# Unions and technology adoption: A qualitative analysis of the use of real-time control systems in U.S. coal firms.

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Link, A. N., & Siegel, D. S. (December 01, 2002). Unions and technology adoption: A qualitative analysis of the use of real-time control systems in U.S. coal firms. *Journal of Labor Research, 23,* 4, 615-630.



**Abstract:**

I. Introduction

In recent decades, many manufacturing firms have adopted new technologies, such as computer-aided design (CAD), computer-aided manufacturing (CAM), computer numerical control (CNC), and just-in-time production (JIT) systems. Implementation of these diffuse technologies can have a dramatic impact on the work environment since they may simultaneously result in downsizing (labor-saving innovations), retraining of the remaining work force ("skill upgrading"), and changes in job responsibilities resulting from integration across the functional areas of business (marketing, manufacturing, R&D, accounting/finance, logistics, purchasing, and product design). A concomitant trend in manufacturing industries is a precipitous decline in the rate of private sector unionization (Potter, 2001), which has been especially steep in the coal mining industry. Thus, a natural question arises as to the nature of the relationship between unions and implementation of these new technologies.[ 1]

**Keywords:** trade unions | coal firms | technology | technological change | mining industry | coal industry | production management | labor research | technology adoption

**Article:**

I. Introduction

In recent decades, many manufacturing firms have adopted new technologies, such as computer-aided design (CAD), computer-aided manufacturing (CAM), computer numerical control (CNC), and just-in-time production (JIT) systems. Implementation of these diffuse technologies can have a dramatic impact on the work environment since they may simultaneously result in downsizing (labor-saving innovations), retraining of the remaining work force ("skill upgrading"), and changes in job responsibilities resulting from integration across the functional areas of business (marketing, manufacturing, R&D, accounting/finance, logistics, purchasing, and product design). A concomitant trend in manufacturing industries is a precipitous decline in the rate of private sector unionization (Potter, 2001), which has been especially steep in the coal mining industry. Thus, a natural question arises as to the nature of the relationship between unions and implementation of these new technologies.[ 1]

Unfortunately, there is a paucity of data on technology adoption and union activity, especially in the mining industry, so it is difficult to conduct an econometric or statistical analysis of this presumed relationship. This void explains why there is little empirical evidence on the effects of unionization on technology adoption at any level of aggregation. Absent the data to conduct a systematic analysis, field-based methods are a reasonable alternative. The advantage of such an approach is that it allows researchers to assess the impact of a specific, well-defined technology on establishments in a given industry.

Although the use of such techniques raises sampling concerns and limits the generalizability of the findings, qualitative analysis can nevertheless be useful in helping to frame issues for further empirical exploration. Field-based research on the economic and managerial implications of technology has received greater attention in recent years, due to the NBER/Sloan Foundation Project on Industrial Technology and Productivity (Helper, 2000) and heightened interest in evaluating technology-based institutions (Link and Scott, 1998; Siegel et al., 1999). Although inductive, qualitative methods may appear to be rather crude, we believe that such an approach is warranted given the lack of systematic data and empirical evidence on this phenomenon.

Herein, we present a qualitative analysis of the influence of unionization on the adoption of a new technology in coal mining: real-time control systems (RCS) technology, as applied to automated mining engineering equipment. Engineers assert that implementation of RCS technology will yield benefits to workers and firms via a reduction in miner fatalities and injuries and an increase in productivity, through automated extraction and hauling of coal. However, given that RCS constitutes a labor-saving innovation, we conjecture that unions may oppose the implementation of this technology.

Our qualitative analysis is based on a series of hypothetical questions posed to managers and miners at nonunion and union coal companies regarding the costs and benefits of technology adoption. Our findings imply that unions may constitute an obstacle to the adoption and use of new technologies, suggesting that further scrutiny of the relationship between union activity and technological change is warranted.

Our study is organized as follows. In Section II, we describe computer-controlled mining systems engineering, or real-time, control-systems-based intelligent equipment and its application to underground coal mining. In the following section, we briefly review aspects of the empirically based rent-seeking literature, in terms of the unionization effect on research and development (R&D) activity. We then extrapolate from that literature to posit the effect of unionization on technology adoption. In Section IV, we present our analysis of the qualitative data related to managers' and miners' expressed preferences about RCS-based intelligent equipment being introduced into their mines. In the final section, we interpret our empirical findings and offer some concluding remarks, including suggestions for future research in this area.

## II. Computer-Controlled or Real-Time Control Mining Systems Engineering[ 2]

Intelligent machine control systems have been used in manufacturing processes since the early 1970s. Real-time intelligent machine control systems applications are a newer form of this class of technologies. Furthermore, their application is more flexible than conventional technologies, including ( 1) robotic or machine tool applications requiring high-speed servo control of machines with either multiple joints or multi-axis of robotic motion, ( 2) systems engineering of the coordination of several machines or several major subsystems to accomplish a set of goals, and ( 3) sensory feedback mechanisms used in communication networks and human interfaces. Thus, real-time control system (RCS) architecture is an engineering methodology that has many applications. RCS represents a cutting-edge technology, although it will not become widely available for another year or two. There is a strong consensus among experts in the field that RCS will constitute a state-of-the-art technology for about a decade.

An RCS architecture consists of the following concepts: establishing a set of integration rules; identifying information models and real-time software execution models to highlight critical components of the RCS problem domain (e.g., intelligent machine control systems); and selecting software engineering implementation techniques that are compatible with any of the above. Software and hardware are the two major divisions of the architecture model. Included in the software are information and execution models. The hardware embodies essential resources, ranging from people to communication networks. The task of an RCS architecture or RCS methodology is to create, in real time, an efficient interface between software and hardware in order to complete a given task. Stated alternatively, an RCS provides a practical guideline or set of architectures to program a robot, or similar equipment, to interact with its environment.

In the early 1970s, the federal government began to provide financial support for fundamental RCS technology, mainly through the National Institute of Standards and Technology (NIST) within the U.S. Department of Commerce (Quintero and Barbera, 1992). More importantly, since 1987, NIST has allocated over $30 million to developing industrial applications of RCS technology, in conjunction with financial support from the private sector. While much of this research is generic and infrastructural in nature, one particular RCS project - computer-controlled mining systems engineering or RCS-based intelligent equipment - is expected to have a significant effect on productivity and labor relations in the U.S. coal industry.

This public-private research initiative began as a joint NIST-U.S. Bureau of Mines' (USBM's) Pittsburgh Research Center (PRC) project in 1988.[ 3] The project's initial purpose was to increase productivity and enhance worker safety in U.S. coal mines. The normative justification offered by the USBM for its direct and indirect support of this project was that safe and productive coal mining is fundamental to the health of the U.S. economy, especially in light of the energy crises of the early and mid-1970s. NIST and the USBM expected that the U.S. should benefit from reduced labor and liability costs (e.g., reduced mine worker fatality and injury) in the coal mining industry, enhanced competitiveness through greater extraction productivity, reduced or contained electric power costs, and faster design-cycle time of mining automation prototypes through the incorporation of a structured method of control system design and integration.

The approach taken on the development of this technology was to transfer the RCS architecture perfected at NIST to researchers at the PRC in order to exploit potential applications of the technology to coal mining and to improve the systems technology. Mining automation was the particular problem that was being solved. A six-step approach to developing intelligent control systems for coal mining operations was initiated: ( 1) maintain and develop a hardware and software testbed that is fully compatible with the development systems used by PRC researchers, ( 2) conduct RCS architecture and design seminars for USBM researchers, ( 3) develop and perform demonstrations of advanced aspects of control, simulation, and animation of the RCS style, ( 4) design and transfer RCS software design tools that further automate the control system design process, ( 5) perform mathematical analyses of critical issues for coal mining automation, and ( 6) actively disseminate results through a variety of forums.

Between 1988 and 1993, the USBM allocated to NIST nearly $1 million to refine the technology and transfer it to the USBM's PRC. One publicized motivation for this allocation of funds was that between 1981 and 1988 there were 893 coal mining fatalities in the U.S. of which 737 occurred underground. Over that same time period, there were 131,888 nonfatal injuries, resulting in a temporary or permanent disability, of which 110,465 occurred underground (Randolph, 1994). The USBM estimated that nearly 40 percent of these fatalities and injuries occurred underground at the mine face (i.e., at the cutting site). Engineers hypothesized that these fatalities and injuries could be eliminated via the full implementation of RCS-based, computer-controlled, mining-systems-engineering equipment. The explanation for this reduction is simple. RCS technology allows workers to operate cutting equipment at a distance of 100 feet, thereby physically removing them from the site of a potential accident.

From 1994 until 1997, when the technology was demonstrated at the PRC, and when it first began to be demonstrated in selected mines in Pennsylvania and West Virginia, all on-site research was sponsored by the USBM. In other words, NIST was involved only in the early stages of technology development and application, which is consistent with its mission of supporting generic infrastructure technology research.

In 1994, as part of their internal evaluation of new technology, the Bureau of Mines projected selected potential social benefits that could arise in the aftermath of the adoption and efficient use of the technology. One category related to reduced fatality and injury rates. In particular, the agency estimated that the direct cost saving per avoided underground fatality was $1.16 million, the corresponding figure for an avoided underground injury was $9.8 thousand. Direct cost savings in the associated USBM models included lost production of the mine due to the fatality/injury, clean-up costs, medical costs, and compensation to the worker or the worker's estate.[ 4]

A second category of social benefits was increased productivity. There are two elements of productivity gains related to the adoption and use of RCS-based coal mining automation. One element is the reduced down time of a mine associated with decreased fatalities and injuries at the cutting face of the mine (see above). The second element stems from the use of automated technology in the extraction and hauling of coal. USBM experts estimated that this technology would increase productivity by 20 percent to 30 percent. In particular, the USBM estimated $10.18 savings per ton from automated extraction and hauling.[ 5] Based on these rather impressive estimates of potential social benefits, USBM presumed that coal-mining companies would eagerly adopt the technology when it became available.

This a priori expectation did not take into consideration the union presence in that industry. In particular, as Burbash (1963,p. 45) noted nearly 40 years ago:

Technological change seems to [exert] the most immediate and powerful effect on the perceptions of the parties to industrial relations. Management's perception of technological change is producing an offensive strategy; the union's perception is in general producing a defensive strategy. Summarily stated . . . automation from the union standpoint . . . is an access link in the chain of economic consequences in which rapid technological change, recession, plant abandonments, and relocation create reduced employment and earnings, and therefore insecurity.

III. Unionization and Technology Adoption

While there are several excellent sources on the United Mine Workers (UMW) of America and the impact of unions and collective bargaining on employment and wages (Fishback, 1992; Fisher, 1942; Vittoz, 1987; Boal and Pencavel, 1994), there have been few studies of the relationship between unions and the adoption of new technologies in this industry or other sectors. Alternatively, the literature on the antecedents and consequences of technological change does not explicitly consider the role of labor unions.[ 6][ 7]

Although labor economists have not attempted to correlate the extent of unionization with direct measures of technology adoption, they have examined the relationship between unionization and both innovation through expenditures on R&D and investment in intangible capital. Unfortunately, the use of such proxy variables limits the accuracy of technology measurement and precludes a precise analysis of timing effects. Based on a union rent-seeking framework, as proffered by Baldwin (1983) and Grout (1984), several empirical studies have shown that unions do induce firms to invest less in R&D activity, ceteris paribus. This finding is robust across studies and methodologies as demonstrated by, for example, Connolly et al. (1986), Hirsch (1991a), and Odgers and Betts (1997).[ 8]

The seminal paper by Cohen and Leventhal (1989) suggests that firms invest in R&D in order to augment their "absorptive capacity," or ability to acquire and absorb new knowledge. Absorptive capacity can be viewed as a prerequisite for the adoption and efficient use of others' new product or process innovations. It follows, then, that decreases in R&D activity brought about by the rent seeking of unions should decrease the probability that a firm will adopt a new technology, ceteris paribus.

Labor economists have estimated firm-level regressions of the following form:

Log (R&D<SUB>i</SUB>) = f (X, UNION), ( 1)

where X is a vector of firm and industry characteristics describing the competitive structure and strategy of the firm's operating environment, and UNION indexes the extent of rent-seeking behavior by unionized workers within the firm. Hirsch (1991a, 1991b, 1997) reports that $\partial \mathrm{Log}(R\&D)/\partial \mathrm{UNION} < 0$, or that higher levels of unionization are associated with lower levels of investment in R&D.

In the literature on the economics of technological change, authors typically assess the determinants of a firm's probability of adopting of a new technology based on estimation of the following equation:

Prob(adoption) = g(Z, R&D). ( 2)

As reported in Siegel (1999), many authors find that $\partial \mathrm{prob(adoption)}/\partial R\&D > 0$. Such a finding indicates that an increase in a firm's expenditure on R&D enhances the likelihood that it will implement a new technology.

In these empirical studies of technology adoption and diffusion (Hannan and McDowell, 1984; Levin et al., 1987; Dunne, 1994), the set of firm characteristics (Z) includes age, size, R&D intensity of the firm, and industry controls. Age is designed to capture possible "vintage" effects, meaning the possibility that firms having a more recent vintage capital stock would be more likely to adopt new technologies because of "innovational complementarities" - a term coined by Bresnahan and Trajtenberg (1995) - or because of lower adjustment costs. Size is included because large firms may have better access to capital or because projected returns exceed threshold levels for adoption only in the case of large-scale projects. This is consistent with one aspect of the Schumpeterian hypothesis, which postulates that large firms conduct more R&D. As noted earlier, theoretical models of technology adoption and diffusion (Cohen and Levinthal, 1989; Jensen, 1988) emphasize the role of R&D investment in assisting companies to overcome informational and technical uncertainties regarding new technologies. R&D-intensive firms may also have lower costs for training and spend less time and effort on integration activities and other aspects of adjustment.

To the best of our knowledge, there are no existing empirical studies of technology diffusion that explicitly consider the role of unions. As shown in Table 1, coal mining is more unionized than the mining industry in general. As in many manufacturing industries, union membership as a percentage of employment has declined steadily since 1983 (the first year of available data). A lack of availability of plant-level data on unionization and technology usage precludes an econometric analysis of the determinants of technology adoption. Hence, we rely on qualitative methods to explore this issue.

IV. Qualitative Analysis of the Role the Unions and Technology Adoption

In 1998, managers in ten companies in Pennsylvania and West Virginia agreed to participate in a qualitative study of the perceived potential effect of unionization on technology adoption. The sample was selected with input from the USBM and the Pennsylvania and West Virginia offices of the UMW to ensure a representative balance between nonunion and union companies and company size. Pennsylvania and West Virginia are not right-to-work states, so coal mines in these states are either nonunion or union.

Selected characteristics of these ten firms in our sample are presented in Table 2. Note that although this is a small sample, there is some variation with respect to size and union status. Four companies operated nonunion mines; six operated union mines. The nonunion firms had an average of two underground mines; union companies had an average of more than four underground mines. The average size of a nonunion mine is smaller than that of a union mine.

Managers in these firms also arranged to have at least 20 miners participate in our study.[ 9] All in all, we interviewed or surveyed 253 managers and miners. The survey instrument was developed in consultation with the PRC and representatives of the United Mine Workers. On-site visits were made to each company and to at least one mine for each firm, in order to explain the survey and to fully describe the RCS-based intelligent equipment. In addition, managers were provided with information regarding projected reductions in work-related fatalities and injuries and estimates of increases in productivity provided by the USBM. When we collected our qualitative data, the RCS-based mining equipment was nearly ready for on-site demonstrations.[ 10]

Demonstration of the Technology. Managers were asked to respond to the following survey question, using response categories from 1 to 7, where 1 represents "strongly opposed" and 7 represents "strongly in favor:"

If the described RCS-based intelligent equipment were made available to your company for a demonstration, what would be the reaction by the ownership of your company?

As shown in Table 3, the average response score from the managers at nonunion companies was 6.75 (ranging from 6 to 7) and the average response score from managers at union companies was 5.83 (ranging from 5 to 7). This difference in means is statistically different at the 5 percent level (t=2.31). This result implies that owners of union companies are more receptive to the demonstration of new technology.

Each group of miners was asked to respond to the following survey question, using the same response scores mentioned above:

If the described RCS-based intelligent equipment was made available to your company for a demonstration, what would be your reaction as a potentially affected miner?

Table 3 reveals that the average response score from the four nonunion samples was 6.03 (range 5 to 7); the average response score from the six union samples was 3.45 (range 1 to 5). This difference in means is statistically different at the 1 percent level (t=9.72).

The findings suggest that managers are more amenable to a demonstration of the technology than miners, regardless of unionization status of the company. Also, nonunion companies are apparently more favorably disposed to a demonstration than union companies, from both a management and a miner perspective. On average, union miners were the only group opposed (response score less than 4) to an on-site demonstration of the technology.

Adoption of the Technology. Managers also responded to a second hypothetical question, using response categories from 1 to 7, where 1 represents "would not be strongly in favor of adopting" and where 7 represents "would be strongly in favor of adopting."

If the RCS-based intelligent equipment is demonstrated as designed in all dimensions, what would be your company's reaction to adopting the technology, assuming that the price of the technology was acceptable to the company's owners?

As shown in Table 4, managers in nonunion and union companies believed that their company would strongly support adopting the new technology. The nonunion responses were 7.0; the average union response was 6.33 (range 5 to 7). Once again, the data show that managers at nonunion companies perceived that their companies were slightly more favorably disposed to the new technology although the means are not statistically different from each other (t=2.01)

Similarly, each sample of miners was asked to respond to the following survey question using the same response categories as above:

If the RCS-based intelligent equipment is demonstrated, based on projected reduced fatality and injury rates what would be your advice to management regarding adopting the technology?

and:

If the RCS-based intelligent equipment is demonstrated as designed in terms of increased productivity, what would be your advice to management regarding adopting the technology?

Miners' attitudes to technology adoption paralleled their attitudes toward having the technology demonstrated. The nonunion members' attitude toward adopting the technology was quite positive both on the grounds of its projected reduced fatality/injury rates and its projected increased productivity. As shown in Table 4, the mean response scores were 7.0 and 6.0 (range 5 to 7), respectively. Not surprisingly, union workers responded positively to the technology's ability to reduce fatalities/injuries. However, union workers reacted quite negatively to its potential to enhance productivity, since they (correctly) perceived it as a labor-saving innovation. Table 4 also reveals that the average response scores were 5.67 (range 5 to 7) and 2.83 (range 1 to 4), respectively. The differences in means to both questions are statistically significant at the 1 percent level (t=6.32 and t=5.04, respectively). In sum, union miners were opposed both to the demonstration and adoption of the new technology.

Technological Displacement of Miners. Managers and miners were also asked about their expectations regarding the association between adoption of the RCS-based technology and worker displacement. This is a natural question to ask, given the nature of the technology.

Thus, managers responded to a third hypothetical question, using response categories 1 to 7, where 1 represents "extremely unlikely" and where 7 represents "extremely likely:"

If RCS-based intelligent equipment is adopted by your company, what is the probability that miners will permanently lose their jobs due to automation?

As shown in Table 5, managers of both the nonunion and union mines were realistic regarding the likelihood of miner displacement in the aftermath of implementation of the RCS technology. The mean nonunion response was 5.75 (range 5 to 7); the mean union response was 6.33 (range 6 to 7). This difference in means is statistically insignificant (t=1.11).

Similarly, each sample of miners was asked to respond to the same statement using the same response categories:

If RCS-based intelligent equipment is adopted by the company, what is the probability that you or some of your co-miners will permanently lose your jobs due to automation?

Similar to managers, miners expected displacement. The mean nonunion response was 6.75 (range 6 to 7); the mean union response was 7.0 - another statistically insignificant difference (t=1.00).

Employer-Employee Relationships. After reflecting on their employees' responses, as well as summary responses from other companies, each manager was asked to respond to the following statements:

Assume your company adopted RCS-based intelligent equipment and it performed as designed along all dimensions. Please respond to the following statements using response categories 1 to 7, where 1 represents "strongly disagree" and where 7 represents "strongly agree:"

Our company would immediately implement a program to train miners to use the new technology

Our miners would accept the progressiveness of the company and would not consider a work slowdown or other forms of protest

The morale of our miners would increase in light of the company's progressive attitude toward new technology

Our ability to hire miners would increase

Expectations differed with regard to the hypothesized impact of technology adoption on four aspects of employer-employee relations. Both nonunion and union managers believed that their company would immediately implement programs to train miners to use the new technology. As shown in Table 6, the mean response scores to this statement were 7.0 and 6.83 (range 6 to 7), respectively, and this difference in means is not statistically significant (t=1.01). Managers at nonunion and union companies do not expect protests to result if the new technology is implemented, as evidenced by average response scores of 6.75 (range 6 to 7) and 5.83 (range 5 to 7), respectively, although the union mangers were statistically less certain (t=2.31).[ 11] There was a statistically significant (.05 level, t=3.63) difference of opinion between the nonunion and union managers in terms of expectations regarding miner morale. An average response score of 3.33 (range 3 to 4) indicates that the morale of nonunion miners was expected to decline with adoption of the new technology. This conjecture is also based on the pattern of responses presented in Table 4, where nonunion miners focused on both the reduced fatality/injury and productivity gains aspects of the new technology, while union miners focused only on the displacement consequences of the labor-saving technology. Finally, there was also a statistically significant, at the 1 percent level (t=6.10), difference of opinion regarding the effect of the new technology on the company's ability to hire miners in the future. The nonunion managers thought the new technology would slightly increase that probability - mean score of 5.25 (range 5 to 6); the union mangers thought just the opposite - mean score of 2.83 (range 2 to 4).

## V. Interpretation of the Data and Concluding Observations

We speculate that if unionization in the coal mining industry continues to decline (Table 1), there will be an increase in the rate of technology adoption. By this, we mean an acceleration in the rate of technological diffusion in coal mines. Certainly, it is reasonable to expect that such adoptions will be lumpy, meaning that due to adjustment costs there will not be a smooth trade-off between the loss of rent-seeking ability (decline in unionization) and management's incentive to invest in new technology. But, if the literature is a guide, then adoption should occur.

As Bresnahan et al. (1999), Siegel et al. (1997), and Siegel (1999) have shown, the adoption of new technology leads to organizational change. For example, Siegel et al. (1997) examined the effects of the adoption of advanced manufacturing technologies on human resource management practices, including proxies for employee empowerment, such as training, changes in job responsibilities, new career opportunities, and enhanced employee control.[ 12] They find a strong association between the implementation of certain types of technologies and enhanced employee empowerment (although they could not segregate these effects for union and nonunion firms). Thus, it is conceivable that coal miners working with new technology, such as RCS, may experience an improvement in quality-of-work life. But clearly, further analysis of the role of unions in technology adoption and the attendant organizational changes is warranted.

Additional quantitative work on these topics requires the construction of new databases. The most comprehensive plant-level data set on technology usage, the U.S. Survey of Manufacturing Technology (U.S. Bureau of the Census, 1989) only covers establishments in five 2-digit industries (SICs 34-38) and does not include the mining sector. These data need to be extended to other industries and linked to additional information on union activity and human resource management practices. Ideally, such information would be collected simultaneously and the survey would be conducted over several years, since there is now a consensus in the literature on skill-biased technological change (Bresnahan et al., 1999) that technological and organizational changes are complementary.

Of course, as noted earlier, a second-best proxy to quantitative information on technology adoption is information on various aspects of R&D activity (funded and performed activity) for the mining industry. Unfortunately, the National Science Foundation has collected and reported R&D expenditure data for mining (SICs 10-14) only since 1996 and will continue to do so at that level of aggregation (under NAICS classification 21).

While economists are most comfortable examining large-scale government databases, we conjecture that the most fruitful research on unionization and technology adoption (especially in the coal industry) will be qualitative in nature. Such field-based work may assume the form of an industry study, as we have presented here, or case studies of the adoption of a single technology within a single mine. The latter also has the appeal of providing a setting for longitudinal analyses.

*We thank John T. Addison, Richard Chaykowski, Barry T. Hirsch, John E. Jankowski, Bruce E. Kaufman, Kenneth Snowden, Daphne Taras, Gregory Tassey, and Raymond Wolfe for useful comments and suggestions during various stages of this research. We also benefited from the advice and expertise of researchers at the National Institute of Standards and Technology and the U.S. Bureau of Mines, and from representatives in various state offices of the United Mine Workers of America. Finally, we thank the coal mine managers and miners who participated in the survey portion of this research.

## NOTES

1 In a similar vein, Townsend et al. (2001) discuss the impact of information technology on private sector unions.

2 Much of this background material comes from NIST (1993) and from personal interviews with NIST scientists.

3 For the history of this research at the Pittsburgh Research Center, see NIST (1994).

4 See FMC Corporation (1976) and Link (1996) for more details about the calculation of these estimates.

5 See Bhatt (1991a, 1991b). In 1994, approximately 40 percent of the more than 1 billion tons of coal mined was mined underground and could have theoretically benefited from the application of this technology.

6 Siegel (1999) reviews such studies.

7 In fact, we are not aware of any technology-adoption studies that compare adoption rates between nonunion and union firms or industries. Similarly, we are not aware of any technology diffusion studies that examine the effect of unionization on the time rate of adoption. While our analysis herein takes but one step in that direction, we urge that readers exercise the utmost caution in generalizing from our anecdotal findings about the coal mining industry or to other unionized industries.

8 Hirsch (1997) reviews this literature.

9 During on-site visits we assisted management in selecting a sample of workers. We ensured that the sample was representative of the labor force at the mine with respect to age and experience.

10 All the managers interviewed and surveyed had some general knowledge regarding the technology; some were familiar with the engineering aspects of the technology based on the research at the PRC.

11 A manager in a union mine in Pennsylvania told us a story about an event in 1997. The company that owned the mine wanted to install a new computer-based scheduling system that would more efficiently allocate miners among the company's four mines. The new technology was software. It would take the company's demand for coal per orders and allocate that demand to the mine(s) with the least average cost per ton (that is based on what each mine's current underground position was). Some miners would work a full week or more to fill the orders, and others would not. The company optimized, yet some workers suffered relative to constant work per mine. In response, the union threatened a slow down unless the owners of the company

would guarantee a minimum number of hours per miner per week. They eventually gave in and the company stopped allocating work based on the new technology.

12 See Conger and Kanungo (1988) and Thomas and Velthouse (1990) for a discussion of constructs developed in the management literature to measure employee empowerment.

Charts to follow with future update.

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