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Organizational Redesign, Information Technologies and Workplace Productivity

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Benoit Dostie and Rajshri Jayaraman

Abstract

Using a large, longitudinal, nationally representative workplace-level data-set, we explore the productivity gains associated with computer use and organizational redesign. The empirical strategy involves the estimation of a production function, augmented to account for technology use and organizational design, correcting for unobserved heterogeneity. Our first-difference and GMM estimates suggest that the productivity premium associated with computer use is not statistically different from zero. Neither is there any evidence to support the idea that complementarities between computer use and organizational redesign have any substantial bearing on productivity.

KEYWORDS: productivity, information technologies, organizational practices, panel data

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1 Introduction

After a two decade lull, productivity in the U.S. and Canada picked up considerably between 1995-2000. In the U.S., for example, business sector labor productivity grew at an average annual rate of 2.6 % from 1996-2000 compared to 1.5 % from 1987-1995. Analogous figures for Canada over the same periods were 2.2% and 1.0%, respectively (Faruqui et al. 2003). Using a growth accounting exercise, Jorgensen and Stiroh (2000) and Oliner and Sichel (2000) argued prominently that this could be attributed to increased investment in information technologies (IT), which led to a direct increase in the productivity of the IT sector and a larger indirect increase in productivity in those industries which invested (most heavily) in IT.

The productivity explosion in the first 5 years of the millennium largely vindicated this view (Jorgensen, Ho, and Stiroh 2006). However, there are at least two reasons to believe that IT cannot be the *full* story. First, the sustained productivity growth in the first 5 years of this century was accompanied by a collapse in IT investment. Second, there is evidence to suggest that the returns to IT are larger than one would expect using a standard growth accounting framework, which typically only takes into account tangible assets (Brynjolfsson and Yang 2001).

Brynjolfsson and Hitt (2003) maintain that a missing piece in this productivity puzzle is complementary investments in organizational design accompanying computerization. This is an idea which is gaining currency in policy circles.[1]

The basic argument of Brynjolfsson and co-authors is that firms are not going to automatically enjoy efficiency gains by plugging a computer in the socket. Rather, it is the organizational redesign which enables them to take advantage of the computing power offered by these machines that results in increased productivity.

This paper explores this basic idea by estimating the productivity gains associated with computer use *and* organizational redesign. It does so from a microperspective, using a rich nationally representative, longitudinal, linked employer-employee data set. Our methodology involves estimating a Cobb-Douglas function, augmented to account for technology use and organizational design. We use our panel data structure to correct for time invariant unobserved workplace heterogeneity through first differences, and use GMM methods to control for potentially time varying unobserved productivity shocks.

When we correct for unobserved workplace heterogeneity, we find that the computer premium is not statistically different from zero. This suggests that IT use

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[1] The 2006 *Economic Report of the President,* for example noted that "The 1995-2001 acceleration [in US productivity] may be plausibly accounted for by a pickup in capital services per hour worked and by increases in *organizational capital*, the investments businesses make to reorganize and restructure themselves, in this instance, in response to newly installed information technology." *(February 2006, p. 26)*

alone cannot explain the productivity growth experienced in the first 5 years of this century. At the same time, we find little evidence to support the idea that complementarities between computer use and organizational redesign increase productivity either. And this holds both in the full, nationally representative sample, and at the industry level. One possibility that we are not able to fully investigate with our data is that our results might be capturing only short-run effects. Still, our results underscore the challenge of finding economically representative, micro-based evidence in support of the claim that organizational redesign and computer use may explain the productivity explosion witnessed early this century.

The paper proceeds as follows. We review the literature in section 2. Section 3 provides a conceptual framework and section 4 presents our data. In section 5, we lay out our empirical strategy. Results are presented in section 6, and section 7 concludes.

2 Related Literature

Despite a sizeable case study literature documenting complementarities between IT and organizational design, only recently has the issue been examined using survey data.[2] In a seminal paper, Bresnahan, Brynjolfsson, and Hitt (2002) explore the implications of complementarities between IT, workplace reorganization, and new products and services for the relative demand for skilled labor and, more peripherally, productivity. This paper is motivated largely by Bresnahan et al. (2002) and contains many complementary results. It is, however, distinct on a number of counts. First, our focus is on productivity rather than labor demand. Second, our data permit us to examine a much larger variety organizational designs for a substantially larger number of observations; our sample is representative of the economy as a whole.[3] Third, because we have access to data regarding organizational *re*design and not just extant workplace practices, we are better equipped to examine the extent to which firms which *adjust* their organizational design in the wake of computerization realize higher productivity.

This paper also speaks to two other strands of literature: one on the effect of IT on productivity and the other on the effect of organizational design on productivity. The former is based almost exclusively on data aggregated at the macroeco-

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[2] This is an oft lamented failure in the literature. See Brynjolfsson and Hitt (2000) for an excellent review. There is also a large sociology literature on the impact of IT on organizational design, ably surveyed in Burris (1998).

[3] Bresnahan, Brynjolfsson, and Hitt (2002) main estimates pertain to 250 firms. Ours pertain to 6,542 workplaces.

nomic, industry, or firm level.[4] This has the drawback of concealing heterogeneity within the firm. In this paper, we study the impact of IT use on *workplace* productivity.

The latter – the impact of organizational design on productivity – has a long tradition. Some of the earliest work in this area took the form of case studies.[5] An alternative approach has exploited changes in organizational structure within firms.[6] Yet another approach has been to conduct intra-industry studies of the effect of workplace practices on industry-specific measures of performance.[7] These studies typically find that innovative workplace practices result in higher productivity.

These approaches have the attractive quality of being rich in detail, thereby permitting an intricate understanding of the channels through which innovative workplace practices affect productivity. This level of detail is possible since the studies in question focus on particular companies, firms, or industries, but comes at a price, which is that one cannot make any generalizations to the broader economy on the basis of their results.

Some headway has been made in overcoming this limitation by analyzing data on a more representative sample of firms. But these studies typically use cross-sectional data (sometimes complemented by a longitudinal component which typically does not include business practices) with low response rates, and measures of organizational design aggregated at the firm or business-line level.[8] These, in turn, make it difficult to correct for firm unobserved heterogeneity, compromises representativeness, and makes it difficult to interpret results since workplace practices often vary across establishments (and not only firms.)

In this respect, work by Black and Lynch (2004) and Black and Lynch (2001) has been ground breaking since it exploits establishment level, partially panel, data containing detailed questions on workplace practices. Nevertheless, the

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[4] Brynjolfsson and Hitt (1995), Brynjolfsson and Hitt (2003), and Stiroh (2004) survey the evidence.

[5] The classic study here on the NUMMI auto assembly plant in Fremont, California (see Krafcik (1988) and Wilms (1995)) was followed by case studies of firms in other industries such an office machine company (Cutcher-Gershenfeld 1991), paper manufacturing (Ichniowski 1992) and apparel manufacturing (Berg, Appelbaum, Bailey, and Kalleberg 1996).

[6] This literature typically concentrates on the effect of incentive pay on firm or worker performance, and includes work by Lazear (2000), Knez and Simester (2001), and Hamilton, Nickerson, and Owan (2003).

[7] Papers taking this tack include Bailey (1993), Arthur (1994), Kelley (1994), Kelley (1996), Dunlop and Weil (1996) and Ichniowski, Shaw, and Prennushi (1997). More recently, Ann Bartel and Shaw (2007) have examined the presence of complementarities between IT and plant-level production mechanisms in the machine-valve industry.

[8] See Huselid (1995), Greenan and Guellec (1997), Huselid and Becker (1996), Caroli and Reenen (2001) and Kato and Morishima (2002).

cross-sectional nature of the data in their 2001 paper and the small panel in their subsequent paper brings us full circle to the problems of unobserved heterogeneity and representativeness, respectively, alluded to earlier. Moreover, although they examine the effect of computer use on productivity, they do not explicitly explore the presence of interactions between computer use and workplace practices in their empirical specifications.

In this paper we use longitudinal, establishment-level panel data, the Canadian Workplace Employee Survey (WES) 1999-2004. WES is large (our final panel comprises $26,006$ observations corresponding to $6,842$ workplaces), nationally representative, and has detailed questions on organizational redesign, computer use, as well as complementary hardware and software adoption and investment. These features allow us to explore the effect of organizational redesign and computer use on an objective measure of productivity in enormous detail, while correcting for unobservability and producing results which are more representative of the economy as a whole and industries therein.

3 Conceptual Preliminaries

Computers have been described as a general purpose technology – an enabling technology whose value added to a firm derives from innovative uses (Bresnahan and Trajtenberg 1995), and innovative uses typically require organizational redesign. To illustrate the complementarities between work organization and computer use, consider the case study of "Aircraft", described in Kling (1994). In 1988 the Aircraft engineers work group convinced management to procure them MACs, whose graphics capabilities would enhance the quality of their designs. Management agreed. As a result, the company's engineers increased the range and scope of problems in which they were involved, gained greater autonomy in decision making, and no longer had to rely on other workgroups in order to complete their project documents. Gains from computerization in this context resulted from a combination of IT-enabled graphics quality, and decentralization as well as reengineering.

More generally, computer-based IT can increase value added in two ways. First, it can directly increase the productivity of workers who use them (as in the case of higher quality graphic design in the example above.) Second, to the extent that one of the main things IT does is increase the potential information available within the firm, it can reduce the costs of communication, coordination, and information processing (Brynjolfsson and Hitt 2000). The extent to which firms benefit from the second depends on whether the "right" organizational structures are in place.

In this paper, we consider the extent to which computer use at the workplace – measured by the proportion of workers using a personal computer on the job – is associated with increased productivity when accompanied by organizational redesign. In particular, we consider 8 types of organizational redesign which can be classified into 3 broad areas.

The first area relates to changes in business processes. This includes greater *integration* among different functional units, *reengineering* of business processes, and total quality management (*TQM*). The second, closely related to the first, is changes in delegation of decision making, by which we mean an increased degree of *decentralization*, an increased degree of *centralization*, or a reduction in the number of managerial levels (*delayering*). The third area concerns adjustments in the workplace's dealings with other firms and includes greater reliance on external suppliers of products and services (*outsourcing*) and greater inter-firm *collaboration* in R&D, production or marketing.

Whether or not IT and organizational redesign are complements in production remains to be seen. What is immediately evident in our data is that organizational redesign often goes hand in hand with IT use. This can be seen in table 1. Column 2 (3) describes the proportion of workplaces, which instituted the workplace redesign indicated in column 1 and had a greater (lower) than industry-average proportion of computer users, and column 4 indicates the difference between the proportions in column 2 and 3. As the last column indicates, workplaces which recently engaged in organizational redesign are also substantially more likely to have above-average computer use.

We turn now to what the literature says about the presence or absence of complementarities between the organizational redesign and IT use.

3.1 Business processes

Integration, reengineering and TQM generically relate to the interaction or allocation of work between different parties, and management style in the business process.

Integration refers to increased communication and coordination among different functional units. Reengineering is in some sense, a more radical version of integration. Its main proponents, Michael Hammer and James Champy, argued that instead of organizing a firm into functional units, such as production, research, accounting and marketing, the firm should be reengineered into a series of processes governed by a team which is responsible for all the functions in the process (Hammer and Champy 1993). TQM, popularized in the early 1990s by such management gurus as Joseph Juran and Philip Crosby, has been described as an "integrated management philosophy"geared towards improving product quality and customer satisfaction.[9]

By reducing the costs of communication and coordination, particularly through the use of computer-aided design and management systems, computers greatly facilitate, and therefore increase the profitability associated with, the integration of functional units. This is even more true of reengineering – a concept which originated precisely in response to the possibilities afforded by new technologies. This is reflected in one of Michael Hammer's manifestos in which he declares, "Instead of embedding outdated processes in silicon and software, we should obliterate them and start over. We should "reengineer" our businesses: use the power of modern information technology to radically redesign our business processes in order to achieve dramatic improvements in their performance" (Hammer 1990, p.105).

If integration and reengineering are well-acknowledged complements to computer use, this is less obvious of TQM, given the breath and variety of its constituent elements. On the one hand, the value added of such things as process improvement and measurement are likely to be enhanced by computer use. But the same need not be said for such factors as "committed leadership" or "employee empowerment", which may well be compromised by computer use.

3.2 Delegation of decision-making authority

Of the three areas presented above, the second – the delegation of decision-making authority within the firm – has received the most intense scrutiny from economists. The theoretical literature has typically taken one of two tacks. The first argues that the presence of communication or information processing costs typically favor decentralization, to the extent that these structures better exploit local information and avoid information transmission leakages.[10] The second approach focuses on incentive problems, in which the decision to decentralize decision making involves a trade-off between agency problems on the one hand, and the benefits associated with the informational advantage of agents on the other.[11]

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[9] See Crosby (1984) and Juran (1992). Although different proponents place different emphases Powell (1995), in a survey of the literature maintains that TQM comprises 12 factors: committed leadership, adoption and communication of TQM through mission statements, closer customer relationships, closer supplier relationships, benchmarking, increased training, open organization, employee empowerment, zero-defects mentality, flexible manufacturing, process improvement and measurement.

[10] See, for example, Bolton and Dewatripont (1994) and Radner (1993).

[11] See, for example, Aghion and Tirole (1997) and Acemoglu et al. (2007). Mookherjee (2006) provides an excellent overview.

To the extent that computers lower communication and information processing costs, the first strand of literature would suggest that increased computer use would increase the relative profitability of centralized decision making. To the extent that IT also improves central management's ability to monitor agents, the loss-of-control literature points to the increased relative profitability of decentralization. The net effect of computer use on the value of centralization versus decentralization is therefore ambiguous.

The effect of increased IT use on the number of managerial levels is less ambiguous.[12] Firms which invest in computing technology are likely to process more data and thereby increase their profitability by *reducing* delayering.[13] Similarly, to the extent that IT facilitates communication, and faster communication reduces coordination problems, thereby alleviating loss-of-control over layers of middle management, IT use reduces profitability associated with delayering.[14]

3.3 Inter-firm interaction

Increased outsourcing to external suppliers of products and services, and greater inter-firm collaboration in R&D, production or marketing, and collaboration involves at least two things. The first is the ability to find an appropriate partner, and the second is being able to customize and coordinate the joint endeavor.[15] In reducing the costs of communication and coordination, computer-based IT is thought to increase the productivity associated with both outsourcing and inter-firm collaboration.

4 Data

Our data come from the Workplace and Employee Survey (WES) conducted by Statistics Canada.[16] WES has been conducted annually since 1999 and we use 6 years of data (1999-2004). Our final sample comprises $26,006$ observations over $6,542$ workplaces. The original WES survey contains $37,073$ observations. The discrepancy between the original and our estimation sample is mainly due to the fact that we drop non-profit-establishments ($4,593$ observations) and establishments for

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[12] The theoretical literature on IT and hierarchies is thin and we are grateful to Roy Radner and Kieron Meagher for invaluable input here.

[13] See Cukrowski and Baniak (1999) for a model of the information-processing role of IT in hierarchies.

[14] See and Meagher (2003).

[15] See Grossman and Helpman (2005) for a formal model.

[16] This is a restricted-access data set available in Statistics Canada Research Data Centers (RDC).

which no employees were sampled ($4,803$ observations). We also drop observations with negative value added ($1,913$ observations).

The survey is both longitudinal and linked in that it documents the characteristics of workers and workplaces over time. Abowd and Kramarz (1999) classify WES as a survey in which both the sample of workplaces and the sample of workers are cross-sectionally representative of the target population. The target population for the workplace component of the survey is defined as the collection of all Canadian establishments who paid employees in March of the year of the survey. The sample comes from the "Business Register" of Statistics Canada, which contains information on every business operating in Canada. The survey is therefore nationally representative of Canadian businesses, except for those located in Yukon, the Northwest Territories and Nunavut and firms operating in fisheries, agriculture and cattle farming. For the employee component, the target population is the collection of all employees working, or on paid leave, in the workplace target population. Response rates for each cross-section are over 75 per cent.

The initial 1999 sample is followed over time and is supplemented at two-year intervals with a sample of births selected from units added to the Business Register since the last survey occasion. In the case of total non-response, respondents are withdrawn entirely from the survey and sampling weights are recalculated in order to preserve representativeness of the sample. In order to control for the design effect in our estimations, we weighted our analysis with the final sampling weights for workplaces as recommended by Statistics Canada.

In 1999, workplace data were collected in person; subsequent workplace surveys were conducted by means of computer assisted telephone interviews. For the employee component, telephone interviews were conducted with individuals who had agreed to participate in the survey by filling out and posting an employee participation form.

We have a relatively precise measure of workplace productivity (our dependent variable) in value added, defined as gross operating revenue minus expenses on materials, training and non-wage benefits.[17] Labor is measured through the number of employees in the workplace as of March 31st of the current year. As with most firm-level data, capital stocks for each firm are not available. We deal with this by treating capital stock as an omitted (possibly time-varying) variable that could be correlated to both computer use and organizational redesign. Our empirical methodology, explained in the next section, is designed to estimate the impact of computer use on and organizational redesign on productivity in a manner which is robust to this omitted variable.

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[17] We prefer using value-added as our measure of output since we have no detailed information on other quantities of intermediate input used by the workplace.

Our main measure of workplace IT use is the proportion of employees using computers (CPU) as part of their normal duties, where the survey specifically defines computers as “a micro computer, personal computer, minicomputer, mainframe computer or laptop that can be programmed to perform a variety of operations”. We use this measure for three reasons. First, computer use is a commonly used “aggregate measure” of technology in the literature, especially in the estimation of the “computer premium” (e.g. Krueger (1993) and DiNardo and Pischke (1997)). Second, it is objectively quantifiable and therefore, less likely to be subject to measurement error. Third, it is readily comparable across workplaces.

Table 2 presents summary statistics for our sample, where the average is taken across workplaces. It indicates that the average workplace level proportion of computer users in this sample is 52 per cent. There is considerable variation in computer use, both between workplaces and within a given workplace over time; the standard deviation of the computer use between workplaces is 0.394 and that within workplaces is 0.376. We also control for workforce characteristics such as union concentration, the proportion of managers and workers with at least a university degree. The workplace averages for these variables is 5%, 20% and 12%, respectively.

In addition to computer use, we control for new technology adoption and new technology investment. The former comprises 3 separate dummy variables which take on value 1 if, respectively, between April of the previous year and March-end of the survey year a workplace implemented (i) a major new software application and/or hardware installation; (ii) computer-controlled or computer-assisted technology; and (iii) other major technologies or machinery. The latter comprises Canadian dollar-amounts for each of two most important investments in these three IT categories.

WES provides a rich set of measures of organizational redesign. The survey asks the following question: “Has your workplace experienced any of the following forms of organizational change between April 1 [of the previous year] and March 31 [of the current year]”, following which firms are asked to respond “yes” or “no” to the 8 types of organizational redesign described in the previous section: (i) greater integration, (ii) greater centralization, (iii) greater decentralization, (iv) reengineering, (v) delayering, (vi) implementation of TQM, (vii) increased outsourcing, and (viii) increased inter-firm collaboration. We also find there is as much within as between workplaces variation in our measures of organisational redesign.

As table 3 indicates, over the sample period roughly a tenth of all workplaces experienced recent changes in business processes in the form of increased integration, reengineering and TQM. Increased centralization was the most common change in delegation of decision-making authority, at 6 per cent over the 6 year of observation, compared to the $2-3$ per cent of workplaces which experienced more decentralization and delayering. And $6-7$ per cent of firms recently experienced increased interaction with outside firms. In addition to the variables mentioned above, each of our regressions includes controls for region and time dummies and, in our full sample, also 3-digit industry.

5 Empirical Strategy

Our estimation strategy is based on a workplace-level Cobb-Douglas production function with longitudinal data that is augmented by measures of organizational design and information technology:

$$\begin{aligned}\ln Q_{jt} &\simeq \beta_0 + \beta_L \ln L_{jt} + \beta_K \ln K_{jt} + \kappa C_{jt} \\ &+ \sum_{r=1}^{8} \delta_r R^r_{jt} + \sum_{r=1}^{8} \rho_r R^r_{jt} C_{jt} + \theta Z_{jt} + \gamma_t + \varepsilon_{jt} \qquad (1)\end{aligned}$$

where j represents workplaces and t time, Q is the firm's value-added; L is freely variable input labor, and K is the state variable capital. The proportion of workers using a computer is denoted by C_{jt}; R^r is a dummy variable equal to 1 if the firm introduced organizational redesign r (of which there are 8 types) and $R^r_{jt}C_{jt}$ denotes the interaction terms between organizational redesign dummies and the proportion of computer users. The vector Z_{jt} contains additional control variables. In all specifications, it includes workforce characteristics such as the proportion of workers covered by a collective bargaining agreement, the proportion of college graduates, the proportion of managers, and regional dummies; in our full sample, it contains controls for industry; and in some specifications it also includes controls for the investment in or adoption of complementary hard- and software. Time-varying intercepts and the error term are captured by γ_t and ε, respectively.

When β_L is close to 1, the coefficient on the proportion of workers using a computer is interpreted as the percentage productivity differential between computer users and non users.[18] It is expected to be positive if employees using a computer are more productive. Coefficients on organizational redesign tell

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[18] To understand how κ reflects the productivity differential between computers users and non-users, one needs to interpret L in equation (1) as the number of effective labour units that depends on the number of computer users L^u and the number of non users L^{nu}

$$L_{jt} = \lambda_u L^u_{jt} + \lambda_{nu} L^{nu}_{jt} = \lambda_{nu} L^a_{jt} + (\lambda_u - \lambda_{nu}) L^u_{jt}$$

where L^a is the actual total number of employees ($L^a = L^u + L^{nu}$). λ_u (and λ_{nu}) are load factors converting the number of employees who use (and who not use) computers into effective labor us whether those workplaces that implement changes in organizational design are also more productive. Finally, interactions between the two components capture possible complementarities between organizational redesign and computer usage. A positive coefficient indicates that a certain practice may be complementary to broad-based computer use at the workplace. One drawback of our econometric specification is that it allows only short-run effect of organizational design and IT on productivity. However, allowing for lagged effects greatly reduces our sample size. We discuss this limitation further in the Conclusion.

Equation (1) is typically estimated using (pooled) OLS. The interpretation of the OLS coefficients may, however, be problematic for two reasons. First, whereas organizational restructuring is measured in our data in terms of changes, the remaining variables in equation (1) are measured in levels. Expressing these level variables in first differences would afford the more natural interpretation of the relationship between changes in organizational structure on changes in productivity. Second, and more importantly, a significant coefficient is not necessarily indicative of computer use impacting productivity or the existence of complementarities (or substitutability) between computer use and organizational design. In particular, if there something unobserved to the econometrician (for example the age of the firm) which is correlated with organizational design, computer use, and productivity, then the observed correlation between them may be spurious.

For these two reasons, we prefer to use first-differencing, allowing us to obtain coefficient estimates robust to the presence of time invariant workplace unobserved heterogeneity that could be related to any of the explanatory variables in equation (1). First-differences have the additional advantage of relying on weaker exogeneity assumptions than fixed effects models. Estimating equation (1) in first-differences involves using $(\ln Q_{jt} - \ln Q_{jt-1})$ as the dependent variable and $(\ln L_{jt} - \ln L_{jt-1})$, $(\ln K_{jt} - \ln K_{jt-1})$, $(C_{jt} - C_{jt-1})$, $(Z_{jt} - Z_{jt-1})$ and R_{jt} (which is already measured in changes) as explanatory variables:

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units. This can be rewritten as

$$\ln L_{jt} = \ln \lambda_{nu} + \ln L^{a}_{jt} + \ln \left(1 + \left(\frac{\lambda_u}{\lambda_{nu}} - 1 \right) C_{jt} \right)$$

where we define C_{jt} as the proportion of computer users in workplace j. Since $\ln(1+x) \simeq x$ for a small x, we can write that κ in equation (1) is approximately equal to

$$\kappa \simeq \beta_L \left(\frac{\lambda_u}{\lambda_{nu}} - 1 \right).$$

κ is interpreted as the relative productivity of an employee who use a computer compared to an employee who does not for $\beta_L = 1$.

$$\begin{aligned}(\ln Q_{jt} - \ln Q_{jt-1}) &\simeq \beta_L(\ln L_{jt} - \ln L_{jt-1}) + \beta_K(\ln K_{jt} - \ln K_{jt-1}) \\ &+ \kappa(C_{jt} - C_{jt-1}) + \sum_{r=1}^{8} \delta_r R^r_{jt} \\ &+ \sum_{r=1}^{8} \rho_r R^r_{jt}(C_{jt} - C_{jt-1}) + \theta(Z_{jt} - Z_{jt-1}) \\ &+ \gamma_t - \gamma_{t-1} + \varepsilon_{jt} - \varepsilon_{jt-1} \qquad (2)\end{aligned}$$

If we assume that $K_{jt} = K_{jt-1}$, this specification also allows us to obtain unbiased estimates of the impact of computer use and organizational redesign even though the capital stock is missing.

If, on the other hand, omitted capital stock is time-varying, i.e. $K_{jt} \neq K_{jt-1}$, or there are other time-varying unobserved effects which are correlated with labor use, organizational redesign, or computer use, then we are confronted with an endogeneity problem and our coefficient estimates will be biased. For example, organizational redesign may be a response to a negative productivity shock, or conversely, a positive productivity shock may render redesign more affordable.[19]

To deal with this eventuality, we estimate a different specification of the production function based on Blundell and Bond (2000). Alternative methods have been proposed by Levinsohn and Petrin (2003) and Olley and Pakes (1996). These methods use the demand function for an intermediate good or investments and invert it to obtain a proxy for the productivity of the firm. For these methods to work, one has to assume that the inversion function is non stochastic. However, this is the case if and only if factor prices are the same across firms. But then, this also implies that labor and the good used in the inverse mapping function are collinear. This helps in explaining why the estimates obtained with these methods are generally very imprecise. The proof of this argument is given by Gorodnichenko (2010), but the criticism is also raised by Bond and Soderbom (2005), Ackerberg, Caves, and Frazer (2006) and Basu (1999).

Following Blundell and Bond (2000), assume that the error term in (1) can be decomposed as follows:

$$\varepsilon_{jt} = \omega_{jt} + \psi_j + \eta_{jt} \qquad (3)$$

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[19] We do find some evidence of the latter when we run regressions of future changes in computers use and future re-organizational change on currant changes in productivity. We find mostly positive associations between changes in value-added and re-organizational changes. All but one coefficient are positive and half are statistically significant at the 5% or 10% levels. We interpret this finding as yet another piece of evidence of the possible link between productivity, IT and reorganizational change.

where ψ_j an unobserved firm effects that can be correlated with computer usage, η_{jt} is the residual error term, and ω_{jt} is defined as

$$\omega_{jt} = \alpha\omega_{jt-1} + e_{jt} \tag{4}$$

with e_{jt} being an unobserved productivity shocks. Note that in this framework, the unobserved capital stock is now embedded within η_{jt}. Given the assumptions in (3) and (4), we can then write the dynamic (common factor) representation of (1) as[20]

$$\begin{aligned} \ln Q_{jt} &= \alpha \ln Q_{jt-1} + \beta_0 - \alpha\beta_0 + \beta_L \ln L_{jt} - \alpha\beta_L \ln L_{jt-1} \\ &+ \kappa C_{jt} - \alpha\kappa C_{jt} + \theta Z_{jt} - \alpha\theta Z_{jt-1} \\ &+ (\gamma_t - \alpha\gamma_{t-1}) + (\psi_j(1-\alpha) + e_{jt} + \eta_{jt} - \alpha\eta_{jt-1}) \end{aligned} \tag{5}$$

or

$$\begin{aligned} \ln Q_{jt} &= \pi_1 \ln Q_{jt-1} + \beta_0^* + \pi_2 L_{jt} + \pi_3 L_{jt-1} \\ &+ \pi_4 C_{jt} + \pi_5 C_{jt-1} + \pi_6 Z_{jt} + \pi_7 Z_{jt-1} \\ &+ \gamma_t^* + (\psi_j^* + \eta_{jt}^*) \end{aligned} \tag{6}$$

subject to three non-linear (common factor) restrictions

$$\begin{aligned} \pi_3 &= -\pi_2\pi_1 \\ \pi_5 &= -\pi_4\pi_1 \\ \pi_7 &= -\pi_6\pi_1. \end{aligned}$$

Note that our first-difference specification is a special case of equation (5) with $\alpha = 1$. Again because organizational restructuring is already measured in terms of changes, the complete specification involves adding R_{jt} and R_{jt} interacted with $\left(C_{jt} - C_{jt-1}\right)$ as additional covariates to specification (5) and (6).

It is possible, as described by Blundell and Bond (2000), to obtain consistent estimates for the parameters in (6) by using GMM methods. The Blundell and Bond (2000) estimator uses the usual moment restriction

$$E[x_{jt-s}\triangle\eta_{jt}^*] = 0$$

where $x_{jt-s} = (Q_{jt-s}, L_{jt-s}, C_{jt-s}, R_{jt-s})$ and $s \geq 2$. Briefly described, the method involves taking first-difference to get rid of workplace fixed effects and then estimating the resulting equation using suitably chosen lagged levels of the variables

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[20] We drop the organizational redesign variables for the moment to keep the notation more straightforward.

as instruments. Given consistent estimates of π and $var(\pi)$, we finally recover parameters estimates for the structural parameter $(\beta_k, \beta_l, \delta, \alpha)$ by imposing common factor restrictions and using minimum distance.

In estimating (6), we use lags from 2 on back to create the GMM-type instruments (as described in Arellano and Bond (1991)). First differences of all the exogenous variables are used as standard instruments. As a specification check, we compute the the Sargan test of overidentifying restriction when using the one-step system estimator. In this case, we cannot reject the null hypothesis that the overidentifying restrictions are valid (Prob. $>$ chi2 = 0.5179).

Standard errors for all of our coefficient estimates are bootstrapped in order to fully account for the stratified sampling procedure used by Statistics Canada. This is also recommended by Donald and Lang (2007) to control for residual clustering at the unit of observation level. Statistical significance is based on the bootstrapped confidence interval.

6 Results

6.1 First-Differences (FD)

Table 4 shows results from estimating the first difference equation (2) with the full sample. This specification allows us to take into account unobserved heterogeneity between workplaces that might drive both computer use and productivity, while relating changes in organizational design with changes in productivity.

It is worth pointing out that in all specifications, the coefficient on L is a very reasonable 0.48, suggesting that our statistical methodology does a good job in obtaining an unbiased estimate for β_L even with the omission of the capital stock.

Column 1 in table 4 does not account for organizational redesign. The coefficient on computer use is close to zero and insignificant. By contrast, pooled OLS estimates (not reported) indicate large positive returns associated with computer use, whereby a computer user is, on average, 37-47% more productive than a non-user. Since, as we saw in section 4, within (over time) variation and between (cross-sectional) variation contribute almost equally to total variation, this discrepancy in the FD and pooled OLS estimates cannot be attributed to lack of time variation in computer use within a given workplace. This suggests that that once unobserved heterogeneity is controlled for, computer use has no effect on productivity in the aggregate sample. Including dummies for organizational redesign – integration, re-engineering, TQM, centralization, decentralization, delayering, outsourcing and collaboration – in column 2 leaves this estimate largely unchanged.

These results underscore two important points. First, computer-associated productivity premium typically found in OLS regressions seemingly captures the fact that workplaces which are more productive (for unobserved reasons) also have a relatively high proportion of computer users. Second, it is unlikely that the productivity growth observed in the macro data can be attributed solely to computer use in workplaces.

Column 3 allows for potential complementarities between organizational redesign and computer use by adding 8 interaction terms between our measures of organizational redesign and computer use. Even if changes in computer use has no direct bearing on productivity, surely complementarities between such changes and organizational redesign do? Column 3 of table 4 suggests that this is not the case. The interaction terms between computer use and our organizational redesign dummies are statistically insignificant. The only consistent exception is the positive delayering interaction. Moreover, all the organizational redesign dummies are also statistically insignificant, suggesting that new models of organizational structure alone have no bearing on productivity either, and there is considerable variation in organizational redesign.

One possible explanation for this is that, as Ichniowski, Shaw, and Prennushi (1997, p.295) note, “If firms adopt work practices in a complementary fashion, then empirical tests should consider the impacts of groups of practices rather than simply the effects of individual practices.” In order to test whether groups of practices, rather than individual practices impact productivity, we estimated the effect of 3 aggregated categories of organizational change along the lines described in Section 3, comprising three dummy variables for business process, delegation of decision-making authority, and inter-firm interaction respectively.

Aggregation of practices in such a manner would also alleviate the fears of another possible explanation, namely that disaggregated measures we present measurement error. In particular, despite detailed clarification of what is intended by each of the 8 types of organizational redesign, it is conceivable that, say, decentralization was confused with delayering, or that outsourcing was not properly distinguished from collaboration. Using aggregated categories does change our results: significant interactions between computer use and organizational redesign are generically absent.

The FD specification gives unbiased estimates of the impact of computer use and organizational redesign as long as workplace unobserved heterogeneity does not vary over time. But, we still may be concerned about time-varying sources of heterogeneity. If computers are correlated with only the time-varying IT investments, then controlling for the use of (column 4) as well as investments in (column 5) IT hardware and software directly addresses endogeneity due to omitted variable bias. Including such controls in columns 4 and 5 of table 4 leave the coefficient estimates for our variables of interest qualitatively unchanged.

If time-varying unobserved determinants of productivity other than complementary investments in IT hardware and software are correlated to computer use or organizational redesign, however, endogeneity remains a concern. We deal with this eventuality by estimating equation (1) using GMM methods.

6.2 GMM

Table 5 presents the results of equation (1) using GMM with the structural assumptions embedded in equations (3) and (4). The results, documented in table 5, are qualitatively similar to our FD results presented in table 4. The coefficient on the proportion of computer users, although positive, remains statistically insignificant. This suggests that our finding that computer use has no significant impact on productivity is robust to both fixed as well time varying sources of endogeneity, including changes in capital stock.

The results pertaining to organizational redesign are also qualitatively similar to the FD estimates in table 4. Both the organizational redesign dummies, as well as their interaction terms are statistically insignificant. (The only exception here is outsourcing, which is only marginally significant.) These FD and GMM estimates are puzzling, to say the least. Why would an organization give computers to its workers or engage in organizational restructuring if neither – whether in isolation or in combination – had any bearing on productivity?

7 Specification checks

7.1 Results by industry

One seemingly natural explanation is that the estimates in tables 4 and 5 are too restrictive. They assume that computer use and organizational redesign mean the same thing and have the same effect on productivity across different industries. Reality is likely to be more nuanced. Reengineering, for example, is likely to mean something totally different to firms in the construction industry than firms in the entertainment industry. This form of measurement error may be responsible for imprecise estimates.

Moreover, as a number of recent intra-industry and within plant studies have shown, the utility of IT, organizational redesign, and the degree to which the latter facilitates productivity gains from the former, is likely to vary from industry to industry. Centralization at a petroleum plant may, for example, lead to productivity improvements if only a handful of people with computers have control over largely automated processes, whereas centralization in an insurance firm where human-capital intensive data gathering is important is likely to be effective only if most employees have computers. Therefore, a zero aggregate impact could mask what is in fact a negative interaction (substitutability) within some industries and a positive interaction (complementarities) within others. Failure to allow for this type of measurement error and unobserved heterogeneity may account for large standard errors in our organizational redesign coefficients and interactions in our full sample results described above.

Table 6 summarizes IT use as well as organizational redesign by 3-digit industrial classifications.[21] These industries include natural resource extraction (NAT); primary product manufacturing (FAB1); secondary product manufacturing (FAB2); labor intensive tertiary manufacturing (FAB3L); construction (CON); transportation (TRA); communications (COM); finance and insurance (FIN); business services (BS); and the entertainment industry (ENT). Our disaggregated samples are sizable: the data contain between 1100 and 3200 observations in each of these industries, corresponding to between 320 and 900 workplaces.

Table 6 indicates that both computer use as well as the choice of organizational redesign exhibit large inter-industry variation, with more widespread computer use in service than in manufacturing industries. Computer use varies from a high of 88% in financial services (FIN) to a low of 28% in primary product manufacturing (FAB1), and various types of organizational redesign are much more common in some industries than others.

Table 7 presents productivity estimates disaggregated by industry. It indicates that in 9 of these 10 industries, the coefficient on computer use is statistically insignificant (row 2), echoing our findings from the full sample that computer use has no bearing on productivity. The only exception is transportation, where where a point estimate of 0.25 suggests substantial productivity gains associated with computer use.

A cursory look at the coefficients of the dummy variables and interactions with computer use in Table 7 suggests that, in contrast to table 5, organizational redesign may have some bearing within some industries. Still, as the results described below indicate, there is little evidence to support the suggestion that organizational

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[21] We also have data for 4 additional industries, (i) capital intensive tertiary manufacturing, covering printing, machinery, computer and electronics, electric equipment/appliance/component, and transportation equipment (ii) retail trade and consumer services (iii) real estate, rental and leasing operations (iv) and education and health services. We do not present results pertaining to them in order to avoid overly unruly tables, since they demonstrated *no* evidence of significant complementarities (or substitutability) between organizational redesign and computer use in our GMM estimation. All estimates are available upon request.

redesign – whether in isolation or in conjunction with computer use – is a productivity driver in these data.

Two types of organizational redesign which have received a great deal of attention in business practice – reengineering and TQM – have no impact on productivity in any industry. This may be surprising, but what is even more puzzling is that some types of organizational redesign seem to have a negative impact on productivity. This would seem justifiable if such redesign exhibited complementarities, and there is some evidence of this. In finance (FIN), outsourcing has a negative direct effect, but has a positive interaction effect with computer use. A similar pattern can be observed in the case of integration in business services (BS). In both cases, however, the point estimate on the interaction terms suggests that *all* the workers would have to use a computer in order to counteract the negative level effect. (And in the case of natural resources (NAT), outsourcing exerts a negative direct effect without any statistically significant evidence of complementarities with computer use.)

The only other evidence of complementarities between organizational redesign and computer use are economically significant, with large point estimates, but only marginally statistically significant – as in the interactions between computer use and (respectively) delayering in labor intensive tertiary manufacturing (FAB3L); outsourcing in communications (COM); and decentralization in entertainment. In sum, the data provide weak evidence at best of potential complementarities between organizational redesign and computer use.

Some types of organizational redesign have statistically and economically significant effects on productivity without any evidence of complementarities. Integration of different functional units is associated with a 38 percent increase in productivity in primary sector manufacturing (FAB1), collaboration in R&D with a (marginally significant) 37 percent increase in tertiary labor-intensive manufacturing (FAB3L), and centralization with a 34 percent increase in productivity in construction (CON). In finance (FIN), however, a large increase in productivity associated with R&D collaboration is offset by a negative interaction term for computer use, which as we have seen has no direct impact on productivity in this industry. In transportation (TRA), a positive level effect of delayering on productivity is accompanied by a negative interaction term; but in this case, computer use is associated with direct productivity gains.

Taken together, these results suggest that organizational redesign is unlikely to be a major driver of productivity growth in these data, even allowing for industry-specific variation.

7.2 Results by workplace size

Among the reasons why we do not find any impact of computer use on productivity, compared for example to Bresnahan, Brynjolfsson and Hitt (2002), is their focus on large publicly traded firms. Unfortunately, we do not have any information about whether the firm is publicly traded or not. However, we can allow the impact of computer use and organizational design to vary by workplace size (as measured by the number of employees). Table 8 shows such results for specification (3) of the first-difference model. *Tiny* refers to workplaces with 1 to 9 employees (7317 observations), *Small* to workplaces with 10 to 99 employees (6013 observations), *Medium* to workplaces with 100 to 499 employees (4015 observations) and *Large* to workplace with more than 500 employees (932 observations).

Again, the impact of computer use on productivity is very imprecisely estimated. Although point estimates suggest an increase in returns with workplace size, it is impossible the reject the null hypothesis that these returns are nil. In terms of organizational design, no clear pattern emerges, suggesting again that the implementation and impact of reorganizational design and computer use are very heterogenous across workplaces.

7.3 Results by type of workplace

Another potential reason why we do not find any impact of computer use on productivity is our focus on workplaces. If the impact of computer use and organizational design on productivity at the workplace level depends on the computer use and complementary organizational designs at other workplaces owned by the same firm, our previous estimates will not reflect the real impact of these two investments. It is possible to go some way toward testing this hypothesis. The WES distinguishes between three types of workplaces. The first type, described as the non-integrated portion (NIP), comprises small independent workplaces, for example a corner store that is not part of a chain (5289 observations). The second type could be small or large workplaces, but that are part of multi-unit firms (MULTIP - 5040 observations). The last type are large business that could have multiple physical location but information is provided at the highest level (SIP - 3716 observations).[22] Table 9 shows such results for specification (3) of the first-difference model.

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[22] The difference between MULTIP and SIP workplaces is rather technical, Statistics Canada defines a statistical location as one that can report employment and payroll at the location level. In MULTIP workplaces, there are many statistical locations corresponding to many workplaces. In SIP workplaces, there is only one statistical location even though the workplace can be spread among multiple physical units.

With respect to the statistical significance of the coefficient estimates, our earlier conclusions are unchanged. There is again a lot of heterogeneity in the impact of computer use and organizational design on productivity. However, based on the point estimates, it is interesting to note that the impact of computer use is highest for independent workplaces, whereas the same impact is lower for workplaces with more complex organizational structure.

8 Conclusion

The first 5 years of the millennium witnessed a sustained increase in productivity despite a collapse in IT investment. It is often suggested that organizational redesign which accompanies IT use may account for this. In this paper we examined this claim from a microeconomic perspective. We exploited nationally representative, establishment-level survey data spanning 1999-2004, containing a rich set of measures pertaining to IT use and organizational redesign, and used panel data techniques to deal with unobserved workplace heterogeneity.

Accounting for unobserved time invariant and variant workplace heterogeneity through first-difference and GMM estimation respectively, we find the productivity premium associated with computer use is close to zero and statistically insignificant. Since these data are nationally representative, this would suggest that the "computer revolution" is not responsible for the productivity boom witnessed in the beginning of this century.

This leaves organizational redesign and complementarities between these and IT use as a potential explanation for productivity growth. But there is little evidence in our data to suggest that these have any substantial bearing on productivity. In the full sample, our first difference and GMM estimates suggest that (with the possible exceptions of delayering and outsourcing, which are marginally significant in some specifications) organizational redesign does not impact productivity, either in isolation or in conjunction with computer use.

At the industry level we find that some types of organizational redesign matter for some industries. But the evidence not compelling. In most cases our GMM estimates indicate that only one type of organizational redesign has any bearing on productivity; some types of organizational redesign have a negative impact on productivity; few industries demonstrate the presence of complementarities between organizational redesign and computer use; and in some industries, they are substitutes.

In sum, these rich, nationally representative micro data provide little support for the idea that productivity growth has been driven by either computer use or changes organizational structure which have accompanied computer use.

There are at least three possible explanations for these “negative” results. First, our coefficients may simply be capturing short-run effects, reflecting a potentially costly period of adjustment to a new organizational structure, which will be compensated for with long-run gains. One way to account for this possibility is to see whether there are any lagged effects of computer use and organizational redesign on productivity. When we include once- and twice-lagged measures of organizational redesign and computer use as explanatory variables in our productivity regression, however, their coefficients remain statistically insignificant. Although samples in these specifications are considerably smaller and no longer representative (especially with two lags), this finding does suggest that potentially costly short-term adjustment does not entirely explain our empirical puzzle.

A second explanation is that the decision to institute new organizational structures is driven fads in particular industries rather than any tangible productivity benefits. For some industries and some types of practices – reengineering and TQM in manufacturing industries, for example – this does not seem entirely implausible.

A third explanation is that computer use is too coarse a measure to capture synergies between IT use and organizational redesign. Garicano (2000), for example, argues that different types of technology (technology that lowers learning cost and technology that lowers communication costs within the organization) can have different effects on organizational structure. Empirically, Bloom and al (2009) find some cross-sectional evidence to support Garicano’s argument. However, while our data set has many advantages in terms of coverage and representativeness, it does not contain the information that would allow us to capture the types of channels put forward by Garicano (2000).

The results of this paper highlight the need for more work in this area. If computer use does in fact have a direct impact on productivity, it must be driven by other types of IT investment or more subtle transformations in the kind of work done using these computers, which suggests potential complementarities with workplace human capital. And if substantial complementarities between organizational redesign and computer use do indeed exist, then the devil must be in the detail. For managers interested in harnessing the power of computers through organizational redesign though, our results suggest that there is no generic panacea.

Table 1: Intensity of computer usage and organizational design

	% workers using a computer*		
Type of organizational design	Greater	Lower	Diff
Changes in business processes			
Greater integration	0.183	0.078	0.105
Reengineering	0.236	0.151	0.085
Implementation of TQM	0.164	0.098	0.066
Changes in delegation of decision making			
Greater centralization	0.137	0.045	0.092
Greater decentralization	0.042	0.018	0.024
Delayering	0.057	0.023	0.034
Adjustments in dealings with other firms			
Increased outsourcing	0.156	0.089	0.066
Increased collaboration	0.140	0.059	0.081

*Note.**Percentage of workers using a computer relative to the industry average.

Table 2: Summary statistics

	1999		2001		2003		ALL	
Variable	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.
ln(Value added) ($)	12.461	1.528	12.446	1.495	12.431	1.505	12.508	1.491
ln(L)	1.712	1.106	1.796	1.107	1.821	1.113	1.820	1.105
Prop. CPU Users	0.473	0.420	0.520	0.412	0.539	0.414	0.519	0.465
Workforce control variables								
Proportion unionized	0.046	0.179	0.051	0.185	0.041	0.174	0.050	0.187
Proportion managers	0.175	0.215	0.238	0.267	0.202	0.242	0.203	0.238
Proportion graduates	0.125	0.252	0.125	0.267	0.115	0.257	0.124	0.266
Number of obs.	4625		4457		4455		26006	

Note. Value added is measured in Canadian dollars. *L* refers to the number of employees in the firm. Proportion of CPU users refers to the proportion of employees using computers (i.e. “micro computer, personal computer, minicomputer, mainframe computer or laptop that can be programmed to perform a variety of operations”) as part of their normal duties.

Table 3: Summary statistics

Variable	1999 Mean	2001 Mean	2003 Mean	ALL Mean
Changes in business processes				
Integration	0.12	0.08	0.08	0.09
Re-engineering	0.19	0.13	0.11	0.12
TQM	0.13	0.08	0.05	0.08
Changes in delegation				
Centralization	0.09	0.06	0.02	0.06
Decentralization	0.03	0.03	0.02	0.02
Delayering	0.04	0.02	0.03	0.03
Dealings with other firms				
Outsource	0.13	0.07	0.05	0.07
Collaboration	0.10	0.06	0.04	0.06
Industry				
Natural Resources (NAT)	0.02	0.02	0.01	0.02
Primary manufacturing (FAB1)	0.01	0.01	0.01	0.01
Secondary manufacturing (FAB2)	0.02	0.02	0.02	0.02
Labour tertiary (FAB3L)	0.03	0.03	0.03	0.03
Capital tertiary (FAB3K)	0.03	0.03	0.04	0.03
Construction (CON)	0.08	0.08	0.09	0.08
Transport (TRA)	0.13	0.11	0.12	0.12
Communication (COM)	0.01	0.02	0.01	0.01
Retail (RET)	0.35	0.34	0.35	0.35
Finance and insurance (FIN)	0.06	0.06	0.05	0.05
Real estate (REA)	0.04	0.04	0.04	0.04
Business services (BS)	0.12	0.14	0.12	0.12
Education and health care (EH)	0.09	0.09	0.09	0.09
Information and culture (ENT)	0.02	0.02	0.02	0.02
Number of observations:	4625	4457	4455	26006

Table 4: Workplace Productivity and Computer Use - First-Difference Coefficient Estimates

	(1)	(2)	(3)	(4)	(5)
ln(L)	0.482**	0.479**	0.480**	0.478**	0.478**
	(0.103)	(0.104)	(0.107)	(0.107)	(0.107)
Prop. CPU users	-0.005	-0.003	0.000	-0.007	-0.007
	(0.028)	(0.028)	(0.067)	(0.066)	(0.066)
Changes in business processes					
Integration		0.023	0.028	0.024	0.024
		(0.040)	(0.047)	(0.047)	(0.047)
CPU*Integration			-0.181	-0.171	-0.174
			(0.173)	(0.165)	(0.166)
Re-engineering		0.003	0.004	0.003	0.003
		(0.026)	(0.031)	(0.032)	(0.032)
CPU*Re-engineering			-0.003	-0.018	-0.019
			(0.156)	(0.157)	(0.156)
TQM		0.000	0.001	-0.004	-0.004
		(0.050)	(0.048)	(0.045)	(0.046)
CPU*TQM			-0.195*	-0.177	-0.175
			(0.060)	(0.065)	(0.069)
Changes in delegation of decision making					
Centralization		0.061	0.061	0.064	0.064
		(0.040)	(0.044)	(0.045)	(0.045)
CPU*Centralization			0.225	0.234	0.235
			(0.198)	(0.201)	(0.200)
Decentralization		-0.046	-0.043	-0.035	-0.036
		(0.109)	(0.111)	(0.108)	(0.108)
CPU*Decentralization			-0.123	-0.121	-0.121
			(0.231)	(0.228)	(0.227)
Delayering		-0.046	-0.079	-0.073	-0.073
		(0.048)	(0.051)	(0.052)	(0.051)
CPU*Delayering			0.429**	0.424*	0.426*
			(0.092)	(0.099)	(0.100)

cont'd.

Table 4: Workplace Productivity and Computer Use - First-Difference Coefficient Estimates (Cont'd)

	(1)	(2)	(3)	(4)	(5)
Adjustments in the workplace's dealings with other firms					
Outsource		-0.153	-0.164	-0.162	-0.162
		(0.074)	(0.076)	(0.076)	(0.076)
CPU*Outsource			0.247	0.252	0.251
			(0.276)	(0.273)	(0.275)
Collaboration		0.037	0.040	0.038	0.038
		(0.035)	(0.041)	(0.040)	(0.040)
CPU*Collaboration			0.039	0.041	0.043
			(0.056)	(0.050)	(0.049)
Workforce control variables	YES	YES	YES	YES	YES
New technologies dummies	NO	NO	NO	YES	NO
New tech. $ invested	NO	NO	NO	NO	YES
Industry dummies	YES	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES	YES
Regions dummies	YES	YES	YES	YES	YES
# Observations	18479	18479	18479	18479	18479
# Workplaces	6542	6542	6542	6542	6542

Note. Dependent variable is ln(Value Added) at time t minus ln(Value Added) at time t-1. Statistical significance based on bootstrapped confidence interval: *=10%; **=5%; ***=1%. Bootstrapped standard errors in parentheses. Workforce controls include union concentration, proportion of managers, and proportion of workers with at least a univ. degree. New technologies dummies incl. 3 dummy variables equal to 1 if the workplace instituted a major new hard/software, computer controlled- or assisted device, or other major tech or machinery. New tech $ invested are CAN$ investments in the 3 technologies.

Table 5: Workplace Productivity and Computer Use - GMM Coefficient Estimates

	(1)	(2)	(3)	(4)	(5)
ln(L)	0.475***	0.476***	0.476***	0.472***	0.475***
	(0.044)	(0.044)	(0.047)	(0.046)	(0.046)
Prop. CPU users	0.043	0.048	0.048	0.050	0.053
	(0.064)	(0.070)	(0.057)	(0.058)	(0.058)
Changes in business processes					
Integration		0.009	0.035	0.036	0.036
		(0.020)	(0.040)	(0.038)	(0.038)
CPU*Integration			-0.042	-0.046	-0.046
			(0.061)	(0.061)	(0.057)
Re-engineering		-0.011	-0.011	-0.009	-0.011
		(0.019)	(0.032)	(0.031)	(0.031)
CPU*Re-engineering			-0.003	-0.007	-0.001
			(0.004)	(0.045)	(0.046)
TQM		-0.023	-0.025	-0.030	-0.029
		(0.023)	(0.035)	(0.038)	(0.036)
CPU*TQM			0.003	0.012	0.006
			(0.058)	(0.057)	(0.055)
Changes in delegation of decision making					
Centralization		-0.016	-0.015	-0.018	-0.018
		(0.022)	(0.045)	(0.046)	(0.046)
CPU*Centralization			0.001	0.002	0.001
			(0.067)	(0.066)	(0.064)
Decentralization		0.056	0.015	0.009	0.003
		(0.034)	(0.066)	(0.072)	(0.066)
CPU*Decentralization			0.076	0.084	0.095
			(0.103)	(0.105)	(0.1)
Delayering		0.045	0.026	0.024	0.026
		(0.043)	(0.059)	(0.060)	(0.064)
CPU*Delayering			0.027	0.026	0.022
			(0.081)	(0.085)	(0.089)

cont'd.

Table 5: Workplace Productivity and Computer Use - GMM Coefficient Estimates (Cont'd)

	(1)	(2)	(3)	(4)	(5)
Adjustments in the workplace's dealings with other firms					
Outsource		-0.017	-0.079*	-0.077*	-0.083**
		(0.026)	(0.044)	(0.041)	(0.042)
CPU*Outsource			0.122*	0.117*	0.123*
			(0.070)	(0.065)	(0.064)
Collaboration		0.001	0.010	0.009	0.01
		(0.020)	(0.048)	(0.045)	(0.046)
CPU*Collaboration			-0.023	-0.025	-0.022
			(0.073)	(0.068)	(0.067)
Constant	9.400***	9.409***	9.373***	9.375***	9.364
	(0.501)	(0.045)	(0.472)	(0.480)	(0.481)
α	0.272***	0.272***	0.275***	0.275***	0.275***
	(0.040)	(0.037)	(0.039)	(0.039)	(0.040)
Workforce control variables	YES	YES	YES	YES	YES
New technologies dummies	NO	NO	NO	YES	NO
New tech. $ invested	NO	NO	NO	NO	YES
Industry dummies	YES	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES	YES
Regions dummies	YES	YES	YES	YES	YES
# Observations	11172	11172	11172	11172	11172
# Workplaces	3898	3898	3898	3898	3898

Note. Dependent variable is ln(Value Added). Statistical significance based on bootstrapped confidence interval: *=10%; **=5%; ***=1%. Bootstrapped standard errors in parentheses. Controls are described in the note to table 4.

Table 6: Summary Statistics by Industry

	NAT	FAB1	FAB2	FAB3L	CON	TRA	COM	FIN	BS	ENT
Prop. CPU users	0.399	0.283	0.399	0.320	0.298	0.564	0.402	0.882	0.779	0.785
Changes in business processes										
Integration	0.123	0.166	0.143	0.117	0.066	0.131	0.148	0.191	0.082	0.182
Re-engineering	0.137	0.251	0.215	0.203	0.096	0.133	0.175	0.245	0.134	0.235
TQM	0.076	0.123	0.165	0.120	0.071	0.082	0.104	0.093	0.068	0.077
Changes in delegation of decision making										
Centralization	0.081	0.099	0.094	0.060	0.032	0.072	0.107	0.165	0.056	0.105
Decentralization	0.020	0.040	0.019	0.031	0.012	0.026	0.048	0.022	0.022	0.061
Delayering	0.046	0.043	0.028	0.032	0.029	0.026	0.047	0.038	0.029	0.047
Adjustments in the workplace's dealings with other firms										
Outsource	0.067	0.104	0.097	0.130	0.095	0.095	0.089	0.069	0.061	0.077
Collaboration	0.048	0.116	0.131	0.099	0.046	0.079	0.064	0.095	0.072	0.089

Note. This table provides summary statistics by 3-digit industrial classification for the following industries: natural resource extraction (NAT), comprising Support Activities for Forestry, Oil and Gas Extraction, Mining (except Oil and Gas), Support Activities for Mining; primary product manufacturing (FAB1) comprising wood products, petroleum and coal, non-metallic minerals, and primary metals ; secondary product manufacturing (FAB2) comprising chemicals, plastic and rubber, and fabricated metal products; labor intensive tertiary manufacturing (FAB3L) comprising food, beverage and tobacco, textiles and textile products, clothing, leather, furniture, and miscellaneous; construction (CON); transportation (TRA); communications (COM); finance and insurance (FIN); business services (BS) comprising professional, scientific and technical services, management of companies, administrative and support services; and the entertainment industry (ENT).

Table 7: Workplace Productivity and Computer Use - GMM Coefficient Estimates by Industry

	NAT	FAB1	FAB2	FAB3L	CON	TRA	COM	FIN	BS	ENT
ln(L)	0.654**	0.488***	0.623***	0.1	0.305***	0.746***	0.504***	0.559***	0.599***	0.517***
	(0.266)	(0.106)	(0.141)	(0.135)	(0.068)	(0.09)	(0.179)	(0.131)	(0.113)	(0.153)
Prop. CPU users	0.25	0.174	0.126	0.13	-0.007	0.247**	-0.036	0.22	0.09	0.335
	(0.164)	(0.278)	(0.146)	(0.156)	(0.17)	(0.104)	(0.185)	(0.253)	(0.147)	(0.206)
Changes in business processes										
Integration	0.058	0.321**	0.158	-0.179	-0.075	0.132	-0.15	0.196	-0.431*	-0.075
	(0.149)	(0.157)	(0.143)	(0.117)	(0.132)	(0.094)	(0.175)	(0.434)	(0.228)	(0.178)
CPU*Integration	-0.055	-0.505	-0.348	0.12	0.088	-0.105	0.259	-0.249	0.491*	0.073
	(0.435)	(0.361)	(0.376)	(0.247)	(0.365)	(0.161)	(0.261)	(0.44)	(0.255)	(0.215)
Re-engineering	0.145	-0.013	-0.191	0.061	-0.093	0.072	-0.157	-0.431	-0.066	0.151
	(0.163)	(0.142)	(0.118)	(0.083)	(0.152)	(0.073)	(0.177)	(0.333)	(0.144)	(0.19)
CPU*Re-engineering	-0.266	-0.03	0.471	0.008	0.252	-0.218	0.254	0.419	0.113	-0.241
	(0.294)	(0.277)	(0.304)	(0.199)	(0.323)	(0.135)	(0.289)	(0.335)	(0.167)	(0.218)
TQM	-0.15	-0.024	0.009	-0.044	-0.144	-0.045	0.259	-0.529	0.21	0.334
	(0.149)	(0.165)	(0.111)	(0.113)	(0.138)	(0.097)	(0.184)	(0.428)	(0.169)	(0.29)
CPU*TQM	0.32	-0.311	0.017	0.095	0.12	0.16	-0.211	0.409	-0.269	-0.511
	(0.485)	(0.385)	(0.292)	(0.307)	(0.438)	(0.158)	(0.259)	(0.447)	(0.205)	(0.328)
Changes in delegation of decision making										
Centralization	-0.074	-0.177	0.083	-0.104	0.294***	-0.016	0.33	0.509	-0.075	0.023
	(0.151)	(0.193)	(0.166)	(0.17)	(0.143)	(0.125)	(0.223)	(0.4)	(0.216)	(0.152)
CPU*Centralization	-0.094	0.204	0.041	-0.018	-0.484	0.028	-0.485	-0.447	0.001	-0.101
	(0.359)	(0.39)	(0.383)	(0.322)	(0.32)	(0.184)	(0.334)	(0.417)	(0.244)	(0.193)
Decentralization	0.124	-0.131	0.021	-0.208	-0.035	0.026	0.254	0.826	-0.261	-0.8
	(0.288)	(0.291)	(0.233)	(0.145)	(0.335)	(0.146)	(0.199)	(0.544)	(0.343)	(0.538)
CPU*Decentralization	-0.309	0.096	-0.063	0.23	0.426	-0.064	-0.201	-0.747	0.18	1.143*
	(0.605)	(0.551)	(0.513)	(0.341)	(0.689)	(0.213)	(0.313)	(0.553)	(0.383)	(0.628)
Delayering	0.259	-0.106	0.432	-0.3	0.076	0.373***	0.149	-0.249	0.018	0.364
	(0.281)	(0.224)	(0.268)	(0.185)	(0.23)	(0.145)	(0.273)	(0.643)	(0.24)	(0.318)
CPU*Delayering	-0.149	0.34	-1.228**	0.672*	0.35	-0.412**	-0.468	0.411	-0.011	-0.384
	(0.359)	(0.475)	(0.576)	(0.344)	(0.696)	(0.2)	(0.445)	(0.656)	(0.287)	(0.374)

cont’d.

Table 7: Workplace Productivity and Computer Use - GMM Coefficient Estimates by Industry (Cont'd)

	NAT	FAB1	FAB2	FAB3L	CON	TRA	COM	FIN	BS	ENT
Adjustments in the workplace's dealings with other firms										
Outsource	-0.386**	-0.086	-0.256	0.032	-0.065	0.03	-0.206	-0.955**	-0.186	0.363
	(0.185)	(0.164)	(0.207)	(0.114)	(0.166)	(0.117)	(0.186)	(0.396)	(0.277)	(0.309)
CPU*Outsource	0.606	0.546	0.44	-0.03	-0.152	-0.053	0.602*	1.073**	0.224	-0.438
	(0.435)	(0.357)	(0.387)	(0.307)	(0.317)	(0.182)	(0.372)	(0.443)	(0.283)	(0.408)
Collaboration	0.103	-0.187	-0.041	0.318*	-0.025	0.001	-0.126	1.034**	-0.047	-0.075
	(0.155)	(0.162)	(0.124)	(0.163)	(0.183)	(0.124)	(0.225)	(0.438)	(0.305)	(0.227)
CPU*Collaboration	-0.263	0.325	0.086	-0.256	-0.115	0.066	-0.084	-1.097**	-0.032	0.103
	(0.337)	(0.317)	(0.274)	(0.298)	(0.442)	(0.181)	(0.331)	(0.458)	(0.328)	(0.271)
Constant	12.706***	8.062***	8.982***	9.344***	10.107***	8.541***	11.566***	9.895***	7.768***	13.759***
	(2.55)	(2.792)	(2.666)	(1.582)	(1.187)	(1.003)	(2.321)	(1.4)	(1.962)	(2.496)
# Observations	511	685	626	757	1241	1442	533	953	924	520
# Workplaces	180	232	217	263	424	499	212	327	329	174

Note. The empirical model estimated in this table is analogous to that in table 5, but disaggregated by 3-digit industry, as described in the note to table 6. Statistical significance based on bootstrapped confidence interval: *=10%; **=5%; ***=1%. Bootstrapped standard errors in parentheses. Estimates include year and region dummies as well as workforce control variables and new technologies dummies described in the note to table 4.

Table 8: Workplace Productivity and Computer Use - First-Difference Coefficient Estimates by Workplace Size

	Tiny	Small	Medium	Large
Prop. CPU users	0.037	0.061	0.011	0.105
	(0.163)	(0.093)	(0.127)	(0.097)
Changes in business processes				
Integration	0.014	0.075**	0.054	-0.131**
	(0.091)	(0.037)	(0.099)	(0.055)
CPU*Integration	0.008	-0.390**	0.023	0.434**
	(0.251)	(0.164)	(0.196)	(0.204)
Re-engineering	0.017	-0.038	-0.080*	0.085
	(0.077)	(0.058)	(0.046)	(0.056)
CPU*Re-engineering	0.123	0.139	0.033	-0.171
	(0.404)	(0.215)	(0.192)	(0.143)
TQM	-0.028	0.060	0.000	0.067
	(0.108)	(0.078)	(0.072)	(0.062)
CPU*TQM	-0.294	-0.002	-0.075	0.358
	(0.224)	(0.248)	(0.247)	(0.220)
Changes in delegation of decision making				
Centralization	0.065	0.049	0.025	0.063
	(0.116)	(0.047)	(0.113)	(0.057)
CPU* Centralization	0.001	0.492**	0.088	-0.362*
	(0.346)	(0.193)	(0.200)	(0.200)
Decentralization	-0.262	0.106	0.090	-0.158
	(0.212)	(0.084)	(0.058)	(0.116)
CPU* Decentralization	-1.962***	-0.397	-0.031	-0.532
	(0.478)	(0.457)	(0.317)	(0.330)
Delayering	-0.105	-0.010	-0.035	0.067
	(0.197)	(0.053)	(0.155)	(0.063)
CPU*Delayering	0.649	0.263	0.007	0.234
	(0.782)	(0.327)	(0.213)	(0.377)

cont'd.

Table 8: Workplace Productivity and Computer Use - First-Difference Coefficient Estimates by Workplace Size (Cont'd)

	Tiny	Small	Medium	Large
Adjustments in dealings with other firms				
Outsource	-0.191*	-0.086	0.037	-0.057
	(0.104)	(0.053)	(0.072)	(0.067)
CPU*Outsource	0.090	0.231	0.372	-0.137
	(0.432)	(0.666)	(0.362)	(0.218)
Collaboration	0.049	-0.004	-0.029	0.185***
	(0.130)	(0.048)	(0.071)	(0.059)
CPU*Collaboration	0.075	-0.082	0.007	-0.115
	(0.320)	(0.239)	(0.287)	(0.232)

Note. Dependent variable is ln(Value Added). Statistical significance based on bootstrapped confidence interval: *=10%; **=5%; ***=1%. Bootstrapped standard errors in parentheses except for large workplaces. Controls are described in the note to table 4.

Table 9: Workplace Productivity and Computer Use - First-Difference Coefficient Estimates by Workplace Type

	NIP	MULTIP	SIP
Prop. CPU users	0.178	-0.039	-0.235
	(0.138)	(0.193)	(0.312)
Changes in business processes			
Integration	0.015	-0.065	0.102
	(0.087)	(0.091)	(0.120)
CPU*Integration	-0.654*	0.036	0.089
	(0.360)	(0.246)	(0.382)
Re-engineering	0.007	-0.021	-0.180**
	(0.073)	(0.058)	(0.087)
CPU*Re-engineering	0.148	0.045	0.330
	(0.466)	(0.253)	(0.323)
TQM	0.015	-0.067	0.065
	(0.083)	(0.118)	(0.068)
CPU*TQM	-0.354	-0.366	0.190
	(0.340)	(0.302)	(0.306)
Changes in delegation of decision making			
Centralization	0.144	0.125*	-0.068
	(0.097)	(0.071)	(0.091)
CPU* Centralization	0.506	0.463*	-0.169
	(0.318)	(0.251)	(0.261)
Decentralization	-0.357*	0.292**	-0.047
	(0.188)	(0.129)	(0.198)
CPU* Decentralization	0.138	0.781*	0.670
	(0.572)	(0.453)	(0.671)
Delayering	0.046	0.064	-0.027
	(0.164)	(0.098)	(0.137)
CPU*Delayering	1.294**	0.322	-0.505
	(0.571)	(0.326)	(0.547)

cont'd.

Table 9: Workplace Productivity and Computer Use - First-Difference Coefficient Estimates by Workplace Type (Cont'd)

	NIP	MULTIP	SIP
Adjustments in dealings with other firms			
Outsource	-0.176*	-0.069	0.174
	(0.097)	(0.102)	(0.123)
CPU*Outsource	-0.091	1.023	-0.667*
	(0.368)	(0.758)	(0.383)
Collaboration	-0.002	0.109*	0.041
	(0.086)	(0.062)	(0.085)
CPU*Collaboration	-0.246	-0.124	-0.179
	(0.299)	(0.374)	(0.342)

Note. Dependent variable is ln(Value Added). Statistical significance based on bootstrapped confidence interval: *=10%; **=5%; ***=1%. Bootstrapped standard errors in parentheses Controls are described in the note to table 4.

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