Role	2	0.13	0.8811	
Trial Number	9	1.75	0.0869	*
Communication Cost by Trial Number	9	0.80	0.6216	
Role by Trial Number	18	2.92	0.0001	***
Communication Cost by Role by Trial Number	18	1.54	0.0780	*

* $p < 0.10$, ** $p < .05$, *** $p < .01$

Table 8. Experiment 6 – Means by Cost (Std Dev)			
	Variables		
	Average Time per Guess	Guess Accuracy	Number of Guesses
Low Cost	26.42 secs. (16.53)	2.69 pegs (0.51)	6.67 guesses (3.56)
High Cost	36.20 secs. (29.30)	2.73 pegs (0.49)	6.35 guesses (2.97)

Table 7. Experiment 2 - Guess Time

Variable	Df	F	P	
Feedback Demands	1	2.49	0.1455	
Communication Cost	1	5.87	0.0359	**
Feedback Demands by Communication Cost	1	2.34	0.1569	
Role	2	0.81	0.4584	
Role by Communication Cost	2	2.98	0.0727	*
Role by Feedback Demands	2	0.44	0.6468	
Trial Number	9	9.36	0.0001	***
Trial Number by Communication Cost	9	.066	0.7404	
Trial by Role by Feedback Demands	9	2.36	0.0179	**
Trial by Role	18	0.73	0.7789	
Trial by Role by Communication Cost	18	1.00	0.4642	
Trial by Role by Feedback Demands	18	1.46	0.1109	
Trial by Role by Communication Cost by Feedback Demands	27	0.90	0.6062	

* p< 0.10, ** p<.05, *** p<.01

Table 8. Experiment 2 - Guess Accuracy				
Variable	Df	F	P	
Feedback Demands	1	0.27	0.6136	
Communication Cost	1	0.50	0.4936	
Feedback Demands by Communication Cost	1	0.11	0.7492	
Role	2	1.80	0.1892	
Role by Communication Cost	2	0.07	0.9294	
Role by Feedback Demands	3	0.69	0.5660	
Trial Number	9	7.36	0.0001	***
Trial Number by Communication Cost	9	0.74	0.6750	
Trial by Role by Feedback Demands	9	3.84	0.0003	***
Trial by Role	18	4.87	0.0001	***
Trial by Role by Communication Cost	18	0.76	0.7408	
Trial by Role by Feedback Demands	18	1.21	0.2567	
Trial by Role by Communication Cost by Feedback Demands	27	0.81	0.7295	

* p< 0.10, ** p<.05, *** p<.01

Table 9. Experiment 2 – Guess Number

Variable	df	F	P	
Feedback Demands	1	10.64	0.0085	***
Communication Cost	1	1.58	0.2372	
Feedback Demands by Communication Cost	1	1.43	0.2597	
Role	2	0.43	0.6589	
Role by Communication Cost	2	1.09	0.3555	
Role by Feedback Demands	3	1.30	0.3014	
Trial Number	9	5.33	0.0001	***
Trial Number by Communication Cost	9	1.30	0.2468	
Trial by Role by Feedback Demands	9	0.20	0.9932	
Trial by Role	18	1.03	0.4309	
Trial by Role by Communication Cost	18	1.44	0.1199	
Trial by Role by Feedback Demands	18	1.25	0.2261	
Trial by Role by Communication Cost by Feedback Demands	27	0.67	0.8929	

* p< 0.10, ** p<.05, *** p<.01

Table 10. Experiment 1 & 2 - Guess Time

Variable	Df	F	p	
Communication Cost	1	11.53	0.0024	***
Cognitive Cost	1	6.88	0.0149	**
Communication Cost by Cognitive Cost	1	0.07	0.7882	
Role	2	1.58	0.2168	
Role by Communication Cost	2	1.45	0.2455	
Role by Cognitive Cost	2	0.11	0.8935	
Role by Communication Cost by Cognitive Cost	2	1.25	0.2956	
Trial Number	9	15.16	0.0001	***
Trial Number by Communication Cost	9	0.45	0.9071	
Trial Number by Cognitive Cost	9	1.71	0.0883	*
Trial Number by Communication Cost by Cognitive Cost	9	1.04	0.4109	
Role by Trial Number	18	1.52	0.0787	*
Role by Trial Number by Communication Cost	18	0.76	0.7524	
Role by Trial Number by Cognitive Cost	18	1.51	0.0826	*
Role by Trial Number by Communication Cost by Cognitive Cost	18	1.14	03098	

* p< 0.10, ** p<.05, *** p<.01

Table 11. Experiment 1 & 2 - Guess Accuracy				
Variable	df	F	P	
Communication Cost	1	1.77	.1963	
Cognitive Cost	1	7.42	0.0118	**
Communication Cost by Cognitive Cost	1	0.34	0.5679	
Role	2	1.32	0.2778	
Role by Communication Cost	2	0.23	0.7926	
Role by Cognitive Cost	2	1.62	0.2090	
Role by Communication Cost by Cognitive Cost	2	0.23	0.7975	
Trial Number	9	15.49	0.0001	***
Trial Number by Communication Cost	9	0.42	0.9215	
Trial Number by Cognitive Cost	9	1.46	0.1641	
Trial Number by Communication Cost by Cognitive Cost	9	0.82	0.5986	
Role by Trial Number	18	11.22	0.0001	***
Role by Trial Number by Communication Cost	18	0.99	0.4714	
Role by Trial Number by Cognitive Cost	18	0.73	0.7764	
Role by Trial Number by Communication Cost by Cognitive Cost	18	0.87	0.6105	

* p< 0.10, ** p<.05, *** p<.01

Table 12. Experiment 1 & 2 - Guess Number

Variable	df	F	P	
Communication Cost	1	8.40	0.0079	***
Cognitive Cost	1	2.26	0.1457	
Communication Cost by Cognitive Cost	1	5.00	0.0349	**
Role	2	0.53	0.5918	
Role by Communication Cost	2	0.03	0.9736	
Role by Cognitive Cost	2	1.23	0.3021	
Role by Communication Cost by Cognitive Cost	2	0.62	0.5418	
Trial Number	9	5.57	0.0001	***
Trial Number by Communication Cost	9	1.18	0.3109	
Trial Number by Cognitive Cost	9	0.37	0.9463	
Trial Number by Communication Cost by Cognitive Cost	9	0.77	0.6465	
Role by Trial Number	18	2.73	0.0002	***
Role by Trial Number by Communication Cost	18	2.43	0.0009	***
Role by Trial Number by Cognitive Cost	18	1.63	0.0503	*
Role by Trial Number by Communication Cost by Cognitive Cost	18	0.38	0.9907	

* p< 0.10, ** p<.05, *** p<.01

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