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The Effects of Human Resource Management Systems on Economic Performance: An International Comparison of U.S. and Japanese Plants

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This study uses personally collected data from 41 steel production lines to assess the effects of Japanese and U.S. human resource management (HRM) practices on worker productivity. The Japanese production lines employ a common system of HRM practices including: problem-solving teams, extensive orientation, training throughout employees' careers, extensive information sharing, rotation across jobs, employment security, and profit sharing. A majority of U.S. plants now have one or two features of this system of HRM practices, but only a minority have a comprehensive system of innovative work practices that parallels the full system of practices found among the Japanese manufacturers.

We find that the Japanese lines are significantly more productive than the U.S. lines. However, U.S. manufacturers that have adopted a full system of innovative HRM practices patterned after the Japanese system achieve levels of productivity and quality equal to the performance of the Japanese manufacturers. This study's evidence helps reconcile conflicting views about the effectiveness of adopting Japanese-style worker involvement schemes in the United States. United States manufacturers that have adopted a definition of employee participation that extends only to problem-solving teams or information sharing do not see large improvements in productivity. However, U.S. manufacturers that adopt a broader definition of participation that mimics the full Japanese HRM system see substantial performance gains.
(*Human Resource Management; Productivity; Japan*)

1. Introduction

Recent research finds that systems of innovative human resource management (HRM) practices that promote employee participation improve a firm's economic performance.[1] A natural way to provide a further test of the performance effects of systems of HRM practices is to make international comparisons of the performance of similar Japanese and U.S. manufacturers. Large Japanese manufacturing firms are now well known for a distinctive system of work practices that promote worker participation. Work practices that long characterized the labor-management relations of many U.S. manufacturers offer a sharp contrast to the more participatory Japanese system, although many U.S. manufacturers have now adopted their own approaches to employee participation by introducing a number of work practice innovations (Osterman 1994).

[1] For a review of recent evidence, see Ichniowski et al. (1996).

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To make direct cross-national, establishment-level comparisons of HRM practices and performance outcomes, we extend our previous research on the performance effects of HRM practices in a sample of steel finishing lines (Ichniowski et al. 1997) by personally assembling data for a sample of comparable Japanese steel lines. To our knowledge, this is the first study to provide a direct comparison of the work practices and performance outcomes for a sample of U.S. and Japanese manufacturing establishments that employ a common production technology. These unique U.S. and Japanese establishment data enable us to make three important comparisons.

1. We compare the performance of the Japanese steel finishing lines with their distinctive set of HRM practices to the performance of all comparable U.S. lines to determine whether the Japanese lines have a productivity advantage on average.

2. We compare the performance of Japanese lines to that of the U.S. lines that have adopted systems of HRM practices that match closely the system used by the Japanese lines to test whether a similar system of HRM practices produces similar performance in U.S. and Japanese plants.

3. We compare the performance of lines in the United States that have more traditional HRM practices to the performance of Japanese lines and U.S. lines with the most innovative HRM systems to determine whether the latter approaches raise performance levels compared to the more traditional approach in the United States.

2. A Systems Perspective on HRM Practices

Recent theoretical research argues that it is important to analyze a firm's work policies "not in isolation, but as part of a coherent incentive system" (Holmstrom and Milgrom 1994, p. 990). This systems perspective is based on the notion that employment practices often complement each other, so that the adoption of one employment practice is only effective when it is adopted in combination with one or more supporting work practices.

This systems perspective is especially important when analyzing the work environment of Japanese manufacturers investigated in this study. Itoh (1994, p. 258) concludes that "many distinct features of Japanese human resource management . . . are likely to constitute a 'system': they are closely interrelated, and one aspect could not exist without all the others." Milgrom and Roberts (1990) argue that the HRM practices typically found in large Japanese manufacturers provide a particularly clear illustration of a system of complementary elements.[2]

For example, problem-solving teams are central to the *kaisen*, or continuous improvement, process and are a prominent feature of the work organization of large Japanese manufacturers. Yet by themselves, these teams are not likely to elicit worker participation in continuous improvement activities. Problem-solving teams may require employment security policies to be effective because an employment security policy helps allay workers' fears that their productivity-improving ideas could lead to a loss of jobs. Employment security will in turn be complementary with other HRM practices, including flexible job assignments, to allow businesses to reassign workers to more productive jobs in response to changes in product demand. Flexible assignment of workers to multiple jobs requires training to provide workers the skills needed in multiple jobs. Careful employee selection and greater employee voice also become more valuable due to the longer expected careers for employees and the lower probabilities of exit.

According to this view, employee participation initiatives such as problem-solving teams require a set of complementary practices in order to improve economic performance. Existing empirical research on productivity effects of HRM practices supports this view. Several recent studies find that systems of complementary practices that promote employee par-

[2] Baker et al. (1994) and Kandel and Lazear (1992) also identify complementarities among specific HRM practices. Note that Aoki (1994) argues that the system of practices governing the employment relations of Japanese firms is itself complementary with other attributes of the Japanese firm including information processing systems, companies' relations with suppliers and banks, and features of the broader institutional environment. Because our sample is restricted to production lines in a very narrow product line with a single technology, it is beyond the scope of this study to investigate these broader complementarities.

ticipation improve productivity while work practice innovations, such as work teams or quality circles, adopted in isolation do not (Ichniowski et al. 1996, Ichniowski et al. 1997).

3. HRM Practices in Japanese and U.S. Production Sites

Theoretical and empirical research therefore suggests that studies must measure a firm's entire set of work practices to specify the HRM environment correctly. This section describes the systems of HRM practices in the 41 U.S. and Japanese steel finishing lines that provided performance data for this study. We collected data on the actual HRM practices at each line from extensive on-site interviews with labor relations managers, mill operations managers, supervisors, local union officers, and production workers. We measure the HRM practices in the steel making facilities for the 1986–1992 period to match the time period covered by the performance data available for this study.

3.1. The Japanese System of HRM Practices

According to our interviews, HRM practices for blue-collar workers are very comparable across all Japanese integrated steel mills during the time period considered in this study. The HRM practices described in this section apply to all Japanese steel finishing lines in our sample and correspond closely to the prototypical description of work practices employed by large Japanese manufacturers.

The organization of work in Japanese steel finishing lines is characterized by significant worker participation in problem-solving teams and rotation of workers across jobs. Problem-solving teams—known as *jishu kanri* (JK) teams in the Japanese steel industry—are central to the work activities of Japanese steel employees.[3] JK teams in the finishing lines are comprised of six to eight workers (including a team leader) and are the direct vehicle through which *kaisen*, or continuous improvement, activities take place. Team members identify a problem area from several broad categories, such as cost reduction, productivity and efficiency improvements, quality, workplace safety, and environmental improvement, and typically complete several JK projects in a year. According to data from one Japanese production site, 55% of the hours devoted to JK activities were outside the workers' scheduled shift hours, for which workers are compensated, and the remainder were during regularly scheduled shift time. JK themes are evaluated through several commendation procedures.

A second important feature of work organization is the regular practice of planned job rotation. A production employee in one of this study's Japanese steel finishing lines begins work on the simpler jobs at the entry end of this production process and then rotates through all the other jobs on the line in a planned progression. Production workers are expected to master all jobs on the line within the first ten years of employment.

Japanese steel mills identify new candidates for their production and maintenance jobs through close relations they maintain with high schools and industrial schools in their regions. Screening of the candidates involves tests in English, Japanese, and mathematics, and industrial school graduates are tested in their particular areas of specialization, for example mechanical or electrical engineering. In addition to employee screening, employee orientation is especially extensive. During his first twelve months, an employee receives extensive training under the close supervision of senior coaches, who stress the nature of company policies and strive to instill norms of behavior on the job.

Training in Japanese steel mills encompasses training in production skills, communication and problem solving skills, and a set of other activities designed to improve workers' understanding of production issues. This training is provided through a lifetime

[3] While the term *jishu kanri* is widely applied throughout the Japanese steel industry, some mill sites in Japan may use different names for these activities depending on the evolution of these problem-solving teams at the site. Some mills had introduced predecessors of these team-based work activities, such as zero defect programs and quality circles by the early 1960s. In 1969, after zero defect and quality circle programs were widespread in the Japanese steel industry, the Japanese Iron and Steel Federation adopted the term *jishu kanri* for these activities, leading to widespread adoption of this name.

education system that is designed to match the needs of employees progressing through a typical employee's career path. New employees receive extensive off-site training in production skills during their first twelve months with the company. Then, as employees rotate through different production jobs, they receive additional skills training specific to the new jobs. After a period of seven or eight years, a cohort of employees who have learned many production jobs reconvene for additional off-site classroom training. After this point, as employees are promoted to the ranks of deputy assistant foremen, assistant foremen, and foremen, they receive additional training in technical matters or managerial skills. In addition to technical skills, training in safety and maintenance occurs on a regular basis over these years.

Managers and employees in interviews also attested to the considerable knowledge about production operations that they gain through JK problem-solving activities. Employees receive basic problem-solving training to support JK activities, and the JK team leaders receive special JK training. In addition, employee knowledge about their finished steel product is enhanced through a regular practice of employee visits to customers and suppliers to understand special needs of those businesses or to investigate specific quality problems that customers are experiencing.

Japanese steel mills also maintain high levels of labor-management communication through numerous joint labor-management committees established at the level of the company, mill site, department, and shop production unit. Joint meetings, particularly those at higher levels of the organization, consider issues related to the company's employment policies. Topics include production plans, investment plans, staffing projections and adjustments, safety and health, education and training, and some aspects of the workers' pay and work schedules. According to interviews with union and management officials, because joint labor-management committees consider such a wide range of topics, the distinction between joint meetings and formal collective bargaining has become blurred over time. Still, changes in wages and benefits are determined through separate formal collective bargaining. Finally, while a formal grievance procedure is set forth in labor contracts as part of the labor-management communication procedures of most Japanese mills, these procedures are little if ever used.[4]

The Japanese steel companies in this study follow a policy of employment security. The companies have maintained this policy even though the total number of workers directly employed in the companies' mills has declined substantially with the secular decline in demand for steel production since the 1970s.[5] To maintain employment security during a prolonged industry contraction, Japanese steel mills rely heavily on worker mobility. Workers affected by a planned reduction in force may be transferred inside their current department, inside their mill, to a subcontractor or other firm nearby their current works, to another mill of the same parent company, or to a subcontractor of another mill of the parent company. Depending on the type of transfer being considered, the company negotiates with union officials through the appropriate mill- or company-level labor-management committee. For example, transferring employees to work outside the company, referred to as "seconding" the employees, typically involves negotiations in mill- or company-level labor-management committees. When a steel company "seconds" an employee, the company subsidizes the difference in pay between the pay at the parent company and the pay rate at the subcontractor for whom the employee works.

Compensation for production workers in the Japanese steel mills has up to four main components. First, wages increase with the number of years of service an

[4] According to interviews, grievance procedures have atrophied because of the ample opportunity for labor-management communication through joint committees, the willingness of management to adopt changes after discussions with workers or union officials, and a seemingly shared desire to resolve issues among members of a given shop's own local work community without intervention from outsiders. At one mill, workers will still occasionally avail themselves of their mill's grievance procedure, and labor and management representatives there point to the stronger socialist faction at this mill for the continued reliance on grievance machinery.

[5] At one Japanese steel company, the total number of employees working at the company's steel mills declined by over 30% between 1970 and 1990.

employee has with the company. Seniority-based, or *nenko*, pay is a common feature of compensation determination throughout large Japanese manufacturing establishments. Second, the Japanese steel companies in this study award pay differentials to individual employees based on merit evaluations by supervisors. While this component of pay accounts for 24% of the wage bill according to one company, there is little inter-worker variation in merit payments so that most of the variation in wages among workers is attributable to the seniority-based *nenko* payments. Third, workers receive a semiannual bonus payment, the terms of which are negotiated each spring by the companies and unions and determined largely by recent profitability levels of the company. Finally, in one of the Japanese companies, a worker's job classification is a fourth determinant of his pay. In this company, pay rates vary according to an assessment of the knowledge, skills, and level of responsibility for each job.

In sum, the Japanese production lines employ a common system of HRM practices including: problem-solving teams, rotation across jobs, extensive orientation, training throughout employees' careers, extensive labor-management communication, employment security, and compensation based largely on seniority-based wages and profit sharing. We refer to the combination of HRM practices used in Japanese finishing lines as the *Japanese HRM system*.

3.2. HRM Systems in U.S. Work Sites

Steel finishing lines in the U.S. sample exhibit substantially more variation in their HRM practices than do Japanese producers. We grouped lines according to the four different systems of HRM practices that the lines employ, as shown in the last four columns of Table 1.

The Traditional System. The *traditional HRM system* in U.S. finishing lines is comprised of a distinctive set of work practices: narrowly defined jobs; strict work rules; incentive pay based on quantity and not quality of output; no work teams; no practice of managers sharing financial information or meeting regularly off-line with workers or their union representatives; no screening; training only from "what you pick up on the job"; close supervision by a relatively large number of foremen; and communications channeled through an adversarial grievance procedure.

The Low Teamwork and Communication System. A second group of lines has borrowed the work-team policy common to Japanese establishments, but has few innovative work practices. Lines which we categorize as following the *low teamwork and communications system* have all made some attempt to initiate worker involvement in teams, and this effort is always coupled with some labor-management communication practices, either sharing of financial information or regular meetings between line managers and workers or their union representatives. However, other than these two work practice innovations, the set of HRM practices that comprise this HRM system is similar to those that comprise the traditional system. Furthermore, despite the formal work team policy, no line with the low teamwork and communication system has a high level of worker involvement in teams.

The High Teamwork and Training System. A third set of lines in the United States moves further away from the traditional U.S. system by adopting additional innovative work practices. As in the low teamwork and communication system, lines in this third group also have work teams and information sharing procedures. All lines in this group also provide regular and extensive skills training for workers. Furthermore, at all lines in this third group, a majority of workers participate in problem-solving activities, with workers receiving training in problem-solving processes. We therefore refer to this category as the *high teamwork and training system*. Lines in this category always lack one or more of the following innovative HRM practices: extensive screening, job rotation or reduced job classifications, performance-based pay schemes, or employment security.

The Innovative System. A fourth group of production lines in the U.S. sample employs a system of HRM practices with elements that parallel the entire system of work practices found in Japanese establishments. Managers of these lines spent well over a year carefully selecting, orienting, and training new employees before employees began work on the line. All employees are trained in technical line operations,

Table 1 Percentage of Production Lines with Specific HRM Practices Within Five Different HRM System Categories[a]

Practices in Seven HRM Policy Areas	Japanese HRM System	Innovative U.S. System	High Teamwork & Training U.S. System	Low Teamwork & Communic. U.S. System	Traditional U.S. System
1. *Incentive Pay*					
a. Multi-Attribute Incentive Pay	0.00	1.00	0.31	0.00	0.00
b. Extensive Profit Sharing	1.00	0.00	0.15	0.31	0.00
2. *Recruiting*					
a. Very Extensive Screening	0.00	1.00	0.15	0.00	0.00
b. Lengthy Orientation Period	1.00	0.00	0.00	0.00	0.00
3. *Teamwork*					
a. High % In Prob. Solv. Teams	1.00	1.00	0.85	0.10	0.00
b. Workers in Multiple Teams	1.00	1.00	0.62	0.00	0.00
c. Some Teamwork Practice	1.00	1.00	1.00	1.00	0.00
4. *Employment Security*					
a. Employ. Security Pledge	1.00	1.00	0.23	0.48	0.00
5. *Job Flexibility*					
a. Job Rotation	1.00	1.00	0.15	0.03	0.00
b. Combined Job Classes	0.00	1.00	0.38	0.00	0.00
6. *Training*					
a. Off-Site Train, All Workers	1.00	1.00	0.69	0.00	0.00
b. Off-Site Train, Some Workers	1.00	1.00	0.92	0.07	0.00
7. *Labor-Management Communication*					
a. Information Sharing	1.00	1.00	0.54	0.62	0.00
b. Regular Meetings with Workers	1.00	1.00	0.77	0.72	0.00

Note: [a]The sample for Table 1 is based on production lines and not production-line months. Column 1 shows means for the 5 Japanese production lines in the data set. Columns 2–5 shows means for different categories of U.S. production lines. This sample for columns 2–5 includes 54 observations, and not just 36 U.S. production lines, because, for U.S. lines that switch HRM practices during the sample period, it includes one observation for each different combination of HRM practices that the lines experience. For the sample of line-month observations used in the productivity analyses ($n = 2594$), 15.6% are from Japanese lines. Of the U.S. sample ($n = 2190$, 9.3% have the innovative U.S. system, 13.8% have the high teamwork and training system, 41.7% have the low teamwork and communication system, and 35.2% have the traditional U.S. system.

statistical process control, and team problem-solving techniques, and are involved in on-going problem-solving teams. Workers are trained to do all jobs on the line and regularly rotate across tasks. Employee pay is based on a multiattribute gain-sharing plan or a "pay-for-knowledge" system in which employees' salaries increase as they progress through a series of knowledge and skill banks. Finally, workers enjoy an implicit employment security pledge and have regular contact with union officials and with the relatively few managers on the line. We refer to U.S. finishing lines that have this full complement of innovative work practices that match closely the Japanese HRM system as lines with the *innovative HRM system.* We will use the terms "work practice innovation" or "innovative HRM practice" when referring to individual HRM practices, such as work teams, employment security, or on-going training in U.S. establishments, that are found in the low teamwork and communication system and in the high teamwork and training system as well as in the innovative HRM system.

3.3. A Comparison of the Japanese System and the Innovative U.S. System

Table 1 summarizes the distinctive features of the four U.S. systems and the Japanese system of work practices.[6] The four HRM systems in U.S. steel finishing

[6] To classify the U.S. lines shown in Table 1, we used three different statistical procedures to categorize lines according to their HRM practices—Nominate scaling, Guttman scaling, and a simple 0 to 7 HRM index. Each procedure identifies four distinctive HRM categories, and the assignment of lines to the four categories is nearly

lines represent a hierarchy with the traditional system adopting none of the features of the Japanese system, the low teamwork and communication system adopting a quality circle-type practice and a labor-management communication practice, and the high teamwork and training system showing high participation in teams, information sharing procedures, extensive skills training, and occasionally some other innovative practice common to the Japanese system. The HRM practices which comprise the innovative U.S. system match closely the entire set of practices which constitute the Japanese system.

Still, some differences exist between the specific practices in the Japanese system and in the innovative HRM system in the United States. The degree of screening through skills tests and personality tests is considerably more extensive in the U.S. system, while the period of orientation and indoctrination lasts much longer in the Japanese system. Job flexibility is accomplished in the innovative U.S. system through more frequent movement of workers across tasks than in the Japanese model where workers' rotations through jobs is a more gradual process. Finally, U.S. lines have incentive pay plans that tie employees' pay to several line-specific criteria, while in Japanese lines, incentive pay comes in the form of company-level profit sharing payments that are a sizable percent of annual pay.[7]

3.4. Is the Japanese HRM System Transferable to the United States?

Based on case study evidence of failed employee participation efforts in some firms, some have claimed that "Japanese-style HRM" is not transferable to U.S. manufacturers—that the Japanese approach can only work in the context of the Japanese culture. The systems perspective described in §2.1 suggests that key Japanese practices, such as problem-solving teams, can be effectively transferred to the United States if U.S. firms also adopt other complementary practices. Many scholars of work relations in Japan echo this view. Cole (1979) argues that Japanese quality control circles "may well be applicable [in the United States] if appropriate adaptations are made to accommodate the circles to U.S. conditions." Dore (1973) argues that the "Japanese employment system is an emergent organizational form which represents an evolutionary advance over the [form adopted by] early industrializers" and will become more common among newer firms in the U.S. (Dore 1973, as quoted in Lincoln and Kalleberg 1985, p. 739). Similarly, Florida and Kenney argue that this evolution has helped firms "harness the intellectual as well as the physical capabilities of workers" (1991, p. 383).

No prior study has assembled the data necessary to provide a direct test of the performance effects of the Japanese system and a comparable work system in the U.S., such as the innovative system described above.[8] Existing empirical evidence about adoption of participatory work practices does not conclusively address whether HRM practices that are common among large Japanese manufacturers work in U.S. firms. Evidence showing that innovative HRM practices such as work teams are becoming more common among U.S. firms suggests that U.S. firms are finding it increasingly important to adopt the work practices used by Japanese manufacturers.[9] However, other studies that track em-

identical across all procedures (see Ichniowski et al. 1997, pp. 296–298 for further explanation). While we use the categories shown in Table 1 to describe the HRM environment of the lines in the productivity regressions to follow, the results of the productivity regressions are again nearly identical when the HRM categories derived from the alternative statistical procedures are used.

[7] The U.S. producers have profit sharing plans 48 percent of the time, but these plans tend to pay from zero to ten percent of compensation; in Japan, profit sharing pays closer to 40 percent. Still, while profit sharing payments may be a larger share of total compensation, the variation in the Japanese profit sharing payments may be less, as some of the profit sharing payment is in fact a guaranteed payment.

[8] While not directly addressing the issue of whether participatory HRM systems have different effects on performance in different countries, MacDuffie's analysis (1995), which considers the efficiency of auto assembly plants in different countries, including the United States and Japan, provides the most relevant comparisons on these questions.

[9] Osterman's study (1994) of a representative sample of U.S. work establishments finds that some 62% of U.S. establishments have some experience with employee participation, defined as use of work teams, quality circles, or job rotation. Among a sample of large Fortune 1000 firms, Lawler et al. (1992) find that 70% report having experience with employee involvement. These figures represent significant growth in employee participation. For example, Oster-

ployee involvement efforts over longer periods paint a different picture, showing that most employee participation efforts in the U.S. are not long-lived, but are instead disbanded soon after adoption, suggesting that most employee involvement initiatives in the U.S. may not be effective.[10] By comparing the performance levels of steel finishing lines that have the Japanese system, the innovative U.S. HRM system, and other HRM systems in the U.S. with fewer innovative work practices, we provide an explicit test of whether the Japanese HRM system works in the U.S.

4. Sample, Model of the Production Process, and Performance Data

4.1. Sample

Through site visits and extensive interviews with managers, production supervisors, and line employees, we collected precise data on performance measures and the technology of the steel finishing lines in addition to the comprehensive data on HRM practices detailed in the previous section. The sample for our analysis includes data from 36 U.S. production lines and 5 Japanese production lines.[11,12] The productivity analysis below is based on a panel sample of up to 2,594 monthly observations on these 41 U.S. and Japanese production lines—or an average of about five years of monthly observations on a given U.S. or Japanese finishing line.[13]

4.2. Modeling the Production Process

To develop convincing models of the productivity of these lines, we toured each line with an experienced engineer, area operations manager, or superintendent. These tours gave us a detailed understanding of this production process and an opportunity to discuss the best ways to measure and compare the performance outcomes of different finishing lines. All lines in the sample use the same continuous production process. These lines treat very long flat sheets of steel that are about $\frac{1}{8}$th-inch thick. A coiled roll of this steel strip weighing some 12 tons is loaded on the entry end of the line and the beginning of this steel strip is welded to the end of the coil currently running through the line. A long, continuous sheet of steel unrolls from the coil at the front end of the process and threads its way through the machinery that treats the steel. After the finishing treatment, the steel is recoiled and cut at the exit end of the process.

The very specific nature of this production process makes it possible to develop a specific model of production. The potential tonnage produced by line i in month t, or output Q_{it}, is a function of three things: the amount of tonnage loaded onto the line, or steel input I_{it}, the speed of the line, s_{it}, and the number of hours that the line is scheduled to run that month, h^s_{it}:

$$\text{Potential } Q_{it} = \gamma(I^*_{it}s^*_{it}h^s_{it}) \tag{1}$$

man reports that only one-third of the employee involvement programs in his sample are more than five years old.

[10] Drago (1988) finds that a majority of quality circle initiatives fail to survive more than a few years.

[11] In total, we visited 45 U.S. lines at 22 different locations. Four of the 45 U.S. lines visited had only recently begun operations or had not yet started operating and so could not supply productivity information. Of the remaining 41 lines, 36 provided comparable information for estimating the performance models.

[12] In Japan, we visited four steel mills of one company and one mill of a second company. These five sites had a total of 21 lines. The first Japanese company provided data on all three finishing lines in operation at one of the four sites. The second company provided data on the two lines in operation at that site. No performance data were provided for a third line at the mill site of company two since that line had been operating for less than one-half year.

[13] Because the Japanese sample covers fewer lines than the U.S. sample, we were particularly concerned about how representative the sample of Japanese lines was of the broader population of these types of finishing lines among the four large Japanese steel manufacturers. HRM practices for the Japanese lines in the sample for our productivity analyses are identical to the practices at all other mill sites of the two Japanese companies participating in this study. Furthermore, labor relations and personnel managers from these two companies concurred that their employment practices were also the same ones used by all other integrated steel makers in Japan. Concerning performance of the lines, while officials of the Japanese companies would only provide monthly line-specific data from one mill site each, covering a total of five finishing lines, company-level statistics indicated that the performance of these lines was typical of other finishing lines owned by these companies. Furthermore, foremen at the mill sites for which performance data were provided indicated that the performance of the five lines in this sample is typical of performance levels of other finishing lines of this kind in Japan, based upon information shared across companies at industry-wide meetings for foremen and superintendents.

where the quantity in parentheses in (1) is the volume of steel through the line in month t, and γ is an estimate of the density of steel. Thus, potential output is determined by the capacity of the line (and therefore the sizes of coils that are loaded on the line), the speed of the line, and the amount of scheduled running time.

The actual steel produced on the line differs from potential production defined in (1) because the line does not run all of its scheduled hours. Unscheduled "delays" are line stoppages due to problems on the line. Thus, actual production is a function:

$$\text{Actual } Q_{it} = [\gamma(I^*_{it}s^*_{it}h^s_{it})](1 - d_{it}) \tag{2}$$

where d_{it} is delays, or the fraction of scheduled hours which are lost due to unscheduled line stops, and $(1 - d_{it})$ is *uptime.* Once the technological parameters of the line are specified and coil size is determined by technology and product demand conditions, *actual production depends entirely on uptime.* Increases in uptime are increases in tonnage and productivity.

Equation (2) models tons of output, but the quality of these tons is a key issue when examining the effectiveness of HRM practices. The standard industry measure of quality performance for these lines is the "prime yield" rate. The prime yield rate is the percent of total production in a month that meets specific industry standards for designation as "prime" finished steel, denoted Y_{it} here. Adding to Equation (2), quality tons is defined:

$$\text{Quality } Q_{it} = Y_{it}[\gamma(I^*_{it}s^*_{it}h^s_{it})](1 - d_{it}). \tag{3}$$

The number of quality tons depends upon uptime and prime yield rates. Though these two variables are not directly related to one another, there can be indirect relationships between the variables. For example, a mechanical problem that causes a delay might also have been causing quality problems.

4.3. Dependent Productivity and Quality Variables

The dependent productivity variable, uptime ($U_{it} = 1 - d_{it}$), is the percent of scheduled operating time that the line actually runs. It has a mean of 0.928 and a standard deviation of 0.047 in the sample of 2,594 "line-month" observations used in the empirical analyses. It ranges from 0.398 to 1.0. The dependent quality variable, prime yield rate, has a mean of 0.946 and a standard deviation of 0.043 in our panel data set. It ranges from 0.407 to 1.0. Because the percent prime yield variable is the ratio of prime tons to total tons, estimates of the effects of HRM measures or other control variables on this measure of quality will not reflect any effects of these variables on the uptime productivity variable.

4.4. Variables in the Performance Equations

Given the uptime and prime yield measures of performance, the regressions we estimate are:

$$U_{it} = f(MNT_{it}, VN_{it}, CAP_{it}, IQ_{it}, HRM_{it}) + e_{it} \tag{4}$$

$$Y_{it} = g(MNT_{it}, VN_{it}, CAP_{it}, IQ_{it}, HRM_{it}) + u_{it} \tag{5}$$

where the same vector of variables affect uptime and yield, though the coefficients differ, and the measurement error in the residuals is assumed (for now) to be independently and identically distributed.[14]

The uptime productivity variable measures the percent of scheduled uptime the line operates. If increases in scheduled downtime make it easier for lines to achieve higher levels of uptime, and if scheduled downtime is correlated with the HRM measures, then coefficients on the *HRM* variables obtained from (4) will be biased estimates of their effects on productivity. There are two categories of scheduled downtime. One category is downtime due to lack of orders. During our sample period, downtime due to lack of orders is virtually nonexistent in the finishing lines. A second category of scheduled downtime is downtime for scheduled maintenance. Some lines may have low levels of unscheduled delays simply because they schedule more downtime for maintenance work. We control for this possibility directly by including the variable *MNT* in Equations (4) and (5) which measures the number of annual eight-hour maintenance shifts for the line.

Finishing lines in the sample vary in the vintage of their capital. Older finishing lines will have more

[14] Given the nature of the production function, it is possible that a cross-sectional correlation exists between the residuals in Equations (4) and (5), suggesting the need for seemingly unrelated regression estimates. However, such estimation cannot result in efficiency gains when the sets of right-hand-side variables are identical in the two equations, which is the case here (Greene 1997, page 676).

equipment failures and lower uptimes. Because older lines also tend to have more traditional work practices, apparent negative effects of more traditional HRM environments on uptime could therefore reflect the effects of older, less efficient capital. Equations (4) and (5) therefore include the vector *VN* which measures the year the line was built, current age of the line, and the squares of these variables. Unscheduled downtime is also high, and quality low, during startup periods for new lines. Therefore, we also include a dummy variable indicating whether the line is in the first twelve months of operations and a 1 to 12 time counter for the first twelve months of operations.

While the basic steel finishing technology for the lines in this sample is very homogeneous, there are some differences across lines in certain pieces of equipment. Through our on-site inspections and interviews, we identified and collected a comprehensive set of data on technological features of the lines that affect their productivity. *CAP* in Equations (4) and (5) is a vector of up to nine dummy variables indicating the presence of specific features of the equipment along the line that could complicate the production process, making delays more likely, or streamlining operations and thereby reducing delays. *CAP* also includes a variable for periods when new equipment was being installed on a line, since these periods tend to have relatively high levels of delays and low quality, and a dummy variable for the degree of computer automation of the line.[15] Finally, *IQ* is a 1 to 5 index of the quality of the steel input from industry sources based on the quality of steel provided by each line's steel supplier. Lower quality steel input tends to cause more line delays and yield lower quality output, according to those interviewed. The *IQ* control variable changes over time for lines that switch suppliers during the sample period.

In total, the uptime productivity equation includes up to twenty-five controls for detailed characteristics of the lines. The prime yield models include the same set of controls as in the uptime models, but also include a set of five dummy variables to control for slight differences in the ways in which different lines define prime yield.

The HRM practices in (4) and (5) are measured with a vector of five dummies for the different U.S. and Japanese HRM systems described in §3. Thus, by including this vector of HRM system variables in the performance equations represented in (4) and (5), we are able to provide direct evidence on the three comparisons listed in the introduction concerning the impact of participatory HRM systems on performance of U.S. and Japanese manufacturing facilities.

5. The Effects of U.S. and Japanese HRM Systems on Productivity

Because the panel data set includes longitudinal monthly data on each of the 41 finishing lines, we first rewrite the uptime productivity equation in (4) to introduce a serially correlated error:

$$U_{it} = \beta' X_{it} + e_{it} \tag{6}$$

where X_{it} is the vector of right-hand-side variables in (4), and $e_{it} = \rho_{it} e_{it-1} + u_{it}$. We allow for line-specific serial correlation by estimating ρ_{it} separately for each line using generalized least squares (GLS).[16] Table 2 reports the coefficients on the HRM variables from GLS productivity equations. The column 1 regression estimates the average uptime differential between Japanese and all U.S. lines that is independent of the effects of the controls for technological and vintage differences in the production process. The coefficient on the Japan dummy variable indicates that Japanese lines are significantly more productive than U.S. lines. On average,

[15] Data needed to create more fine-grained measures of computer automation of the lines were not available. We created the computer automation dummy based on our direct observations of the lines and discussions with line engineers. Because computer automation is higher in newer lines, this dummy serves as another control for vintage and sophistication of the capital stock.

[16] Because the dependent productivity variable is bounded at one, we also estimate the performance regression as tobits with a mass point at one. While not reported in the table, the magnitude and level of significance of all coefficients in the tobit estimations are virtually identical to those obtained in the GLS specifications, most likely because very few lines have uptimes or yield levels at the upper boundary of 1.0.

Table 2 The Effects of U.S. and Japanese HRM Systems on Productivity
[dependent variable: % uptime; n = 2594]
[GLS; panel-specific serial correlation]

	(1)	(2)	(3)	(4)	(5)	(6)
1a. Japanese HRM System	0.049*** (0.005)	0.073*** (0.006)	–	0.052*** (0.005)	0.077*** (0.006)	–
1b. Japanese HRM System—Company #1	–	–	0.074*** (0.006)	–	–	0.076*** (0.006)
1c. Japanese HRM System—Company #2	–	–	0.068*** (0.008)	–	–	0.074*** (0.008)
2a. U.S. Innovative HRM System	–	0.073*** (0.008)	0.072*** (0.008)	–	0.074*** (0.008)	0.072*** (0.008)
2b. U.S. High Teamwork & Training HRM System	–	0.036*** (0.005)	0.037*** (0.005)	–	0.039*** (0.005)	0.039*** (0.005)
2c. U.S. Low Teamwork and Communication HRM System	–	0.015*** (0.004)	0.014*** (0.004)	–	0.020*** (0.004)	0.019*** (0.004)
3. Controls for Production Process Technology[a]	yes	yes	yes	yes	yes	yes
4. Year Dummies	no	no	no	yes	yes	yes
Log-likelihood	7228.9	7282.8	7283.3	7256.1	7306.8	7306.7

Table Notes: [a]Other controls in the uptime productivity model include: number of years line has been operating and years squared; year line was built and year built squared; dummy for startup period (first twelve months of operation) and a 1-to-12 time trend for month of startup; 1-to-5 index of quality of steel input; number of annual eight-hour maintenance shifts; dummy for type of customer; maximum width of line and its square; maximum line speed and its square; nine dummies to indicate specific pieces of equipment on the line and the age of one of these equipment features; a dummy to indicate high and low levels of computerization of line controls; and a variable to measure 6-month periods from the date any new major pieces of equipment are introduced.

*** Significant at the 0.01-level.

The mean value of the line-specific serial correlation coefficient is 0.46 for column (2).

line delays in Japanese lines are some 4.9 percentage points lower than in U.S. lines, or Japanese lines are about five percent more productive.

Column 2 breaks out the group of all U.S. lines into the four different HRM categories—the innovative system, the high teamwork and training system, the low teamwork and communication system, and the traditional U.S. system which is the omitted group. The results in the column 2 model show a clear hierarchy of productivity effects. Compared to the productivity of the traditional U.S. system, the low teamwork and communication system achieves productivity that is 1.5 percentage points higher; the high teamwork and training system 3.6 percentage points higher; and the innovative U.S. system 7.3 percentage points higher.

The column 1 and 2 results support two important conclusions. First, Japanese production lines operating under their distinctive approach to HRM are significantly more productive than the average U.S. production line. Second, U.S. production lines with the innovative system that parallels closely the Japanese system perform equally as well as the Japanese lines. Specifically, the coefficient on the Japanese system variable is not statistically different from the coefficient on the U.S. innovative system variable ($F[1, 2564] = 0.09$). This evidence supports the view that *U.S. producers that follow the Japanese* ***system*** *of HRM practices match the high levels of productivity of Japanese producers*. The productivity of these lines far outpaces the productivity of U.S. lines that continue to follow the traditional U.S. system. When U.S. lines confine their adoption of innovative practices to work teams and information sharing without other supporting work practices, productivity levels are only slightly higher than the productivity of U.S. lines with the traditional U.S. system.[17]

The column 3 specification allows for different productivity effects for lines owned by different Japanese companies. The lines of the two different Japanese companies exhibit very similar levels of line uptime. An F-test cannot reject the hypothesis that coefficients on the Japan Company 1 and Japan Company 2 variables are equal ($F[1, 2563] = 1.74$), indicating equally high levels of productivity across all Japanese lines. Finally, the models in columns 4–6 replicate the columns 1–3 models but add a set of year dummies to the models. The inclusion of the year dummies has virtually no effect on the pattern of results shown in the column 1–3 models.

The coefficients on the control variables in the productivity equations are largely in the expected directions and most are statistically significant (see the Appendix table). These coefficients indicate that lines have more delays with: lower quality steel input; older production technologies; start-up periods; higher line speeds and wider coils; and the periods when new equipment is being installed. Contrary to expectations, scheduled maintenance does not, on average, significantly raise uptime (though it does raise yield). One possible explanation, suggested by our field research, is that problem-solving teams in Japanese and innovative U.S. lines have helped make maintenance work more efficient, leading to fewer hours of maintenance in the lines that have achieved high levels of uptime (see footnote 26 for examples).

Inclusion of the control variables in the productivity models is consequential, because control variables are correlated with the *HRM* variables. For example, the more innovative HRM systems tend to be in newer lines. Average years of startup for lines in the different HRM categories are: 1986 for innovative lines, 1969 for the high teamwork lines, 1961 for the low teamwork lines, and 1956 for the traditional lines. The sample's Japanese lines opened in the late 1960s and early 1970s. Several variables measuring features of the capital equipment are also related to capital vintage and so are also correlated with the HRM system variables.[18] Because newer equipment has higher uptimes, models that exclude controls for detailed features of the capital equipment yield even larger estimates of the performance impacts of more innovative HRM systems.[19]

6. The Effects of Japanese and U.S. HRM Systems on Product Quality

Estimates of the performance effects of different HRM systems in Table 2 focus on one dimension of

[17] As shown in Table 1, the specific HRM practices within any HRM system category are always very similar. In three of the HRM system groupings, the general HRM practices are identical (i.e., mean value of 1.0). However, some variation in HRM practices occurs within the high teamwork system and in the low teamwork system. The variation of individual HRM practices within these HRM system groups allows for an interesting test of the marginal benefits of individual work practices.

We show in Ichniowski et al. (1997, 309–311) that the adoption of an additional individual HRM policy within a given HRM system group has no impact on productivity, and that the HRM system variables add explanatory power to models that already contain the full vector of individual HRM practices. While these tests support the conclusion that it is the HRM system variables (and not the effects of the component practices) that matter, other interesting tests are precluded by the lack of variation in HRM practices within the most innovative groups. For example, we are unable to test whether all components of the innovative or Japanese systems are essential for problem-solving and JK teams to be effective, because there is no variation in the individual HRM practices within these systems.

[18] More detailed descriptive statistics on the control variables by HRM group are available from the authors.

[19] It would be instructive to estimate fixed effects models in addition to the GLS models presented. For example, because lines with the innovative HRM system screen workers carefully, it is possible that the innovative system of HRM practices may only be effective with specific kinds of U.S. employees. Unfortunately, no U.S. line with the innovative system and no Japanese line changed their HRM practices during the data period; thus fixed effects models cannot test this possibility. However, some U.S. lines did switch from the traditional system into the communication system and into the high teamwork and training system. Estimates of the coefficients (and standard errors) for the low teamwork and communications system variable and the high teamwork and training system variable from a fixed effects model are 0.025 (0.006) and 0.035 (0.008) respectively—similar to the estimated effects for these variables in the GLS models in rows 2b and 2c of Table 2. While fixed effects models cannot estimate the productivity effects of the Japanese or innovative systems, the fixed effects coefficients that can be estimated provide particularly strong evidence that changes away from the traditional system to HRM systems with more innovative practices do improve productivity. For a detailed discussion of fixed effects estimates, see Ichniowski et al. (1997).

performance—productivity. However, when considering the competitive advantages that Japanese manufacturers are thought to possess, it is common to think of higher levels of product quality of Japanese manufacturers. Table 3 presents estimates of the effects of the U.S. and Japanese HRM systems variables on the prime yield quality measure. The results in column 1 indicate that on average Japanese lines have significantly and substantially higher prime yield rates than do the U.S. lines. The coefficients in subsequent columns indicate that the four U.S. HRM system variables exhibit a hierarchy of quality effects as in the productivity models, but now there is less difference between the middle two HRM systems. The prime yield rates in the Japanese and innovative U.S. lines are significantly and substantially higher than the prime yield rates achieved under either the high teamwork and training system or the low teamwork and communication system. The lowest levels of quality are found in lines with the traditional U.S. system. Japanese lines have the highest prime yield rates, which are somewhat higher than the prime yield rates in those U.S. lines with the innovative system.

The Table 3 column 3 specification allows the estimated quality levels to vary across the lines of the two Japanese companies, and there is little difference. The coefficients on the HRM system variables are virtually unaffected when year dummies are added to the prime yield models in columns (4)–(6). The general pattern of findings demonstrates that Japanese lines and innovative U.S. lines achieve substantially higher quality levels than U.S. lines with any of the other three HRM systems,

Table 3 The Effects of U.S. and Japanese HRM Systems on Product Quality

[dependent variable: % prime yield; $n = 2154$]
[GLS; panel-specific serial correlation]

	(1)	(2)	(3)	(4)	(5)	(6)
1a. Japanese HRM System	0.069***	0.146***	–	0.065***	0.145***	–
	(0.006)	(0.010)		(0.006)	(0.010)	
1b. Japanese HRM System—Company #1	–	–	0.155***	–	–	0.154***
			(0.011)			(0.011)
1c. Japanese HRM System—Company #2	–	–	0.144***	–	–	0.145***
			(0.011)			(0.010)
2a. U.S. Innovative HRM System	–	0.107***	0.113***	–	0.104***	0.110***
		(0.010)	(0.011)		(0.010)	(0.011)
2b. U.S. High Teamwork & Training HRM System	–	0.053***	0.059***	–	0.052***	0.058***
		(0.007)	(0.008)		(0.007)	(0.008)
2c. U.S. Low Teamwork and Communication HRM System	–	0.053***	0.055***	–	0.050***	0.053***
		(0.007)	(0.008)		(0.007)	(0.007)
3. Controls for Production Process Technology[a]	yes	yes	yes	yes	yes	yes
4. Year Dummies	no	No	no	yes	yes	yes
Log-likelihood	7471.2	7591.5	7591.9	7491.5	7616.7	7621.6

Table Notes: [a]Other controls in the uptime productivity model include: number of years line has been operating and years squared; year line was built and year built squared; dummy for startup period (first twelve months of operation) and a 1-to-12 time trend for month of startup; 1-to-5 index of quality of steel input; number of annual eight-hour maintenance shifts; dummy for type of customer; maximum width of line and its square; maximum line speed and its square; nine dummies to indicate specific pieces of equipment on the line and the age of one of these equipment features; a dummy to indicate high and low levels of computerization of line controls; a variable to measure 6-month periods from the date any new major pieces of equipment are introduced; and five dummies for slight differences in how prime yield is defined in different lines.

*** Significant at the 0.01-level.

The mean value of the line-specific serial correlation coefficient is 0.52 for column (2).

though the Japanese system is superior to the innovative U.S. system.[20]

The empirical results show that technologically similar production lines achieve gains in *both* productivity (or uptime) and product quality when systems of innovative HRM practices are introduced. This is a noteworthy outcome, because managers typically experience the negative tradeoff between productivity and quality—on any given production line, an increase in line speed lowers quality. However, when technological change is introduced on a production line, such a negative tradeoff need not exist: New, more technologically sophisticated, physical capital often simultaneously raises both productivity and product quality.[21] The introduction of innovative HRM systems is analogous to a technological change, because problem-solving teams can devise ways of improving the production line to elevate one performance outcome without harming the other, or to elevate both (for examples, see footnote 26).

7. Accounting for the Limited Adoption of the Innovative HRM System in the U.S.

The results in Tables 2 and 3 consistently show that the finishing lines achieve superior performance under the Japanese HRM system and the innovative HRM system in the U.S. The magnitudes of the performance effects attributable to the different HRM systems are economically important. Using data on these costs made available by one line in the United States, we calculate that a conservative estimate of the difference in operating income due to a one percentage point increase in uptime to be about $30,000 per month.[22] The uptime advantage of seven to eight percentage points enjoyed by the innovative system over the traditional U.S. HRM system, and the two to three percentage point advantage of intermediate HRM systems over the traditional system in the United States, translate into large gains in revenues and operating incomes. The increases in prime yield rates due to more innovative HRM systems add to these already substantial improvements in operating incomes.

Given these large performance differentials associated with innovative HRM systems, an important question is why the innovative system is not more widespread in the U.S. Several explanations can be ruled out. First, the direct costs of the innovative HRM practices themselves appear to be far less than the benefits of increased performance.[23] Second, the pattern of results does not support an interpretation that the estimated performance gains due to HRM systems can only be achieved in certain types of lines, such as newer lines, thereby limiting the adoption of the

[20] In fixed effects quality models, estimated coefficients (and standard errors) on the high teamwork and training variable and on the low teamwork and communication variable are 0.042 (0.007) and 0.050 (0.008), respectively, providing further evidence that the changes in the HRM systems are themselves responsible for the differences in the observed levels of performance.

[21] The coefficients on the control variables in the uptime and yield regressions provide some evidence of a tradeoff between uptime and yield—numerous coefficients are opposite in sign in yield versus uptime (see the Appendix table). Overall, the control variables are simultaneously picking up two effects: the static cross-sectional correlations across lines, when there is a negative tradeoff between uptime and yield, and the dynamic correlations (within lines over time and between new and old lines) when there is a positive correlation between yield and uptime due to technological improvements. On balance, the correlation between yield and uptime is 0.489 in the raw data.

[22] Operations managers explained to us the losses caused by line delays. During an unscheduled line stop, the line loses revenue from planned output, but still incurs fixed costs, such as capital depreciation charges (that exceed $5,000 *per hour* in some lines), and certain variable costs, such as wages, which are typically paid during downtime. Lines do not incur other variable costs, such as costs of steel inputs and substantial portions of the energy costs, during line stops. Our calculation of the effect of a delay on operating income is based on this information.

[23] We estimate that the direct costs of the innovative HRM policies is about $2,100 per month for each percentage point gain in uptime—considerably below the gains in revenue and operating income due to a one percent gain in uptime. According to interviews at the sites, the main differences in the costs of HRM policies between the traditional system and the innovative system include: the time production workers would meet off the line, additional HRM staff, consultants for training and team development, fixed costs for developing policies, and costs of employment security for wages paid during idle time. The innovative system also saves on certain costs, such as fewer management personnel. In our calculation here, we assume one less foreman in innovative lines than in traditional lines, and amortize any fixed costs of innovative HRM policies over a five-year period.

innovative system among older lines. The performance models include direct controls for differences in the vintages of the lines. While a positive correlation exists between innovative HRM systems and newer capital stocks, some old lines do have innovative HRM practices and exhibit higher performance than older lines with more traditional HRM practices.[24] Third, the evidence also does not support an explanation that some unmeasured aspect of line quality makes the more innovative HRM systems ineffective among lines with more traditional HRM systems. The strongest evidence against this interpretation is from the fixed effects models which show that the same lines with the same workers have higher productivity and quality after adopting more innovative systems than when they had the traditional HRM system.[25]

While an analysis of the overall effects of innovative HRM systems on profitability is beyond the scope of the data available for this study, the pattern of empirical results suggest that difficult-to-measure "switching costs" are likely to be the most important obstacles to more widespread adoption of the productivity- and quality-improving HRM systems. In particular, brand new lines in greenfield sites uniformly adopt innovative work practices. As startups, these lines do not face switching costs. Those older lines that adopt the most innovative practices are typically "reconstituted" lines—lines that have been closed and later reopened by new owners—and these lines also would not have switching costs because the lines had been closed. Changing the traditional U.S. HRM system to the innovative system in an on-going line would cause a costly upheaval in work relations among employees. This dramatic change in HRM systems would alter the rights and privileges of different groups of workers, change the status of foremen and senior workers, and require new investments in training to develop new technical and social skills.

8. Worker Behavior and the High Performance of Japanese Production Sites

The conclusion that the Japanese and innovative HRM systems are themselves responsible for the high levels of productivity and quality, rather than some omitted measure of line quality, would be strengthened with evidence on differences in worker behavior between lines with innovative HRM systems and lines with more traditional systems. During our field investigations, we observed dramatic differences in worker behavior across lines with these different HRM systems. In particular, extensive problem-solving activity exists only in the Japanese lines and in the U.S. lines with the innovative system, and this activity directly improves uptime and prime yield rates.

One Japanese mill provided data on the JK problem-solving activity for its two finishing lines for 1992. Workers on one line completed 52 JK projects in 1992 and workers on the second line completed 39 projects. During our tours of Japanese lines and the innovative U.S. lines, engineers showed us concrete examples of many of the recent continuous improvement projects, and described how these projects help produce consis-

[24] Old U.S. lines that were closed and later reopened by new owners and managers typically adopt more innovative HRM systems. Several Japanese lines in our sample date back to the 1960s and are older than some U.S. lines with the traditional or low teamwork and communication HRM systems. Results from the performance models show that older lines in Japan and older lines in the U.S. with some innovative work practices in their HRM systems, exhibit substantially higher levels of productivity and quality than do other old lines with more traditional practices.

[25] See footnotes 19 and 20 supra. While the absence of lines that switch to the most innovative HRM system or the Japanese system precludes fixed effects estimates of the impacts of these two HRM systems, other pieces of evidence suggest that unobservable measures of quality are not likely to be the explanation for the estimated HRM coefficients. First, coefficients on control variables in OLS and fixed effects models are very similar providing some assurance that the OLS models include all important line-specific determinants of productivity. Second, the collection of precise data and the on-site inspections of each production line in our sample with experienced managers make it unlikely that the models omit any technological determinants of performance. Finally, the qualitative evidence reported in §8 identifies real differences in worker behavior found only in Japanese and innovative U.S. HRM systems that are responsible for productivity differences. The HRM practices themselves and not some unobserved factor would seem to be the most likely causal factor behind these performance-enhancing differences in worker behavior.

tently higher levels of productivity and quality.[26] The number of projects for a finishing line is only a small percentage of the total number of projects implemented mill-wide. Records for one Japanese mill show that during the 1980s total JK projects completed fluctuated between 2,000 to 3,000 per year, and the majority of these projects focused on improving productivity or quality or on reducing operating costs. Production workers in Japanese lines and innovative U.S. lines also collaborated more with co-workers, responded more quickly to quality imperfections in the steel, and made more productive decisions on the line. In contrast, problem-solving was nonexistent in U.S. lines with the traditional system and very limited in lines with the intermediate systems. The essential point here is that a system of human resource practices that supports employee participation enables workers to fine tune their production process with fairly minimal investments, and these productive worker behaviors are much less common in lines with other HRM systems.

9. Conclusion

This study uses a unique body of personally collected data on one very specific kind of steel-making production process to compare the work practices and performance outcomes for very similar U.S. and Japanese production lines. The homogeneity of the sample and the careful specification of the productivity model permit particularly precise performance comparisons. The study's empirical results directly address the three comparisons listed in the Introduction:

1. We find that Japanese lines are five percent more productive than U.S. lines, on average, after controlling carefully for differences in the quantity and quality of the technology on the production line. Thus, the question is, what causes this productivity advantage?

2. We find that U.S. lines that adopt a full set of innovative HR practices that are comparable to those of the Japanese lines are as productive as the Japanese lines. There is no statistically significant difference in the productivity levels of the Japanese and innovative U.S. lines. Thus, the productivity advantage of Japanese lines arises primarily from the HRM practices they employ, not from other factors, like cultural differences.

3. We find that the set of lines having innovative HR practices, in Japan and in the U.S., are on average seven percent more productive than the U.S. lines employing traditional HR practices. This provides an important confirmation of our earlier work that uses only U.S. data to evaluate the effectiveness of innovative HRM practices that promote employee participation (Ichniowski et al. 1997).

We also find that quality gains accompany the productivity gains—that both uptime and yield rise with innovative HRM systems. The early detractors of the "quality movement" believed that quality improvement would come at the expense of lower productivity (Cole and Scott 1999). We find that the introduction of innovative HR practices is comparable to the introduction of technological change—production lines can simultaneously achieve improvements in two performance outcomes that were long considered tradeoffs.

There are also reasons to suspect that the performance improvements due to these HRM systems may be greater than the productivity and quality gains measured here. First, U.S. and Japanese problem-solving teams also devote considerable time to saving materials, energy, and other input costs, which are not captured in the two performance measures we investigate. Second, the data indicate that the problem-solving teams in the highest performing lines devised ways to reduce maintenance

[26] Examples of JK projects in Japanese lines include the installation of dust collectors or tents to reduce foreign substances settling onto the steel coils in the line, thereby increasing prime yield. Employees figured out ways to reduce water spraying on the line and to improve the clamps when steel coils are sheared, both leading to reduced delays. One award-winning JK project involved the installation of newly designed rollers which reduced scrap rates by 900 tons per month and increased output on the line by 2.9 tons per man hour. Similar examples of problem-solving team projects in U.S. lines include: the addition or repositioning of line gauges; a process to stamp job numbers on the steel and visible crd displays of job numbers for operators; and improved exit end stands to limit coil damage. One team of production workers at a U.S. line described how they used their continuous improvement process to eliminate breaks in welds between subsequent coils, a problem that numerous outside experts could not solve, thereby reducing delays considerably. Problem-solving teams also find ways of reducing time spent on maintenance, by reconfiguring rolls, changing their standby location, or increasing the number of standby rolls.

hours. Third, innovative HRM systems appear to create an "option value." That is, highly skilled, well-trained employees create the capacity to respond quickly to future changes in production and market conditions. Specifically, Japanese finishing lines in our sample have long maintained very high levels of uptime and prime yield between 98 to 100%, yet JK projects still produce "continuous improvements" in these lines. Japanese managers indicated that this result was not paradoxical. They emphasized that there are constant "shocks" to the production line—the depreciation of the existing capital that lowers performance, the introduction of new pieces of equipment on the line, and changes in product types and customer specifications—that would all normally contribute to reductions in performance. JK teams are a primary vehicle for achieving continuous improvement in this dynamic production environment to maintain the highest possible levels of productivity and quality.

Finally, the evidence in this paper helps reconcile conflicting views about the effectiveness of Japanese-style worker involvement schemes in the U.S. While more research is required on the limited adoption of innovative HRM systems in the U.S., the debate about the effectiveness of Japanese-style employee participation can be addressed by clarifying what is meant by the "Japanese" approach. Limited effects of participatory work practices in the U.S. do not appear to be due to differences in the culture or characteristics of U.S. and Japanese work forces. Rather, U.S. manufacturers will realize only modest performance gains when they limit their participation initiatives to only one or two innovative practices, such as quality circles or information sharing. U.S. manufacturers who embrace a broader definition or participation, that calls for the adoption of a comprehensive set of innovative HRM practices, will match the higher levels of productivity and quality found in Japanese plants.

Appendix

Table Full Set of Coefficient Estimates Uptime and Prime Yield Models (Table 2 Column 2 Uptime Model and Table 3 Column 2 Prime Yield Model)

Variable	Uptime	Yield	Variable	Uptime	Yield
1a. Innovative HRM System	0.073***	0.107***	8c. Equipment Dummy 2c	0.078***	0.044***
	(0.008)	(0.010)		(0.008)	(0.009)
1b. High Teamwork & Training System	0.036***	0.053***	9. Equipment Dummy 3	0.004	0.001
	(0.005)	(0.007)		(0.003)	(0.002)
1c. Low Teamwork & Com. System	0.015***	0.053***	10. Equipment Dummy 4	0.008***	0.0002
	(0.004)	(0.007)		(0.003)	(0.002)
2. Japanese HRM System	0.073***	0.146***	11. Equipment Dummy 5	0.016***	0.004
	(0.006)	(0.010)		(0.004)	(0.003)
3. Index of Steel Input Quality	0.007***	0.0044***	12. Age of Dummy 5 Equipment	−0.0011***	0.0005***
	(0.001)	(0.0010)		(0.0002)	(0.0001)
4a. Year Built	0.018***	−0.013***	13. Equipment Dummy 6	0.038***	0.018***
	(0.003)	(0.002)		(0.008)	(0.006)
4b. Year Built^2	−0.0001***	0.0001***	14. Dummy for Low Computerization	−0.020***	−0.027***
	(0.00002)	(0.00002)		(0.003)	(0.003)
5a. Lineage	0.005***	0.0018***	15a. Maximum Line Speed	−0.018***	0.017***
	(0.001)	(0.0007)		(0.005)	(0.004)
5b. Lineage^2	−0.0001***	−0.0003***	15b. Maximum Line Speed^2	0.0015***	−0.0019***
	(0.00002)	(0.00001)		(0.0004)	(0.0004)
6a. Dummy for Start-up Period	−0.066**	−0.014	16a. Maximum Width	−0.0057***	0.012***
	(0.017)	(0.010)		(0.0018)	(0.001)
6b. Time Trend for Start-up Period	0.006**	0.0018	16b. Maximum Width^2	0.00005***	−0.0001***
	(0.002)	(0.001)		(0.00001)	(0.00001)
7a. Equipment Dummy 1a	0.018***	0.004***	17. Dummy for Type of End User	0.0065	−0.029***
	(0.004)	(0.002)		(0.006)	(0.005)

Appendix Table *Continued*

Variable	Uptime	Yield	Variable	Uptime	Yield
7b. Equipment Dummy 1b	0.018***	−0.007***	18. New Equipment-Value during six	−0.0025***	−0.0008***
	(0.004)	(0.003)	month installation	(0.0005)	(0.0002)
8a. Equipment Dummy 2a	0.017***	−0.026***	19. Maintenance Shifts Per Year	−0.00001	0.000006
	(0.008)	(0.006)		(0.000006)	(0.000017)
8b. Equipment Dummy 2b	0.033	−0.002	20. Intercept	0.378***	0.935***
	(0.009)	(0.005)		(0.088)	(0.067)
Mean ρ	0.46	0.52	Log-likelihood	7282.8	7591.5

Table Note: Prime Yield Model also includes four dummies for slight differences in how different lines define prime yield. ***Significant at the 0.01 level; **Significant at the 0.05 level; *Significant at the 0.10 level.

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