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Workplace Transformation and the Rise in Cumulative Trauma Disorders: Is There a Connection?*

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I. *Introduction*

The workplace transformation movement in the U.S. has made rapid progress since its emergence in the early 1980s. A recent survey of manufacturing establishments with at least fifty workers found, for example, that roughly half of the surveyed plants had embarked on experiments with quality circles, work teams, or total quality management techniques (Osterman, 1994, p. 177). Employee involvement schemes, such as quality circles (QCs) and work teams, are being combined with programs, such as total quality management (TQM), to improve product quality and eliminate inefficiencies in production.[1]

Over roughly the same time period that workplace transformation has been advancing, occupational illnesses related to cumulative trauma disorders (e.g., conditions due to repeated pressure, vibration, or motion, such as carpal tunnel syndrome) have also been rising. The rate of cumulative trauma disorders (CTDs) in manufacturing (number of illnesses per 10,000 workers) went from 16.6 in 1984 to 104.6 in 1991. While CTDs accounted for only 18 percent of all occupational illnesses in 1980, by the decade's end this number had grown to 56 percent. Indeed, by the early 1990s, illnesses associated with CTDs resulted in the longest absences from work of all health and safety-related events and exposures (U.S. Department of Labor, 1992, pp. 3, 5).[2]

This trend has not escaped the attention of the Occupational Safety and Health Administration which in November 1999 advanced sweeping ergonomic standards designed to address the problem. California has recently adopted ergonomic standards, but the proposed OSHA standards are even more stringent. The proposed federal standards cover 27 million employees and will require 1.6 million employers to disseminate information about ergonomics and to adopt a system for reporting and responding to problems.

Is there a connection between these two trends in the workplace? Case study evidence, much of it from Japanese auto transplants in the U.S., suggests that there is. We explore the association between workplace transformation and CTD rates across a broad range of manufacturing industries. Utilizing a recent survey of establishments with information on the extent of experience with transformed workplace practices, in combination with industry-level data on CTD rates over the late 1980s and early 1990s, we offer statistical evidence on the association between workplace transformation and the health of workers.

II. *Case Study Evidence*

There is some case-study evidence suggesting that transformed workplaces are subject to higher rates of CTDs. The causal connection typically emphasized in this literature is that workplace transformation "rationalizes" the production process — making job tasks more repetitive, for example — and increases the intensity with which workers must produce, thereby subjecting workers to a greater risk of CTDs.

The effect of repetition and work intensity on CTDs is potentially worsened by other common features of transformed workplaces: rapid model changes in production, a liberal use of contracting-out for parts, "just-in-time" production (which dictates a small parts inventory), and worker responsibility for quality control. Workers are especially vulnerable to CTDs during model changes, when they are forced to exert pressure on unconditioned muscles. Contracting-out often leads, at least initially, to greater parts defects which, in the context of low inventories and increased worker responsibility for quality control, forces workers to strain to install ill-fitting parts.

Ergonomists confirm that these are indeed causal factors in the rise of repetitive stress disorders. Excessive force, repetition, and little recovery time — breaks per shift or unutilized seconds in the job cycle — all contribute positively to worsening CTDs (Armstrong, 1986; Putz-Anderson, 1988). Additional implicating factors include excessive work rates, job stress, long work days, and lack of task variety (National Institute for Occupational Safety and Health, 1993).

There seems to be little debate that transformed workplaces demand great labor effort from workers. Fucini and Fucini (1990, p. 37) note that most Japanese auto transplants — which are presumably among the most advanced in terms of workplace transformation — attempt to run as close to 60 seconds of work per minute as possible. Babson's (1993, p. 13) survey of workers at the Mazda plant in Flat Rock, Michigan revealed that three-quarters of the surveyed work force felt that their work pace was so intense that they would be either injured or worn out before they reached retirement.

Do transformed workplaces demand greater intensity from workers than other, comparable establishments that have not undergone transformation? Productivity comparisons are suggestive. Womack et al. (1990, p. 2) note that Japanese transplants in the auto industry can assemble vehicles with an average of 21.2 hours of labor compared to 25.1 hours for other domestic auto plants. Brown and Reich (1989, p. 32) found that productivity increased by roughly 50 percent when the NUMMI auto plant — a Toyota-GM joint venture in Freemont, California — was transformed from its former operation as GM-Freemont.

A few studies have explicitly linked workplace transformation to harder or more sustained effort by workers. Treece (1989, p. 80) found that workers at the NUMMI plant worked 55 seconds out of every minute, while at the comparable, but untransformed, GM-Linden plant workers worked only 45 seconds out of every minute. Ichniowski et al. (1997) found that transformed workplaces in a specific line of steel finishing experienced increased "uptime" in production, suggesting increased work effort per unit time, compared to similar untransformed workplaces.

The link between rationalization of production, work pace, and workplace health and safety has been emphasized in several case studies. Berggren et al. (1991), visited a number of Japanese transplants in the U.S. and found growing health and safety complaints related to the intense pace, repetitive job tasks, and long hours. At Mazda they found extremely high levels of repetitive strain injuries and an injury rate three times the level of other U.S. auto plants (1991, p. 55).

Rinehart et al.'s (1997) case study of the CAMI auto plant in Canada — a joint venture between GM and Suzuki that began production in 1989 — makes a formal case for the link between workplace transformation, increased intensity of labor effort (including increased hours and overburdened jobs), and rising rates of CTDs. A survey of workers in the plant revealed that roughly 40 percent felt that their jobs exposed them to repetitive strains "all the time or often" (p. 70). Over a two-year period, 1992 to 1994, the number of CTD-related illnesses more than doubled, increasing from roughly 12 percent of all reported injuries and illnesses to roughly 33 percent (p. 80).

Wokutch's (1992) case study of health and safety at a Japanese auto transplant in the U.S. yielded similar findings. In 1988, the injury and illness frequency at this plant (44.4 per 200,000 hours worked) was 91 percent higher than the industry rate and 66 percent higher than the rate for similar auto plants that employ at least 1,000 workers (Wokutch, 1992, p. 192). Strains, sprains, and CTDs accounted for a large share (almost 50 percent) of the reported injuries and illnesses in the plant for 1988 (Wokutch, 1992, p. 195). For CTDs alone, the rate was roughly five times as high as the rate for comparably large auto plants (Wokutch, 1992, p. 195).

Finally, consider the recent experience at NUMMI (Levine, 1995; Adler et al., 1997). Following the 1993 model change, there was a 12 percent increase in worker absences due to health and safety problems. The apparent cause was the prescribed time standards for job tasks under the new model. Although injuries began to increase long before the new standards were met, management failed to respond to the problem and continued with its plan to increase line speeds in order to meet prescribed standards. Cal-OSHA was finally summoned to the plant, resulting in a citation which concluded "serious employee injuries due to repetitive stress, as well as employee symptoms of impending stress injury increased alarmingly" following the model changeover (quoted in Levine, 1995, p. 33).

Increases in the pace of production, resulting in worsened worker health and safety, are not confined to transformed workplaces, however. Some of the most highly publicized cases of increased speed resulting in increased injuries and CTDs come from the meatpacking and poultry-processing industries, which are not typically considered bastions of workplace transformation. In a series of articles in the *Wall Street Journal* (1989, 1994), a formal case was made that the near doubling of line speeds in various plants in these industries during the 1980s resulted in soaring workplace injuries and repetitive motion disorders. Thus, the question remains, "Is there a link between workplace transformation and rising rates of CTDs across American industries?"

III. *Data and Empirical Specifications*

The Organization of Work in American Business Survey is a stratified sample of establishments with fifty or more employees gathered in 1992 to measure the extent of workplace transformation in the U.S. (Osterman, 1994). Among other things, establishments were asked about those workers composing the core occupational work group in the plant and the extent to which this group was involved in practices such as work teams, QCs, TQM techniques, and job rotation at the time of survey. From the survey, we extracted for analysis those manufacturing establishments whose core work groups are blue-collar occupations.[3] Using each establishment's reported 3-digit SIC industry code, information on CTD rates in the establishment's industry was imported into the data set.

In addition to measures of the extent of workplace transformation, the Organization of Work in American Business Survey contains information on a variety of establishment characteristics that are used as control variables in our statistical analysis. The primary set of variables used in the analysis and their definitions appear in Table 1, along with their means and standard deviations. We employ the sample weights provided in the survey to insure that the data are representative of the experience of establishments with 50 or more workers.

One of the unique features of this survey is that each establishment was asked about the year in which its various workplace practices were begun. Thus, in addition to the percentage of an establishment's core work group involved in certain workplace practices in the survey year, we also possess information on the year in which these practices were initiated, thereby allowing us to create a panel data set with which to explore further the association between workplace transformation and CTDs.

The basic specification for all of our empirical investigations constitutes a regression of industry-level CTD rates on various establishment-level workplace transformation variables and other control variables.[4] Our heuristic assumes that industry-level CTD rates capture — albeit, with a certain degree of imprecision — establishment-level experience.[5] Because the measurement error is confined to the dependent variable, the estimated coefficients are unbiased.[6]

IV. *Results*

In column 1 of Table 2 we present the results of regressing[7] CTD levels in 1991 on levels of the workplace transformation variables and other control variables in that year.[8] Under a very liberal standard of statistical significance — namely, a 0.20 level — the

Table 1

Variable Definitions, Means, and Standard Deviations

Variable	Definition	Mean (Std-Dev)
CTD	The number of cumulative trauma disorders per 10,000 full-time workers.	113.67 (116.94)
QC	The percentage of the establishment's core work group involved in quality circles.	35.90 (38.88)
TEAMS	The percentage of the core work group involved in self-directed work teams.	29.26 (38.79)
TQM	The percentage of the core work group involved in total quality management.	39.63 (44.62)
ROTATION	The percentage of the core work group involved in job rotation.	33.14 (38.62)
SKILL CHANGE	A dichotomous variable equaling one if the establishment reported that the skills involved in doing the jobs of the core work group had changed in the past few years, and zero otherwise.	0.64 (0.48)
PLANT SIZE	The number of employees at the establishment.	1602.18 (2483.25)
% UNION	The percentage of the establishment's eligible blue-collar workers covered by collective bargaining agreements.	48.58 (48.55)
% FEMALE	The percentage of the plant work force that is female.	32.19 (20.98)
% BLUE COLLAR	The percentage of the plant work force composed of blue-collar workers.	64.62 (23.32)

results suggest that extensive involvement with teams among the core work group is negatively associated with CTD rates, while involvement with QCs and job rotation is positively associated with CTD rates. Other statistically significant explanatory variables are the percentage of women in the work force, the percentage of blue-collar workers, and plant size — all of which are associated with higher levels of CTDs rates.[9]

The estimated CTD equation in column 1 also possesses controls for the two-digit industry group to which each establishment belongs (*INDUSTRY*). The industry fixed effects are interesting in themselves. The manufacturing industries with the highest CTD rates, ceteris paribus, are transportation equipment, electrical equipment, and apparel and other textile products. Those industries with the lowest CTD rates are chemicals, printing and publishing, and machinery. A specification in which these industry dummies are interacted with the workplace transformation variables suggests, as we

Table 2

Regression Results for Various Specifications of the CTD Equation

(t-statistics in parentheses)

Independent Variables	CTD_{1991} (1)	$\%\Delta CTD_{1986\text{-}91}$ (2)	$CTD_{interpolated}$ Panel (3)	CTD_{dummy} Panel (4)
QC	0.13	0.003	0.11	5.38
	(1.40)	(1.65)	(2.36)	(1.86)
TEAMS	–0.15	0.0004	–0.08	–1.78
	(–1.52)	(0.18)	(–1.59)	(–0.60)
TQM	–0.06	–0.001	–0.13	–9.60
	(–0.64)	(–0.58)	(–3.08)	(–3.20)
ROTATION	0.14	0.00003	0.22	24.24
	(1.47)	(0.01)	(4.44)	(8.02)
SKILL CHANGE	–6.60	0.27		
	(–0.85)	(1.73)		
PLANT SIZE	0.02	0.0005		
	(1.71)	(1.97)		
PLANT SIZE²/1000	–0.01	–0.0006		
	(–1.09)	(–1.69)		
% UNION	0.11	–0.0007		
	(1.22)	(–0.44)		
% FEMALE	0.40	–0.004		
	(1.95)	(–0.87)		
% BLUE COLLAR	0.23	0.003		
	(1.34)	(0.95)		
TIME TREND			13.49	13.14
			(27.58)	(28.17)
INTERCEPT	55.46	0.78	12.98	8.68
	(2.82)	(2.03)	(3.17)	(2.09)
INDUSTRY	YES	YES	NO	NO
ESTABLISHMENT	NO	NO	YES	YES
R^2	0.08	0.07	0.25	0.26
N	336	303	2035	2035

might expect, that the impact of workplace transformation on CTDs varies across industries.[10]

The positive association between job rotation and CTDs is puzzling; we expect extensive job rotation to reduce the time workers devote to repetitive tasks and, therefore, to act as a deterrent to traumas associated with repetitive stress. And indeed there is much evidence to support this view. For example, all parties involved in the 1993 model change at NUMMI agreed, in retrospect, that part of the explanation for the rise in CTDs during this period was management's decision to forego job rotation until a target production standard had been attained (Adler et al., 1997). Rinehart et al. (1997, p. 57) found, in their investigations of workplace transformation at CAMI, that management responded to rising rates of CTDs by introducing a job rotation system. This suggests that the positive association might be the result of endogeneity bias.

To explore this possibility, we employed a two-stage least squares procedure in which the extent of worker cross-training in the establishment was used as an instrumental variable for job rotation. The cross-training variable turned out to be a perfect instrument: It was highly statistically significant (with a t-statistic of 7.0) in the first-stage instrumenting equation, and yet a Generalized Method of Moments specification test revealed that it was not statistically significant as an independent explanatory variable in the CTD equation (Newey, 1985). A Hausman (1978) test for the absence of endogeneity bias was rejected, suggesting that the estimated coefficient on the job rotation variable may indeed suffer from such bias. The estimated coefficient on the instrumented rotation variable is negative but statistically insignificant. (These results are available from the authors on request.)

An additional concern with these results is that they may suffer from left-out variable bias. We are unable to control for all aspects of the production process that might affect cycle times or worker intensity, and which thereby account for some of the variation in CTDs. If these left-out variables are also correlated with features of the workplace transformation movement, their absence from the estimated CTD equation will lead to biased coefficients. However, to the extent that left-out factors are fixed over a given period, first-differencing estimation will yield unbiased results. We utilized the panel data (to be discussed below) to estimate a first-difference model for the years 1986 and 1991, and found our results to be reasonably free from this type of bias.[11]

All of the remaining analyses we conduct with these data explore the determinants of changes in CTD rates over the period 1986 to 1991 — a time of very rapid increase in CTD-related illnesses.[12] Survey and case-study evidence reported in the literature suggest that this period is also one of rapid transformation in workplace practices. Information on the date of introduction of workplace practices among our sample is consistent with the findings in the literature. Of the 66 percent of establishments possessing QCs in 1992, only 30 percent of these had introduced them prior to 1986. The equivalent numbers for TQM and teams over the same period are 56 and 15 percent, and 53 and 20 percent, respectively. Job rotation has a longer history; roughly 40 percent of the 54 percent of establishments utilizing rotation in 1992 had begun these programs prior to 1986.

The results of column 2, Table 2 emerge from the first of three different approaches we take to analyze the determinants of changing CTD rates over this period. The column 2 results do not use information on the history of workplace transformation among the sample of establishments. Instead, they emerge from a specification in which the percentage change in CTD rates over the period is regressed on the levels of the workplace transformation variables and other covariates in 1991. The mean (standard deviation) of CTD variable is 0.98 (2.44).

The results reveal that only one of the workplace transformation variables — namely, QC — is a statistically significant factor in the rising CTD rates of the period. Neither the job-rotation variable nor the teams variable is statistically significant in these results. Rates of cumulative trauma disorders rose most rapidly in medium-size plants[13] and in establishments where the work force has undergone significant skill change. The industry fixed effects are most positive in textiles, apparel, and transportation equipment and most negative in electrical equipment, fabricated metal products, and stone, clay, and glass products.

The results in columns 3 and 4 of Table 2 emerge from analyses of the survey data that make use of information on the history of workplace transformation in the establishments of our sample. Specifically, we have the year, if ever, during which each of the following workplace practices was begun in each establishment: QCs, teams, TQM, and rotation. Retrospective information was available for these workplace practice variables only, and so only these variables appear on the right-hand side of the estimated CTD equations.

Two types of panel data sets, each with 6 years of cross-sectional observations, were analyzed using this establishment-level retrospective information and the corresponding CTD rates over the period 1986-1991.[14] Given the large sample size, we are able to control for establishment fixed effects (*ESTABLISHMENT*). These variables capture those aspects of each establishment that are unchanging over the period and that affect CTDs. We also include a time trend component (*TIME TREND*) to capture the unaccounted-for secular trend in CTD rates over the period. The panel data, in contrast to the approach taken in column 2, allow us to explore issues of timing, and thereby causality, in the trajectories of workplace transformation and CTDs over these years.

For the first analysis, we utilized information on the extent of experimentation, if any, with workplace transformation, and the year, if ever, that each establishment initiated particular features of a transformed workplace. Through a process of linear interpolation, we then created values for the extent of experimentation with each workplace feature for each establishment in the sample for every year from 1986 to 1991. For example, if the extent of QC participation for a particular establishment was 75 percent in 1991 and the program was begun in 1989, QC participation is given a value of 25 percent in 1989 and 50 percent in 1990. We know that the process of workplace transformation does not proceed in such a smooth fashion, however, and so there is likely to be some measurement error in the independent variables.[15]

The results of the estimated CTD equation using this sample appear in column 3. Establishments adopting or increasing the extent of QCs or job rotation witnessed statistically significant increases, beyond the rising secular trend, in CTDs over the period. Those adopting or increasing the extent of teams or TQM were able to achieve significantly lower increases in CTDs.

In the second analysis using retrospective information on workplace transformation, we employ only dichotomous variables to capture the existence or nonexistence of particular workplace features over the period 1986 to 1991. Thus, we make use of information on the year, if any, in which each establishment initiated a given feature of a transformed workplace. For each year over the period, workplace transformation variables take on a value of 1 if the establishment possess the feature, and 0 otherwise. The advantage of this specification over that of column 3 is the absence of measurement error in the independent variables.[16]

The estimated coefficients from this analysis represent the within-establishment change in CTDs associated with the emergence of each feature of a transformed workplace. The results appear in column 4. Note that the sign and statistical significance of the workplace transformation variables are similar in all but one respect to those of column 3: The estimated coefficient on the teams variable is no longer statistically significant.

We suspect that the positive relationship between rotation and CTDs in the column 3 and 4 results is due to simultaneity bias. This may be true of other estimated relationships as well. To explore this possibility, we lagged each independent variable in the column 4 specification by one period and re-estimated the CTD equation. If the estimated coefficients in column 4 do suffer from simultaneity bias, then lagging the independent variables could yield useful information. For example, if CTDs lead rotation, then lagging the rotation variable should cause its estimated coefficient to become less significant, both in size and in a statistical sense.

The results of this analysis (available from the authors on request) offer suggestive evidence in support of the claim that the estimated coefficients on both the rotation and TQM variables suffer from simultaneity bias.[17] The size of both coefficients falls, along with their explanatory power in the model. The *t*-statistic on the rotation variable falls by close to 25 percent, and that on the TQM variable falls by over 30 percent. The estimated coefficient on the QC variable, however, increases substantially, and its *t*-statistic increases by close to 20 percent.

V. *Discussion*

Perhaps the most prudent conclusion to draw from these findings is that, whatever its precise effect, the workplace transformation movement accounts for little of the rise in CTD rates over the period of the late 1980s and early 1990s. Collectively, the workplace transformation variables in column 3, Table 2, for example, account for less than 4 percent of the mean CTD rate.

The dominant explanatory variable in column 3 is the time trend, which accounts for roughly 68 percent of the mean of the CTD variable.[18] We suspect that a good portion of this reflects the growing awareness of CTDs as legitimate health hazards and, therefore, increased accuracy of firm reporting. Indeed, it was during the late 1980s that the Occupational Safety and Health Administration began levying multi-million dollar "mega-fines" against companies that failed to report ergonomic injuries. Future research might investigate the extent to which the recent increase in CTSs reflects a new health and safety problem or whether, instead, it merely indicates greater awareness and more accurate reporting of a long-standing problem in the workplace.

Looking across the four columns of results in Table 2, the only workplace transformation variable that is a robust determinant of CTDs is *QC*.[19] In the column 2 results of Table 2, QCs account for roughly 10 percent of the rise in CTDs over the period. Focusing solely on the robust results from our analysis, one could rightly claim that workplace transformation has contributed positively, if not forcefully, to the rise in CTDs over the period. What, then, is the explanation for the positive association between QCs and CTDs?

A number of possible explanations might be offered. For example, if the rapid increase in reported CTDs is due, in part, to more accurate reporting, and if QCs are more successful at goading management into acknowledging that CTDs are a legitimate job-related illness, then the positive association may be the result of reporting bias. However, in this case we would also expect teams, which are generally more worker empowered than QCs, to have a similar effect, and yet the estimated coefficient on the teams variable is never positive and statistically significant. We are, therefore, skeptical of this explanation. (However, we suspect the positive and nearly statistically significant coefficient on the percent union variable in column 1 of Table 2 may be explained by enhanced reporting.)

Another possible explanation for the observed positive association between QCs and CTDs is endogeneity bias; perhaps QCs are adopted in reaction to, and in an attempt to abate, rising CTDs. For a number reasons, we are not much persuaded by this explanation either. Whereas earlier versions of QCs — often referred to as Quality of Worklife Programs — were indeed initiated in response to workers' workplace discontents (Fairris, 1997), the recent wave of QCs has typically focussed more on product quality and productivity enhancement rather than the quality of working conditions for workers.

Moreover, efforts to purge the results of simultaneity bias yielded no significant change in the relationship. In fact, the positive relationship between QCs and CTDs in column 4 of Table 2 is the only finding that is enhanced when the workplace transformation variables are lagged one year in an attempt to reduce simultaneity problems.

Unfortunately, we were unsuccessful in efforts to employ an instrumental variables technique to directly test and correct for simultaneity bias in the estimated QC coefficient in column 1, Table 2. No viable instrument could be found. To our surprise, neither a variable capturing the importance of product quality to the firm or a variable capturing the importance of a cooperative work force was significant in explaining the variation in QC participation across establishments.

Of course, QCs may emerge not as a mechanism for abating increases in CTDs, but rather as a way of quelling workers' discontent with the worsening health-related effects of the job. An argument often found in the case-study literature is that QCs diminish worker solidarity and help to legitimize management's authority in production

(Parker, 1985), thereby making it easier for employers to increase work pace and shorten cycle times for jobs, which in turn lead to increased rates of CTDs. Indeed, to the extent that QCs merely act as a forum for management to convince labor of the need for enhanced intensity in production — for reasons of competitiveness, for example — they may act as a vehicle for worsening CTDs. Similar kinds of claims, however, have been made about teams (Parker and Slaughter, 1988), and yet we find no evidence of a positive relationship between teams and CTDs.

Our results are obviously far from definitive; there is thus plenty of room for further research into the relationship between workplace transformation and rising rates of CTDs. We think replicating the methodological approach of Ichniowski et al. (1997) in their study of the impact of workplace transformation on productivity is perhaps the most fruitful way forward. Case studies, combined with econometric analyses, of a set of plants producing a relatively homogenous product with significant variation in both the extent of workplace transformation and CTD experience could yield significant insights. Indeed, establishment-level data on CTD rates might reveal that workplace transformation has had a sizeable impact on the health of workers.

If, after further investigation, workplace transformation is found to positively affect CTDs, as many of the case studies allege and as our results tentatively lead us to conclude in the case of QCs, then we must acknowledge that there are costs as well as benefits to the workplace transformation movement. Indeed, the enhanced productivity that is often associated with transformed workplaces may come at the direct expense of workers, in the form of worsened health and safety on the job.

NOTES

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[1]These efforts are based on Japanese management techniques which utilize worker input to improve productivity. Quality circles are labor-management committees that meet regularly on company time to raise problems encountered in production and brainstorm over solutions. Work teams, typically composed of between 10 and 15 workers, extend worker participation directly to the shopfloor by making teams responsible for things such as quality control, troubleshooting, and assigning workers to job tasks. Total-quality management techniques are more management-driven reforms, wherein top management determines the quality priorities, establishes the systems and procedures to be followed, provides resources (e.g., worker training in statistical process control techniques), and then holds workers responsible for quality and its continuous improvement.

[2]Between 1986 and 1991, the CTD rate increased by at least 100 percent in every 2-digit manufacturing industry. Transportation equipment, textile mill products, and apparel led the list of industries with the largest increases. While CTD's are fast becoming a major health concern, they affect a much smaller percentage of the work force than do injuries. For the period 1986-1991, for example, the average CTD rate in manufacturing was less than one-tenth the average injury rate.

[3]CTDs are primarily a manufacturing phenomenon. The 1990 CTD rate for manufacturing (86.7 per 10,000 full-time workers) is at least ten times larger than that for any other private industry category. Moreover, for

much of the period under consideration, CTD rates were unavailable at the 3-digit level in many nonmanufacturing industries.

[4]We briefly considered a second approach to analyzing the data. The establishment-level variables can be aggregated to arrive at industry-level measures of workplace transformation, allowing for estimation of an industry-level CTD equation. However, in quite a few of the 3-digit industry cells the number of establishments was small, leading to some concern about the accuracy of the aggregates, and thus to concerns of measurement error in the independent variables. Interestingly, preliminary estimates using this approach yielded results similar in many respects to those reported in Table 2. These results are available from the authors on request.

[5]To be precise, because the workplace transformation variables capture information about the "core work group" and not the entire plant work force, we assume that industry-level CTD rates capture the experience of the core work group. The percentage of the plant work force composing the core work group varies widely across establishments in our sample; the mean and variance are .49 and .24, respectively.

[6]One source of potential bias in our results is due to the truncated nature of the sample — the Organization of Work in American Business Survey excludes establishments with less than 50 workers. Given data availability, however, there is little we can do to correct for this truncation bias.

[7]We employ a restricted maximum likelihood technique, with random effects when controlling for industry or establishment, that utilizes the Newton-Raphson algorithm.

[8]The survey of workplace transformation was conducted in mid-year of 1992, so we take the information contained therein to be a better reflection of experience in 1991.

[9]Recent research has implicated pregnancy, oral contraceptive use, and gynecological surgery as possible contributing factors in the development of CTDs (U.S. Department of Health and Human Services, 1995, p. 134). This may account for the higher propensity of females to experience CTDs. However, females may also be disproportionately relegated to jobs possessing characteristics that contribute to the development of CTDs. Larger establishments are perhaps more apt to exhibit problems with CTDs because they employ a finer division of labor and specialization, thereby giving rise to greater repetition of tasks.

[10]For example, the impact of QCs on CTDs is significantly larger (compared to all other industries) in the electrical equipment and transportation equipment industries and significantly smaller in the apparel industry. These results are available from the authors on request.

[11]These results are available from the authors on request.

[12]1986 is the first year in which reliable measures of CTD rates were made publicly available at the 3-digit level for manufacturing. Although this disaggregated series begins in 1984, prior to 1986 many of the measures were either missing or unreliable due to small sample size.

[13]The plant size variable is positive and statistically significant, and the plant size squared variable is negative and statistically significant. The percentage change in CTDs rises with plant size until the establishment reaches a work force of around 4,000, at which point the percentage change in CTDs begins to decline from its maximum. This is a common finding in the literature on the determinants of injury rates, where the explanation for the comparatively superior safety performance of very large plants is that they, unlike small and medium-size plants, are experience rated in the determination of workers compensation insurance premiums. Thus, these establishments have an added incentive to control injuries, and perhaps CTDs as well.

[14]Because we do not make use of the other covariates in these analyses, observations with missing values on these variables are not lost. Thus, the sample size of the panel data sets is slightly larger than six times the original sample. If we restrict the analyses of the panel data to (six times) the original sample, however, the results are not substantively different.

[15]Workplace transformation typically takes place with an initial burst of penetration, followed by a slow rate of further advance over time. In our sample, for instance, those establishments with only one year of experience with work teams already posses a majority of the core work group participating in them. Establishments with three years of experience with teams possess an average participation rate that is only 12 percent higher than those with one year of experience, and establishments with six years experience, an average par-

ticipation rate that is only 16 percent higher. With slight variation, both the extent of initial burst and rapidity of further progression are similar for the other workplace transformation features.

[16]We cannot rule out the possibility that some establishments in the sample possessed certain features of a transformed workplace prior to the survey year, but then abandoned these features before the survey was conducted. In certain instances, then, we might attribute the absence of such features to establishments that actually possessed them during some period of our analysis.

[17]Even so, the negative association between TQM and CTDs remains a bit of a mystery. Total-quality-management techniques focus almost exclusively on process changes that eliminate wasted time and motion, increase throughput (i.e., speed), simplify tasks, and reduce cycle times (Appelbaum and Batt, 1994, pp. 88-91), all of which might plausibly be associated with increased, not decreased, CTDs.

[18]When the workplace transformation variables are removed from the equation, the time trend accounts for 71 percent of the CTD variable mean, offering further support to the conclusion that workplace transformation fails to account for much of the rise in CTDs over this period.

[19]We considered the possibility that multicollinearity affected the standard errors of the estimated coefficients on our workplace transformation variables. If establishments adopt workplace transformation features as a package, we might expect there to be high collinearity between the workplace transformation variables. Interestingly, this was not the case. The highest correlations were between QC and TQM (only 0.35) and QC and teams (only 0.33). Further diagnostic tests, based on the method discussed in Feldstein (1973), suggest that mulicollinearity has not affected the integrity of our resuls.

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