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Technology Shocks and Problem-Solving Capacity

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Researchers are increasingly exploring the role that investments in information technologies (IT) has in increasing the performance of the workplace. Investment in IT has accelerated over the last twenty years, thus it is increasingly important to understand why and when these investments have positive performance effects.

In this paper, I posit that a primary objective of firms today is to invest in the *problem-solving capacity* of their workforce, and that this investment is facilitated by investments in IT and by innovative human resource management (HRM) practices. The problem-solving capacity of each worker is defined as having two components. The first component is the *problem-solving aptitude* of the worker, which is a function of his talents, education, training, and experience. The second component is the *connective capital* of the employee, which represents his access (or connections) to other employees who can assist him in solving problems.

Given this definition of problem-solving capacity, investments in innovative HRM practices and in IT represent the mechanism that the firm uses to build problem-solving capacity. Innovative HRM practices, such as the use of problem-solving teams, training of workers, information sharing, careful selection of workers, and the use of incentive pay, are aimed at building the skills for problem-solving and providing the opportunities for problem-solving on the job. At the same time, information technologies greatly enhance problem solving in two ways—by providing greater amounts of information to everyone in the organization, and by providing rapid communication between members of the organization.

The increasing desire on the part of firms to invest in the problem-solving capacity of the workforce has grown over time in part because there have been recent "shocks" or technological progress to enhance it. The technological progress in IT is quite clear to all. Less clear is the technological progress in HRM practices—however, until the 1980s, very few U.S. firms invested in these practices, and thus these methods for making workers more production is a considerable innovation. In sum, decision-making has been moved down the hierarchy to the workers who today have greater amounts of information (due to IT) and who have the decision-rights to make use of that information (due to the introduction of innovative HRM practices).[1]

[1] See Autor, Katz, and Kruegar (1997) for a review of the literature on the causes of rising inequality that have arisen as an emphasis on problem solving has changed the return to skills. For prominent papers on this topic, see Berman, Bound, and Griliches (1994), Berman, Bound, and Machin (1997), Bernard and Jensen (1997, 1998), Chennells and Van Reenen (1998), DiNardo, Fortin, and Lemieux (1996), DiNardo and Pischke (1997), Hunter and Lafkas (1998), Katz and Murphy (1992), Kramarz (1998), and Kruegar (1993).

The Information Technology Shock

The information technology "shock" is well known, yet it is worth reviewing the evidence on the size and timing of this shock. Since 1980, the speed of microprocessers used in pc's has increased more than 100 fold, so that the cost of performing 1 million instructions per second has fallen from $100 to less than 20 cents. The cost of a megabyte of hard disk storage has fallen from $100 in 1980 to less than 1 cent today. Data transmission also skyrocketed, as fiber optics lowered the costs of sending 1 trillion bits of information from $120,000 to 12 cents from 1980 to 1999.

As described by Moore's Law (after Gordon Moore), the density of transistors has doubled every 18 months since 1968, thus the power of computers grew over time. The result is that prices of computers and equipment fell 71 percent between 1995 and 2000. And while purchases of the personal computer began in the early 1980s, its extensive power and thus widespread use developed in the 1990s. And finally, networking really began in the mid-to-late 1990s, with extensive developments in within-firm intranets and the Internet for B2B and B2C communications. As a result of the acceleration of these technological changes, investment in computers and software grew at a 19% annual rate during the 1990s, and accelerated to a 28% annual rate after 1995. Complementary investment in software also doubled in those years (rising from $10 billion in 1980, to $50 billion in 1990, to $225 billion in 1999), though the prices of software only fell by 2% a year.

The Human Resource Management Technology Shock

The introduction of innovative human resource management (HRM) practices over the last twenty years also represents a "technology shock," though it is more difficult to measure the size of the shock. Robert Cole (2000) does a very persuasive job of describing participatory HRM innovations as a shock to managers. Recall that twenty-five years ago, the Japanese system of HRM practices focused heavily on problem-solving teams and the importance of the production worker, whereas the traditional U.S. system of HRM practices gave production workers very little problem-solving involvement. Cole posits that U.S. manufacturers had a huge gap in product quality relative to the Japanese in the 1970s and early 1980s, and yet the U.S. managers were slow to react to this gap and to adopt practices that could close the gap. As he states, "the quality challenge appeared before U.S. companies, for all practical purposes, as a one time 'never having been seen before "event" and thus U.S. managers were slow to

react, questioning the evidence of the value of the Japanese example and reluctant to change beliefs." (Cole, page 74). Some innovative firms took up the challenge, others moved more slowly, and some of the early changers were among Japanese transplants to the U.S. (Cutcher-Gershenfeld, et.al., 1994).

Given this description of the change in the technical knowledge regarding managerial practices, the mid-1980s was a period in which this HRM technology shock struck U.S. firms, and firms were faced with the decision as to whether to adopt the new technology or not. Of course, as with any new technology, the value of the technology is uncertain to all, and the value of the technology is likely to vary considerably across work environments.

As defined in this paper, "innovative HRM" practices are a set of practices that are introduced to elevate "employee involvement" (or EI) among production workers. The greater involvement of production workers might take either of two forms: they may make more decisions during the production process; or, they may be involved in more problem-solving off the line. In previous research, we isolate seven sets of practices that combine to raise employee involvement (Ichniowski, Shaw, and Prennushi, 1997):

- problem-solving teams are introduced to provide production workers with direct input into improving the production process
- rotation across jobs is used to increase training, worker flexibility and increase teamwork
- information sharing is important to provide the information and motivation for greater involvement and decisionmaking
- training is needed to do problem solving and to increase skills for day-to-day decisionmaking
- incentive pay, in the form of some type of pay-for-performance, is introduced to offer the incentive for greater employee involvement
- job security is used to assure workers that improvements in production performance will not result in the direct loss of jobs
- careful screening and selection of workers is required to obtain those who are more skilled in both the direct job-related (mechanical or analytical) skills, as well as the "team skills" to work together to solve problems and to respond to rewards on the job.

Several surveys provide data on the extent of the adoption of HRM, and though there are no surveys of HRM innovations prior to the mid-1980s, there is some retrospective data. Because total quality management (TQM) practices tended to be the first type of Japanese EI

practices that were introduced in the U.S. and other innovative HRM practices followed (Cole, 2000, Ichniowski and Shaw, 2000), it is fairly safe to conclude that prior to 1980, a very small minority of firms had formal HRM systems encouraging employee involvement, and the 1980s is likely to have been a time of initial transition. Lawler, Mohrman, and Ledford (1995) survey large firms, and show that by 1993, 76 percent of these firms had a TQM program in place, and of these firms, the year of introduction was as follows (1995, page 47).

Prior to 1986	19%
Between 1986-1988	25%
Between 1989-1990	32%
Between 1991-1993	24%

Introduction of TQM continued in the 1990s: Osterman (2000, Table 1) reports that the percent of establishments in which more than half of their workforce is involved in TQM: it rose from 25% to 57% from 1992 to 1997. His data refers to establishments, not firms, so the percents will be lower, and his sample is a much broader sample of all establishments that have at least 50 employees. [2]

Turning to specific employee involvement practices, Lawler, Mohrman, and Ledford ask firms about "employee participation groups" and "self-managed work teams" (see Tables 1 and 2). By 1987, 70% of all large firms had some form of employee participation groups, such as off-line problem-solving teams including production workers, and this rose to 93% by 1993. Equally important, these practices became more pervasive within firms: the percent of large firms having more than 20 percent of workers participating rose from 37% to 65% from 1987 to 1993. A more dramatic form of EI, the rearrangement of the production workers into "self-managed work teams" grew faster. From 1987 to 1993, the percent of large firms with some self-managed teams rose from 28% to 68%. Osterman (2000) reports that the extensive use of teams had plateaued by the late 1990s: from 1992 to 1997, the percent of establishments with more than half of the workforce in teams was steady at about 40%.[3] While the percent

[2] Osterman (1994) surveys establishments in 1992, obtaining responses from 875 establishments with 50 or more employees in the non-agricultural private sector. To obtain data that accurately depicts the state of the HRM practices, Osterman needed to identify a set of workers to survey. He asked that the survey respondent be in the operations side of the business and that the respondent identify the largest group of non-supervisory, non-managerial workers at the establishment's location who are directly involved in making the product or providing the service.

[3] Across all establishments, the percent fell slightly from 1992 to 1997—from 41% to 38%--but for a matched sample of firms for these two years, the percent rose slightly from 40% to 41%.

stopped growing, these are very sizable levels of usage. Moreover, usage was widespread across different occupational groups (Table 3).

Osterman also reports that there was a significant growth in the use of multiple HRM practices. From 1992 to 1997, the percent of establishments with two or more practices in use by at least half of the workforce rose from 25% to 38% when he followed the same establishments over time. Moreover, these practices were sustained within establishments: an "overwhelming majority of establishments in place in 1992 maintained that status in 1997" (2000, page 186). And while team use did not grow in his survey, the use of other practices did: the percent of establishments that used job rotation rose from 24% to 47%.

In sum, a conservative assessment suggests that prior to 1980s, virtually no firms had HRM practices emphasizing employee involvement, but that their use grow fairly steadily over the 1980s and into the 1990s. The introduction of EI occurred in the early 1980s; by 1990 approximately half of all firms had some innovations; and since 1990 there has been variable, but continued, progress. Thus, to the extent that HRM represents a technology shock, this shock occurred and adjustments were made in the 1980s and early 1990s, and perhaps to a lesser extent in the mid-to-later 1990s.

The Effects of the IT and HRM Technology Shocks: Changes in Performance

There is now a considerable accumulation of research papers that have examined the effects of investing in HRM practices and of IT on performance. This research has largely coexisted in the separate academic studies of HR and IT, with little overlap until recently, as described below.

For a review of the effectiveness of innovative HRM practices, see Ichniowski, Kochan, Levine, Olson, and Strauss (1997). They conclude that the preponderance of evidence suggests that there are significant performance gains from managerial improvements in HRM, gains that outweigh the costs of these investments.

Their conclusion is consistent with two of our studies of the productivity gains from innovative HRM practices in the steel industry. In the first study, we obtained time series data from 35 finishing lines in integrated steel mills producing one type of flat-rolled product (Ichniowski, Shaw, and Prennushi, 1997), and in the second study of steel minimills we obtained data from 34 lines making one type of bar product (Boning, Ichniowski, and Shaw,

2001). Given very similar products within these studies, and thus production technologies within these studies, we estimate the gains from innovative HRM practices and find them to be substantial.

In evaluating the effectiveness of IT, the evidence for gains is much more mixed, but reviewers of this literature suggest that the performance gains have begun to surface in recent years and are likely to grow in the future. See the recent surveys by Barua and Mukhopadhyay (2000) and by Brynjolfsson and Hitt (2000).

In the last few years, researchers have begun to emphasize the interaction between HR and IT, or that value that organizational changes have in enhancing the value of IT. Discussions of the complementarities between these practices are emphasized in Brynjolfsson and Hitt (2000) and Breshnahan, Brynjolfsson and Hitt (forthcoming) as they provide an explanation for the recently growing returns to IT investment: for these investments to payoff, firms must also invest in organizational changes. Other researchers making this point include: Autor, Levy, and Murnane (1999, 2001, 2001), Black and Lynch (forthcoming), Dunlop and Weil (1996), and Hunter and Lafkas (1998), and Shaw (forthcoming). This point is discussed further below.

How Do Innovative HRM Practices and IT Raise Performance? The Role of Problem-Solving Capacity

How exactly do HRM practices raise performance levels? The popular press talks about the use of employee involvement in inducing production workers to "work harder and smarter" and that phrase does capture the essence of the effectiveness of the practices. Based on research from the steel industry, I and my co-authors posit that when production workers in innovative HRM lines work smarter they are building more "problem-solving capacity."

A individual's "problem-solving capacity" has of two elements. First, is the individual-specific knowledge or training that the individual production worker acquires through his own investments, or K_i for individual i, where these investments may have been financed by the worker (through education or lower wages) or by the firm, as in the traditional Becker investment in human capital. Thus, *K_i is the "problem-solving aptitude"* of the worker—emphasizing that problem-solving activity is the goal of these investments in individual-specific human capital.

Second, problem-solving capacity also includes the individual's access to the problem-solving knowledge of the other employees in his work area.[4] For example, if the production worker is faced with a problem of deteriorating steel surface quality, to solve this problem, he will draw on his own training and experience, but he will have access as well to the training and experience of others through his "connective capital." The *connective capital*, CC_i, is the weighted sum of the problem-solving aptitudes of all other individuals in the firm:

(1) $CC_i = \Sigma \delta_{ij} K_j$ summing over $j=1,.., N_i$, $j \neq i$

with weights equal to δ_{ij} which is the degree to which person i has access to the knowledge of person j, and N_i is the number of other workers in person i's work area. In essence, δ_{ij} is the *problem-solving network* for worker i. When worker i combines his personal problem-solving aptitude with his problem-solving network, he builds his problem-solving capacity.

To emphasize the important elements of the problem-solving network, define the concept of "direct ties" as

(2) Direct $\text{ties}_i = \Sigma \delta_{ij} / N_i$, for $j=1,.., N$, $j \neq i$

So direct ties is equivalent to connective capital except that it sets all $K_j=1$ and normalizes by N_i. This concept of direct ties is closely related to the theory of *social capital* emphasized by organizational theorists. For organizational theorists this measure of "ties" is called "degree centrality." However, organizational theorists generally emphasize the importance of individuals' acquisition of social capital, and only rarely do they focus on the importance of social capital for improving the level of productivity for the firm – they focus on the "micro" level of individuals rather than aggregating across individuals to reach the "macro" level of the firm.[5]

Thus, we define the worker's *problem-solving capacity* to be

(3) $Q_i = K_i + CC_i$

[4] Why is the aggregate knowledge of other workers so important to personal performance? Consider the "educational production function" that we faculty all engage in. We tell our students that it is not so important to learn the facts, but it is important to learn how to solve problems, by knowing what questions to ask and where to look for answers. Thus, in the case of 'problem-solving capital, the worker must have some personal training on the facts and questions, but also must know where to look for the information that he needs to solve the problem he/she faces.

[5] For a review article that does span the micro to the macro effects of social capital, see Leana and VanBuran (1998).

where Q_i is the total problem-solving capacity that is a weighted function of the personal problem-solving aptitude, K_i, and the connective capital, CC_i.

In this formulation of problem-solving capacity, the transferability of knowledge, from worker j to worker i, or the value of δ_{ij}, is a key element of the problem-solving performance of worker i. On a production line, each worker must either solve current operating problems, or he must solve more long-term underlying problems (as when he is a member of a problem-solving team). In both cases, it is important that they utilize both: a) their own training, K_i, and b) the knowledge base of others, K_j, where this is a function of both the quantity of problem-solving knowledge that others have, K_j for j=(all other workers), and the individual's access to that knowledge, δ_{ij} .

The concept of problem-solving capacity is a form of "knowledge capital," which is not a new concept in economics—knowledge capital often refers to the human capital of the scientists, engineers, or marketing researchers who add value to the firm. However, it is rarely applied to all workers including production workers.[6] This definition of problem-solving capacity emphasizes access to the collective knowledge of the entire workforce: individual training builds Becker-style human capital, but in addition, collective knowledge *adds the access that each production worker has to new information that builds knowledge as it is needed on the job.*[7]

[6] For other applications of knowledge capital to production workers, see Cutcher-Gershenfeld (1998), Caroli, Greenan, and Guellec (1997), and Greenan and Guellec (1994).

[7] Other researchers who have emphasized communications networks among workers have developed similar concepts of knowledge capital, though none have formulated the problem-solving capital of (2). Organizational theorists have focused on "social capital" (Nanapiet and Ghostal, 1998, Nonaka and Takeuchi, 1995, and Granovetter, 1973), and others on "learning capital" (Greenan and Guellec, 1994).

How Do They Do It—Evidence on the Investment in Problem-Solving Capacity

In discussing the evidence on the performance effects of HRM practices, I referred to our work on the steel industry: we return to that industry to estimate the value of problem-solving capacity to clarify why innovative HRM practices are performance-enhancing. We return to seven production lines and survey all employees on the extent of their education and experience, and on the patterns of communications that form their problem-solving network. To assess whether HRM practices contribute to problem-solving capacity, we divide the seven production lines into two types of HRM environments: one environment is called "involvement oriented" (IO) because these production lines have an extensive set of innovative HRM practices; the second environment is called "control-oriented" (CO) because these lines have few innovative HRM practices and production workers are carefully controlled by management.

To gather individual-specific data on workers' problem-solving networks, we gave each employee a list of the names of all the people in his work area (managers and staff as well as production employees) and asked the employee to make check marks next to each coworker's name with whom he typically talked to on a daily, weekly, or monthly, basis on issues related to operations. Based on this data, we reach two conclusions.

Production workers on involvement-oriented lines have more personal problem-solving aptitude, $K_{i,,}$ than do workers on control-oriented lines. Using the individual data from our seven lines, we find that workers on the IO lines are better educated. The HRM practices used on these lines imply that these workers have more off-line training, but we did not measure training in our survey of individual employees.

Production workers on involvement-oriented lines have more connective capital, $CC_{i,}$ than do workers on control-oriented lines. Differences across workers in their values of connective capital are driven largely by differences in their problem-solving networks, and these networks are quite different across workers and HRM environments. Table 4 focuses on this network, by displaying calculations of the "direct ties" of equation (2) above. There are striking differences across IO and CO lines, and these differences are statistically significant: the average production worker has three times as many ties on involvement-oriented lines as does the average production worker on control-oriented lines. For non-production workers, the gap is smaller, but huge: foreman/staff/managers typically have twice the contacts on IO lines as they do on CO lines.

In sum, the evidence from these production lines suggests that workers have more problem-solving capacity in environments with more innovative HRM policies. This problem-solving capacity is likely to be enhanced by information technologies.

Problem-Solving Capacity and Information Technology

Define the problem-solving output of the worker as[8]

(1) $q_i = BX_i^{\phi}Q_i^{\gamma}$

where q_i is the problem-solving output of individual i, X_i is other inputs (such as information technologies, the quality of the standard operating procedures for the line, or SPC use), and B is other unobserved inputs to problem solving.

The definition of problem-solving output introduces a role for information technology, in two typical forms. First, IT provides greater amounts of information, at all levels of the organization as the speed and storage capacity has grown. Second, IT facilitates communications across individuals, through email, intranet, and Internet activities.

In our steel mill cases, all mills have seen substantial increases in the use of information technology over the last twenty years. Twenty years ago lines would have been run by operators who stand at positions and mechianicaly control the process or control it though limited computerized controls. Today mills are operated almost entirely from a computerized room that is above the line and processes are changed by typing into keyboards or pushing buttons from this pulpit. Also, the extensive gauges on the line provide a wealth of information to the worker and to the manager. And communications are enhanced through the use of the typical networks described above. In addition to email, at one typical plant visit we observed a manager who had just had his desk pc networked to the operating pulpit on the line and was receiving real-time immediate production-line data.

[8] In defining the R&D knowledge capital that a firm has access to, Griliches (1979) describes similar knowledge inputs for firm i. There is the specific knowledge that the firm has acquired through its own investments (K_i for firm i). Also, there is also the aggregate knowledge of the industry that is of value to this firm (K_a), where this is the sum of the knowledge of all other firms in the industry, $K_{ai}=\Sigma w_{ij}K_j$ over j=(all firms except i), where w_{ij} is the weighting function that represents the "effective fraction of knowledge in j borrowed by industry i." Given these definitions of capital, Griliches writes the production function for the

The Combined Effects of the IT and HRM Technology Shocks: Changes in Decision Rights

For the last ten years or more, researchers have emphasized the movement of decision rights from managers to workers spanning the entire range of the organization. For example, Jensen and Mechling (1992) posit that firms should "co-locate" decision-making authority with employees who have the most relevant information. Furthermore, if knowledgeable line workers are given the authority to make operating decisions, they must also be given the incentives that motivate good decisions (Jensen and Mechling, 1992; Baker, 1992).[9] The advent of both innovations, in HRM practices and in information technologies, has enhanced the value of locating decisionmaking at lower levels in the organization.

Prior to the Japanese technology revolution, most U.S. firms managed their firms through the use of the "hierarchical control" model of management (Aoki, 1986). Under this model, information is passed to the top, decisions are made, and the implementation of the decisions is passed back down to the bottom. Employees are managed through "control"—close supervision rather than involvement and personal incentives or rewards. In the managerial literature, this model is the "Taylorism" approach to management, which was judged to be most valuable when products tended to be commodities that changed little over time (i.e., the Ford Model T), but this approach is likely to fail when quick decisions and innovative changes dominate the creation of firm value. As the Japanese revolution evolved, more firms moved away from the hierarchical to the more participatory model.

The more participatory model of the management of human resources emphasizes two things:

- Production workers possess valuable information about the operation of production lines—information that engineers and supervisors often lack.
- In today's competitive environment, the competitive advantage of U.S. firms is often in the domain of producing niche products, or products that are R&D or knowledge intensive. In this environment, employees at all levels are required to undertake problem-solving activities; the days of producing commodities with cheap labor are gone.

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firm as $Y_i = BX_i^{(1-\gamma)}K_i^{\gamma}K_a^{\mu}$, where Y_i is the output of the firm i, X_i is other inputs (labor and other capital), and B is other technological change.

[9] For more on the assignment of responsibility within firms, see Prendergast (1995), Rosen (1982) and Geanakoplos and Milgrom (1991).

What these organizational models lack is an emphasis on the IT revolution; but its growing evolution in the 1990s clearly reinforces the movement towards decentralized decision-making. As described above, while purchases of the personal computer began in the early 1980s, its extensive power and widespread use developed in the 1990s. Then, of course, true networking began in the mid-to-late 1990s, with extensive developments in within-firm intranets and the Internet for B2B and B2C communications. Thus, when we add the revolution in IT to our model of decision-making within the firm, that only increases the emphasis on problem solving, for the two reasons stated above:

- All individuals now have more information available to them at all levels.
- Communications are much more rapid and information intensive.

An example helps to clarify the concept of problem-solving capacity. In the traditional HR steel facility, if the production worker recognizes a quality problem on the line, such as a surface defect in the new steel, he will call the foreman and report the problem (or he will do nothing and let the line continue running). In the innovative HR facility, he will have more knowledge of options for correcting the problem (due to his higher training level), he will have up-to-date information as to whether the current customer would reject such steel (given greater day-to-day information sharing), and he will have easy access to other production workers and staff so that he can gather the necessary knowledge to solve the problem (perhaps organizing a group of people to help him solve it on the spot). In the organizational literature, the production worker has a "network" of contacts that he uses to develop collective knowledge as that knowledge is needed to solve a specific problem.

In sum, models of decision-making clearly lead to the conclusion that firms today have a much greater incentive to invest in problem-solving capacity, and that innovative HRM practices and IT investments contribute to problem-solving capacity in several ways. Most important, job design matters: in environments with broader job definitions (so workers do a greater range of tasks) and a flatter, less hierarchical, job structure, workers have access to the information that builds problem-solving capacity. In the traditional environment, of narrow jobs and steep hierarchies, the production worker does not have the breadth of knowledge or the authority to solve the production problem. In addition, with little incentive pay and little information sharing, he does not have the incentive to correct the problem quickly. In recent literature, economists have emphasized either the importance of job design (Holmstrom and Milgrom, 1991) or the importance of the information network (Aoki, 1986, and Bolton and Dewatripont, 1994, Appelbaum and Berg, 1998, and Greenan and Mairesse, 1999), but have not combined these in the development of problem-solving capacity.

What Builds Problem-Solving Capacity: The Complementarity of Innovative HRM Practices and IT

The need to build problem-solving capacity implies that firms must invest in a multitude of innovative HRM practices and information technologies. The examples above suggest reasons why HRM practices are increasingly being considered complements in production.[10] The HRM practices that lead to the development of problem-solving skills would include greater training, information sharing, job security, formal problem-solving teams, and screening for workers who are more able to undertake problem solving, and incentive pay to induce higher effort levels.

In our steel industry studies, we conclude that the preponderance of evidence suggests that the full set of innovative HRM practices are complementary.[11] We find that: adopting the full set of innovative practices produces productivity effects that are not evident for individual practices; numerous HRM practices are often adopted in unison, though somewhat sequentially; and our interviews produced support for the conclusion of complementarity (Ichniowski, Shaw, and Prennushi, 1997, and Boning, Ichniowski, and Shaw, 1998). However, there remain differences in the degree of use of individual HRM practices across firms, and these differences often reflect the historical position of the firm and its costs of introducing changes.[12]

Concerning the investments in information technologies, several researchers have pointed out that IT and organizational changes are complements. This is emphasized by Breshnahan, Brynjolfsson, and Hitt (forthcoming) and by Black and Lynch (2001), as summarized above in the section describing the effectiveness of HRM and IT practices.

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[10] See also Dunlop and Weil (1995), MacDuffie (1995), and Appelbaum, etal (1996).

[11] The data needed for rigorously testing for complementarity does not exist in any data set (Athey and Stern, 1998).

[12] For example, one firm has placed a huge emphasis on training because its founder believed in the value of training, while another firm placed its emphasis on incentive pay because of its founder's beliefs. Both plants subsequently moved in the direction of adopting a full set of practices, but this move took time. As another example of historical effects, one plant that uses 12-hour work shifts finds it difficult to encourage problem-solving activities, because workers are reluctant to work overtime given these long hours.

Changes in Labor Demand: Building Problem-Solving Capacity

There is additional evidence, outside the steel industry, that firms are increasingly investing in problem-solving capacity. While there is no data on the investment in connective capital, there is considerable evidence that the amounts of problem-solving aptitude, or K_i , has risen over time.

Very recent research using large data sets has emphasized the greater demand for cognitive skills. Autor, Levy, and Murnane (2001) use CPS data and information on required skills from the Dictionary of Occupational Titles to show that the demand for non-routine cognitive skills has risen over time. Moreover, this increase in cognitive skills is correlated with the use of new technologies. Similarly, Abowd, Haltiwanger, Lane, and Sandusky (2001) construct a data set for all workers in the state of Illinois and demonstrate that the demand for highly skilled has gone up over time, and that it is correlated with measures of technology investment.

This recent research confirms earlier findings of rising skill demand. Holzer (1996) shows that employers are seeking new hires who are better at reading, math, and reasoning than in the past. Similarly, Black and Lynch (1996) show that the demand for skills and problem-solving appear to have risen over time. And, of course, the extensive research showing that the rising returns to skills are correlated with technology use would indirectly reach this conclusion (see Autor, Katz, and Kruegar (1997) for a review).

These analysis of skill demand have focused on data sets that have information on technology investments, not on HRM practices, but in our case study evidence, and in the survey by Black and Lynch, there is evidence that skill demand is also correlated with the use of innovative HRM practices. Steel mills report that they screen new hires very carefully. Mills with innovative HRM practices screen most carefully, looking for mechanical or operating skills, for math and reading skills, and most importantly, for workers who can work well in teams, are self-motivated, and have a positive attitude towards work. As one manager says, they "look him in the eye… [and look for] someone who is willing and able to train and can do the job without supervision." Mills with less innovative practices are not as demanding, but they too screen more carefully than they did in the past, and seek similar skills. Mills use standardized tests or their own tests, and often have panel interviews for the best prospects. In the past, when the steel industry was growing, they did virtually no screening of possible employees. In the steel communities that surrounded integrated steel mills, it was simply standard practice for a

young man to grow up and follow his father or uncle into the mill (Hoerr, 1988, Biesen, 1996). Biesen describes a representative situation: "Dennis Adams had his pick of the mills in 1964. He went to work for Youngstown Sheet and Tube.. because the first bus at his stop was going there." (Biesen, 1996, page 29). Thus, manufacturing jobs that paid fairly well were fairly plentiful and easily obtained for a man with very limited education. This was true of integrated and minimills. Now, the work is much less physical, and even though the educational requirements are only that of a high school education, the less tangible requirements are considerably higher.

Notice that the skills that firms desire of employees given the innovative HR systems are not skills associated with greater education or experience, though greater education and experience could certainly improve workers' performance as well. In the production environment of the steel industry, employers continue to seek production workers with a high school education and some mechanical training or experience—they certainly don't seek the college-educated for production work. However, though the level of education has changed very modestly, the type of worker demanded has changed more dramatically, to focus on the worker with the people skills to interact with others and bring a positive attitude to the job and problem-solving skills.[13]

In sum, there is now an extensive amount of evidence documenting the greater demand for cognitive skills that build problem-solving capacity at every level of the organization, and at every occupational and educational level. In addition, the average firm today seeks workers who have the "team skills" to cooperate and communicate well with others in problem-solving environments, the personal motivation and drive to respond to reward incentives such as pay and recognition, and the desire to take on additional responsibility (perhaps in response to better rewards). Overall, firms want employees with a "can do" attitude or the desire to make a difference in solving problems, and thus being productive.

Investing in Problem-Solving Capacity – Is it for Everyone?

Thus far, I have emphasized the growing importance of investing in problem-solving capacity – to compete in international markets, and to utilize the U.S. comparative advantage in investing in human capital and information technologies. But should all firms invest in greater problem-solving capacity at all levels?

[13] See Black and Lynch (1996), Holzer (1996), Howell and Wolff (1992), Wolff (1996), and Shaw (1998) for other evidence on the rising demand for skilled production workers.

While the average firm should find it increasingly advantageous to make problem-solving investments, these investments certainly have different rates of return across firms and not all should invest. This is evident in our study of minimills. Because of the microeconomic nature of this study, we can estimate a two equation model: one equation estimates the expected gains (or productivity gains) from investing in innovative HRM choices, and the other equation estimates the decision to invest in innovative HRM practices as a function of the characteristics of the technology. We find that the steel mills that gain the most and adopt the most innovative practices are those with more complex production lines and more complex products. This result is intuitively appealing: problem-solving is more valuable when the production environment faces greater problems due to its greater complexity. In other words, firms that produce commodity products and that change their processes little over time will have the least to gain from investing in problem solving. However, other case study analysis in other industries (Bartel, Ichniowski, and Shaw, 2001) shows that firms that produce commodities may well find innovative practices to be valuable, if the production environment is highly capital intensive and high-quality, so both extensive IT and innovative HRM are valued.

This case study evidence on the value of problem-solving is quite consistent with the survey correlations. Osterman (1994) concludes for his establishment survey (described in the next footnote) that plants that are more likely to adopt innovative team practices are those that are in an internationally competitive product market, have a technology that requires high skill levels, and that follow a strategy that emphasizes product quality and service rather than low costs. We also find that adoption is greater in steel mills that face more competitors (Ichniowski and Shaw, 1995). These factors are likely to be correlated with the expected productivity gains, but perhaps also with transition costs as well, because these costs are likely to be lower for newer plants.

While these examples emphasize that not all firms should invest in innovative HRM practices, it is also the case that not all firms should invest in expensive information technologies. For evidence of different values of investing, see Barua and Mukhopadhyay (2000) and Fichman (2000) and Breshnahan, Brynjolfsson, and Hitt (forthcoming) and Brynjolfsson and Hitt (2000).

Conclusion

In this paper, I have emphasized the importance of investing in problem-solving capacity as a means of improving the productivity of the workforce. In essence, the goal of innovative HRM practices and many investments in IT is to build the problem-solving capacity of workers, which depends on: a) workers having the skills to do problem-solving, where these skills include both the personal training and education, but also the access to information through the set of communications contacts that are needed to solve each new problem as it arises on the production line or to do off-line problem solving; on b) workers having the incentive to do problem-solving, by tying pay to production outcomes, and c) firms having the IT investments to facilitate problem solving.

The productivity gains as arising from investments in HRM and IT are interpreted as arising in part from problem-solving activities that these practices generate. Evidence of this comes from a study of the communications by employees in steel mills. We obtain employee-level survey data on the extent to which each production worker communicates with all other workers on operations-related issues (Gant, Ichniowski, and Shaw, forthcoming). We find strong evidence that production workers on lines with innovative HRM practices are much more likely to have higher levels of problem-solving capacity. These production workers have higher educational levels, but the greatest difference is that they have very rich problem-solving networks of personal contacts.[14]

Given this evidence on the value of building problem-solving capacity, it is important to ask, should all firms invest in it? In the steel data that we have, we conclude that firms that operate in more complex environments gain the most from building problem-solving capacity. Not surprisingly, it is not for everyone.

[14] See also Appelbaum and Berg (1998) and Greenan and Mairesse (1999) for similar evidence on differences in communications patterns.

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Table 1

Evolution of EI

	1987	1990	1993
1. Employee participation groups			
a) Zero participation	30%	14%	9%
b) 1-20% of employee's participation	33%	35%	26%
c) 20% or more employee's participation	37%	51%	65%
2. Self-managed work teams			
a) Zero participation	72%	53%	32%
b) 1-20% of employee's participation	20%	37%	49%
c) 20% or more employee's participation	7%	10%	20%
3. Movement of decision? to lower levels			
a) little change	19%	16%	10%
b) moderate change	63%	60%	63%
c) great change	19%	24%	28%

Source: Lahler, Mohrman, and Ledford (1995, pages, 27, 28, 31).

The percentages show the percent of firms that fall into that category. For example, in 1987 30% of the firms had zero employees participating in "Employee participation groups."

Table 2

Adoption of Employee Involvement

	1992 (1)				1993 (2)	1994 (3)
	Any Use		50% or more			
	All	Manufac-turing	All	Manufac-Turing	Any Use	Any Use
Teams	55%	50%	41%	32%	47%	54%
TQM	34%	45%	25%	32%	76%	73%
Quality Circles	41%	46%	27%	30%	66%	
Job Rotation	43%	56%	27%	37%		

Numbers are percent of establishments that have adopted "any use" of the HRM practice or that have "50% or more" of their employees participating.

(1) Osterman (1994)

(2) Lawler, Mohrman, Ledford (1995)

(3) Black and Lynch (1996).

Table 3

Percentage of Firms Having 50% or More Employees

Covered by EI, by Occupation

Manufacturing	62%
Customer service	56%
Distribution	48%
Marketing	47%
Technical	49%
Staff	53%
1st level managers	55%
Mid-level managers	58%
Top managers	58%

Source: Lawler, Mohrman, and Ledford (1995) p. 98.

Table 4

Differences in Direct Ties Across Firms

	N	Control-Oriented Mean	Control-Oriented Standard Deviation	Involvement-Oriented Mean	Involvement-Oriented Standard Deviation
Production workers	425	15.2	15.1	55.3	23.4
Foreman/Team leaders	22	35.6	26.5	72.1	23.7
Staff	39	26.6	28.7	42.0	23.1
Management	93	19.3	23.1	45.3	29.3

For each person i, define direct $ties_a = \Sigma\delta_{ij} / N_i$, for j=1,.., N, $j \neq i$ This table displays the mean values of these direct ties for all individuals in control-oriented and involvement-oriented production environments in our sample of steel production lines.

Source: Gant, Ichniowski, and Shaw (forthcoming).