Job reorganization, Information Technology and Productivity: evidence from American manufacturing *

Philippe Askenazy (Cepremap and CNRS)

October 2001

*I am grateful to Eli Berman for providing some of the data sets used in this paper. I thank participants to seminars at ECARES (ULB), and at French Minister of Finance for helpful comments. The author is responsible for any errors and misinterpretations. E-mail: askenazy@cepremap.cnrs.fr, CEPREMAP-ENS 48 Boulevard Jourdan 75014 Paris, France.

Abstract: This paper gives new evidences on the consequences of information and communication technology in American manufacturing. Using data on productivity merged with statistics on job reallocation, we show that dispersion in job reorganization during the eighties and the early nineties can lead to dramatic total factor productivity (TFP) growth differentials between detailed industries. Investments in computer and data processing systems and excess job reallocation appear to be complementary for productivity. The computerization seems efficient in the highly reorganized industries while it reduces TFP in the others because it weights the capital stock without increasing the output.

Keywords: job reallocation, reorganization, information and communication technology, productivity.

JEL classification: D24 J6 O14 L23.

1 Introduction

Despite a decade of "New economy", the debate on the impact of computerization and more generally of the diffusion of information technology (ICT) on firm performance is still open. Gordon (2000) claims that outside the twelve percent of the economy engaged in manufacturing durable goods including computer hardware, the New Economy's effects on productivity growth are absent, and capital deepening has been unproductive. Moreover the productivity growth revival of the late nineties was fragile (Gordon, 2001); its recent vanishing vindicates the persistent skepticism regarding the ICT to deliver a sustained surge of productivity growth (e.g. Blinder and Quandt, 1997). However the benefits of computers can be delayed, just as were the benefits of electric motors as the turn of the nineteenth century (David, 1990). An important theoretical literature formalizes this idea and emphasizes ICT revolution should be associated with a phase of reorganization of production. This reorganization can be shumpeterian creation-destruction process (Aghion and Howitt, 1998). Firms have also to progressively adapt their organization of work to the new technological environment through a learning curve (Greenwood and Yorugoglu, 1997). An arduous and costly new socio-economic regime should replace the obsolete fordism (David, 2000).

Using manufacturing data from the NBER productivity database, our study suggests that the heterogeneity of reorganization is a key point to understand the productivity performance of detailed American non-hardware producing industries during the last decades. The job reorganization is captured by the observation of excess job reallocation given by Davis, Haltiwanger and Schuh's (1996) data. The main findings are:

(i) Job reorganization and computerization are not correlated with higher total factor productivity.

(ii) In fact, job reorganization is necessary for an efficient use of computers. ICT investments weight the capital stock inducing a decrease of total factor productivity (TFP) but in the same time, they improve output growth proportionally to the level of job reorganization.

This result can be related to the growing volume of literature on innovative workplace practices such as multitask jobs, job rotation, total quality management (TQM) and Just-In-Time (Milgrom et al. (1995), Osterman (2000)). Their adoption has begun in the mid-eighties. Ichniowski et al. (1996) or OECD (1999) review numerous cross-section studies that either exhaustively examine one industry, such as metallurgy or investigate several establishments or firms. These works conclude that the innovative workplace practices have a significant impact on productivity, on quality or on the market value of firms. Investigations using panel data on establishments lead to mitigated results (Black and Lynch (2001), Huselid and Becker (1996), Cappelli and Neumark (1999)); Nevertheless, Huselid and Becker (1996) argue that a huge part of the variance of the information in such panel data can be explained by measurement errors. The connections between organization and ICT have been examined for the 1000 Fortune firms. Thus, Brynjolfsson and Hitt (1998) show for a sub-sample of Fortune firms a complementarity for productivity between decentralization and investments in Information Technology; this result is particularly significant for the nineties. Bresnahan et al. (1998) and (2001) confirm these findings with the same survey; they show that Fortune firms with low IT and low innovative workplace practices have higher productivity than those with one but not the other.

Our evidences complement these findings using another research strategy and an alternative approach of the reorganization process. First, we work at industrial level providing aggregated information. Second, the statistics are longitudinal covering the eighties and the first half of the nineties. Third, we compute an original, comprehensive and global indicator of job reorganization independent from managerial mode and the potential associated bias of measurement.

The paper is organized as follows. The data and the construction of the job reorganization index are presented in part 2. Part three studies the connections between ICT, job reorganization and total factor productivity in the American manufacturing between 1982 and 1996.

2 Data and the index of reorganization

The first subsection details the industrial data. Data on job flows and the computation of the index of reorganization are given in the second subsection.

2.1 Industrial data

We exploit the NBER productivity database computed by Bartelsman, Becker and Gray, the Feenstra's data set on international trade, and data on investments in computers. These stats are available for 4-digit SIC industries (1972 or 1987 classifications). They have been extensively used for investigating the impact of computerization on skill requirement within and between industries (Berman et al. (1994), Autor et al. (1998)).

Bartelsman, Becker and Gray (1996) give a complete presentation of their *Census Manufacturing Industry Productivity Database* and the methodology used for computing the Total Factor Productivity Index. The version (2000) exploited in this paper covers 450 manufacturing industries from 1958 to 1996 in the United States. Most data are drawn from the *Annual Survey of Manufactures.* For each year and each industry, the database provides:

- the 4-digit code SIC (1972 definition),

- the total employment[1],

[1]Payroll and employment are only for operating plants. The ASM does not provide data on the employment of auxiliary units (mainly central offices and also research laboratories and warehousing) at the 4-digit SIC level. Workers in auxiliary units are considered to be non-production workers; their share in the total manufacturing employment has slightly increased over the past 20

- the total payroll (apart from benefits),

- the number of production workers, the annual hours worked by production workers, the wages of production workers,

- the value added, the cost of inputs, the end-of-the year inventories, investment, the real values of equipment and construction stocks,

- the energy costs,

- the value of shipments,

- the price deflators for energy, investments, inputs and final goods,

- and the Total Factor Productivity.

In addition, Feenstra's set gives for each industry the value of exports and imports from 1958 to 1994 (Feenstra, 1996 and 1997). Finally every 5 years, the Census Bureau publishes in its supplemental data for the *Census of Manufactures* the value of investments in computer and data processing systems by 4-digit SIC industries[2]. We would like to have the stock of computer. Unfortunately, these data are not available at 4-digit SIC level. However, following Berman et al. (1994) or Autor et al. (1998), we consider that the level of investments in computer and data processing system in 1982 (resp. 1992) -here divided by the real equipment stock- should proxy for computerization in the early eighties (resp. nineties). Indeed, computer performance dramatically expanded for the last three decades, along the Moore law (doubling power of chips every 18 months); the rate of depreciation of computer and data processing equipment is also particularly high (Tripplet, 1999). Therefore, the flow of investment is a large share of the stock of computer and data processing equipment. Moreover, investments in computer are strongly correlated year by year (1977, 1982, 1987 and 1992).

Hardware producing industries are excluded from our sample. Indeed, our pri-

years; they represented 7 percent of total employment in 1992. Data by 2-digit SIC reveal minor trends among major groups. Therefore, the introduction of non-operating workers may modify only marginally the computation of productivity growth.

[2]Data for computer and data processing systems investment in 1977, 1982 and 1987 have been provided by Eli Berman; data for 1992 has been directly collected from the *Census*.

mary goal is to explore the impact of the diffusion of digitalization on industry performance. Now, the hardware industries exhibits huge total productivity gains (e.g. Gordon, 2000) due to a high innovation rhythm, and, in the same time, they invest massively in ICT, inducing potential bias in the econometric analysis.

Due to disclosure, the computer investments of firms may not have been reported if their number in the industry is too small; moreover, if the investments in computers are low, the Census gives just a row range of estimations. Therefore, the useful data on computers and data processing systems are not available for all industries. The absence of small industries can imply a sample bias. However, we verify that these industries have no clear characteristics (productivity performance, employment composition, wages, openness...), except of course their size[3]. Moreover, all the econometric tests will be weighted by the size of the industries. We have also performed the econometrics of the next section including these industries for which we assign the value zero to their investments in computer[4]; our results are not significantly altered.

Finally, due the revision of the SIC classification in 1987, some additional industries are lacking[5]. 345 4-digit SIC manufacturing industries compose our final sample, accounting for about 80% of the manufacturing workforce or value added.

2.2 Job reallocation and Reorganization

This subsection gives a brief description of the job creation and destruction databases from *Job Creation and Destruction* by Steven Davis, John Haltiwanger, and Scott Schuh (1996) that are available to the public. We use the updated database for 4-digit SIC industries. It contains information concerning:

- year from 1973 to 1993,

[3] The use of the Heckman's two-step method for correcting sample bias leads to results similar to the OLS tests reported in this paper.

[4] This assumption has been adopted by Berman et al. (1994).

[5] Here again, we have verified that the sample bias is negligible.

- annual job creation rate for both startups and continuing establishments (POS_t),

- annual job destruction rate for both shutdowns and continuing establishments (NEG_t),

- 4-digit SIC code.

These exhaustive data are merged with the previous statistics. The sample is then still 345 manufacturing industries (1972 SIC definition).

The total job reallocation is defined as job creation + job destruction. The reallocation is the sum of the decrease or the increase of the number of jobs and of creations and destructions for a given number of jobs. The excess job reallocation EXE_t is equal to job reallocation minus the absolute value of employment trend:

$$EXE_t = POS_t + NEG_t - |POS_t - NEG_t|. \tag{1}$$

Per se, the excess job reallocation indicates reorganization of the labor force and of the production process, shutdowns of obsolete establishments and new startups within an industry (Davis et al., 1996). Because of the persistence of the job creation-destruction rates identified by Davis et al. (1996), we choose to normalize the rate of excess reallocation for the 1983-1992 decade by the value for the previous decade. Thus, for each detailed industry, we define an index of reorganization for the 1982-1992 period as follow:

Definition 1 *Take an industry i. The index of reorganization R_i for the 1982-1992 decade is defined as the ratio of the excess job reallocation rate between 1983 and 1992 included and of the excess job reallocation rate during the previous decade (from 1973 to 1982 included):*

$$R_i = \frac{\sum_{t=1983}^{1992} EXE_{i,t}}{\sum_{\tau=1973}^{1982} EXE_{i,\tau}}. \tag{2}$$

The observed values of R_i range from 0.46 to 2. The mean is 1.07. The dispersion is quite large (standard deviation 0.22). About 13% of industries have massively reallocate jobs between 1982 and 1992 with a R-index above 1.3.

Remark: the index of reorganization for an industry i, R_i, should also be connected to the diffusion of innovative workplace practices during the eighties. Indeed, their development implies changes in the composition of the work force (e.g. Bresnahan et al. (2001), Caroli and Van Reenen (2001)), the emergence of new multitask jobs (Osterman, 2000), or the complete shutdowns of "fordist" factories replaced by "high performance" establishments[6].

3 IT, Reorganization and productivity

We will explore the determinant of productivity growth of detailed manufacturing industries during the 1982-1996 period. The study of the connections between, job reorganization, IT diffusion and productivity meets pitfalls. Productivity growth, job reallocation and investments can be, or explained by, idiosyncratic characteristics of industries. For example, exposure to international competition can encourage firms to adopt new technology (Thoenig and Verdier, 2001) and to extract productivity gains, and simultaneously can imply high job reallocation. For controlling for these potential biases, the main observable characteristics of the industries will be included in the tests:

- the 2-digit SIC code

- the degree of openness $= \frac{exports+imports}{shipments+imports}$

- the intensity in unskilled workers = span of control = number of production workers per non-production worker

- the average wage of production workers

- the average wage of non-production workers

- the labor productivity = value added / employment

- the capital intensity = real capital stock / employment

Summary statistics are reported in table 1.

[6] For example, in the early eighties NUMMI, the flexible joint venture GM Toyota has been installed on the site of a recently closed GM factory.

Moreover, job creation and destruction, and computerization in 1992 are partly endogenous to high productivity growth. Therefore, we will conduct estimations for two periods. First we will regress the total productivity growth between 1982 and 1992 on the computer investment in 1992 and the index of reorganization. Second, we will redo the same tests for a subsequent period, the beginning of the "new economy" decade.

3.1 Productivity performance between 1982 and 1992

We consider this period because:

1) computerization dramatically expand during the eighties with the development of PCs.

2) 1982 and 1992 occurred at about the same point of the business cycle (even if the depression of the early eighties was deeper than one of the early nineties).

3) computer investment statistics are available for 1982 and for 1992.

4) estimations in long differences help to limit the effects of measurement errors.

In order to capture aggregate phenomena, as Berman et al. (1994), Autor et al. (1998) or Feenstra et al. (1999) do, the estimations are weighted by the size of the industry. Moreover, as Berman, Bound and Griliches (1994) argue, weighting reduces data noise caused by the shift of firms between industries and the periodic redrawing of the ASM firm sample. The size of an industry is, here, its average value added share in total value added of the 345 manufacturing industries in 1982 and 1992.

The tables 2A and 2B report regressions of the TFP growth between 1982 and 1992 on computer investments per workers in 1992 and the index of job reorganization. The tests include or do not include controls for the characteristics of industries in 1982; two-digit SIC codes are added in regressions of table 2B. The column (1) table 2A shows the simple regression of the TFP growth on the computer investment intensity in 1992. The correlation is dramatically negative. The introduction of two-digit SIC codes leads to a smaller correlation (test (1) table 2B). This result shows that the heterogeneity among industries is particularly high. However, even if the characteristics of the industries in 1982 are included (column (2)), computerization and TFP growth are not significantly positively correlated, confirming a “Solow productivity paradox” for this period[7]. This conclusion is robust to the introduction of productivity trend during the previous decade (column (3)). The latter is not correlated to the performance during the 1982-1992 decade. International competition seems to have encouraged TFP improvements. Initial capitalistic and production workers intensive industries have enjoyed higher performances; this result can be interpreted as the output of shop-floor rationalization during the eighties. The job reorganization identified by the normalized excess job reallocation is also uncorrelated with the TFP performance, all observable things between equal (test (3)).

However, the diffusion of ICT and the reorganization have more complex impacts on productivity. Indeed, as Milgrom and Roberts (1995) argue, the organizational and technological choices are complementary; The production function is supermodular in workplace organization and ICT use. Lindbeck and Snower (1996) show this property for ICT and new multitask jobs. Thesmar and Thoenig (2000) also find that rapid technological progress has to be associated with an "organistic" organization. In these models, ICT use and organizational transformations have multiplicative effects on productivity. The shumpeterian creative destruction associated with the ICT development should lead to the destruction of old jobs subsequently replaced by new more productive jobs; For example, banks ensure productivity improvement from electronic transactions through the reduction of clerical labor and the creation of computer programmer jobs. Following the O-ring theory formalized by Kremer and Maskin (1996), the higher complexity of the technology transforms the optimal productive match of workers; the skilled workers are matched together while the old

[7]See below, sub-section 3, for a discussion on this point.

firm is mixed, composed of skilled and unskilled workers. Basically, firms can extract major efficiency gains from ICT through spatial reallocations of jobs (Venables, 2001); electronic transmission of information enables service companies to separate front and back offices, the latter being re-localized outside the costly city center; reduction of transaction costs for enhances firm performance thought efficient outsourcing of non-core activities; just-in-time needs a concentration of suppliers around the client factories or distribution units as seen in the automobile industry (Boyer et al., 2000). The job creation-destruction is then a necessary condition for extracting the complete productivity efficiency from the information technologies.

Despite this productive complementarity, firms in different industries can follow different job-creation and job destruction policies depending on the size of their reorganizing costs. The reorganization is not spontaneous. It is a complex learning process (Davis (2000), Kling and Lamb (2000)). The existence of alternative production paradigms can, through imitation, accelerate the organizational change and job reallocation; for example, the toyota system and joint-ventures with Japanese firms help American car manufacturers to develop the lean production (Womack et al., 1996). Conversely, firms can have to invest in ICT independently of their job reorganization patterns because of changes of their technological environment (compatibility with their suppliers, client or business networks...).

What is the consequence of the synergy between ICT and reorganization of jobs for the analysis of the TFP growth among manufacturing industries?

Assume, for an industry i, the production function "historically" verifies

$$Y_{i,t} = A_{i,t} K_{i,t}^{\alpha_i} f_i(L, H, ...) \tag{3}$$

where Y is the value added, A denotes the level of total factor productivity, K is the equipment stock, and $L, H, ...$ denote the others production factors (production workers, non-production workers...).

Now, assume that at date t_0, a new technology emerges: the ICT. This technology is embodied in new machines. The efficiency of the investments in ICT depends on the degree of job reorganization. Explicitly, for $t \geq t_0$, the production function is:

$$Y_{i,t} = A_{i,t}(K_{i,t} + R_{i,t}C_{i,t})^{\alpha_i} f_i(L, H, ...), \tag{4}$$

where $C_{i,t}$ is the real stock of ICT (computer and data processing equipment).

The log-linear econometric estimation of the total factor productivity as performed for the NBER productivity database cannot take into account such structural change at date t_0. Therefore, if the number of years before t_0 in the longitudinal sample used for the estimation is large, then the estimated production function will be still the historical function. In this case, for $t \geq t_0$ the Total Factor Productivity given by the econometric model is not A_t but $T\tilde{F}P$:

$$T\tilde{F}P_{i,t} = A_{i,t} + \alpha_i \log[\frac{K_{i,t} + R_{i,t}C_{i,t}}{K_{i,t} + pC_{i,t}}], \tag{5}$$

where p is the price index used for computing the equipment stock in data. Considering[8] $C << K$, at order one, the previous equation becomes linear:

$$T\tilde{F}P_{i,t} = A_{i,t} + \alpha_i \frac{R_{i,t}C_{i,t}}{K_{i,t}} - \alpha_i \frac{pC_{i,t}}{K_{i,t}}. \tag{6}$$

Note that if $R = 0$ then computerization depresses total factor productivity because it weights down the capital stock without increasing the labor productivity; this mechanism dominates as long as $R < 1$ (if the price of computer and data processing system are correctly evaluated i.e. $p = 1$). This equation shows that the price index p plays a crucial role for the observation, from the NBER productivity database, of the Solow paradox; indeed, even if $R > 1$ (i.e. the computerization is efficient),

[8] The Census of Manufactures shows nominal investments in computer and data processing system account for a small share of total investments (from 0,5 to 10% for most industries). Moreover, according to Jorgenson et al. (2000), the IT (computer, communications, software) share in total capital does not exceed 10% in 1992. Using a wide definition of IT (O-technology: office, computing, accounting machinery and communication, scientific and engineering equipments), Morisson (1997) finds that, in 1991, ITs account for less than 10% of capital stock for most manufacturing industries and reach 30% for the machinery producers.

if the price p is overestimated then investments in ICT depress the computed total factor productivity. In that sense the Solow paradox may be partially the results of measurement errors (see also Tripplet (1999) on this issue).

For tractability, we add a constraint of equality of the α_i. Then, we will investigate the complementarity of job reorganization and computerization estimating the equation:

$$\log(TFP_{i,1992}) - \log(TFP_{i,1982}) = c + \psi R_{i,1992} I_{i,1992} - \xi I_{i,1992} + \nu . x_i + \epsilon_i, \qquad (7)$$

where TFP_i is the estimation of the total factor productivity, and x_i denotes the vector of idiosyncratic characteristics of the industry i. The key advantage of this equation is that it is valid even if the deflators for ICT are not correctly evaluated. Errors in prices will just change the magnitude of the estimated values of ψ and ξ but will not alter their signs and their significativities.

The columns (4) and (5) of tables 2A and 2B report the estimations of the previous equation including or not the characteristics of the industries. These various tests give coherent results. As expected, the cross product of computerization and job reorganization is significantly associated with TFP improvements. The coefficient of the computer investment is also significantly negative. The magnitude of these correlations is large. The table 3 reports the estimated TFP performances for various values of I and R. They are based on the results of test (5) table 2B. Recall that if the price index used for computing the capital stock overestimates the improvement of ICT equipment, then the TFP is mechanically depressed. Therefore, the dramatic "effect" of high computerization when $R < 1$ should be taken with caution. In that framework, the table 3 is mainly significant line by line. In any cases, the combination of job reorganization and investments in ICT is associated with dramatic productivity growth differentials among detailed non-hardware manufacturing industries during the 1982-1992 decade. For example, if $R_i = 1.3$ (i.e. R_i is equal to the mean of the observed job reallocation plus the standard deviation), and $I_i = 9.4$ dollars per thousand dollars of equipment stock (i.e. I is equal to the mean of our sample), the industry i exhibits an about 0.1% per annum higher total factor productivity compared to an industry satisfying R and I equal to the means. If I_i is higher, e.g. equal to the mean plus the standard deviation, this difference reaches 0,6% per year.

We can extend the econometric model. Indeed, on the one hand, the job reorganization per se can have positive effects on productivity; without direct connections with ICT, job reallocation can lead to a more efficient match of workers and jobs. On the other hand, job reorganization induces costs which can be present during a transitory phase: training costs, progressive learning by doing for new hired workers, getting new production units under ways... Consequently, the R index is included in the regressions:

$$\log(TFP_{i,1992}) - \log(TFP_{i,1982}) = c + \psi R_{i,1992} I_{i,1992} - \xi I_{i,1992} + \phi R_{i,1992} + \nu . x_i + \epsilon_i, \quad (8)$$

The coefficient associated to R is significantly negative suggesting that transitory costs exceed benefits between 1982 and 1992 (columns (6), tables 2A and 2B). The estimated effect of computerization and of $R \times I$ are larger than in the previous estimations, and their significativities are also improved.

3.2 The endogeneity biases

The previous "effects" should be potentially under or over-estimated, because the estimations are subject to endogeneity and simultaneity biases:

- Firms (or detailed industries) which have realized large TFP gains during the period 1982-1992 can finance investments in ICT and can be encouraged to acquire up-to-date technologies, especially if they have observed that their past productivity gains were effectively the results of computerization (in connection with the job reorganization).

- High TFP performance can also finance job restructuring. Moreover, TFP acceleration seen as the output of innovation should induce higher creation-destruction of jobs during the decade.

- Therefore, the combination of ICT and job reorganization can also be partially endogenous to high productivity growth.

Basically, these assertions raise doubts on the direction of the causality in the strong correlation between TFP growth and $R \times I$. We will try to correct for the endogeneity biases using two methods. First, the computer investments in 1992 are instrumented by the lagged investments in 1982. Second, the complementarity between job reorganization and computerization is examined for the period 1992-1996.

We do not find adequate instrument for the job reorganization. However, the level of computer and data processing equipment in 1992 can be easily instrumented. Indeed, the computer investments in 1982 are strongly correlated to the investments in 1992 and uncorrelated to the productivity growth between 1982-1992[9]. The correlation is 0.66 and very significative. Because of data lacks, the number of observations is reduced to 323; nevertheless, we have performed the first regressions for this sub-sample and have not found significant difference compared to the whole sample[10]. The columns (7) in table 2A and 2B report the IV tests. The coefficients associated to the combination of computerization and job reorganization are virtually two times higher than those obtained with the ordinary least squares, and more statistically significant. The positive effect of the span of control vanishes with the instrumentation of the computerization. This result can signify, in absence of job re-

[9] To avoid any potential endogeneity, we also use the investments in 1977 as instrument. The number of observations is unfortunately drastically reduced; however, for this sub-sample, the results were very closed to those obtained using the 1982 statistics. Note also that the computer investments in 1977 or 1982 are not correlated to the job reorganization during the 1982-1992 decade.

[10] Heckman's two-step procedure gives quite similar results.

organization, the industries (or firms) that are intensive in skilled (non-production) workers, more invest in ICT, but this policy is a complete waste. This view seems supported by the fact that the estimated coefficient for computerization is higher and strongly statistically significant.

However, again, the potential endogeneity bias for job reorganization is not corrected. For solving this pitfall, the analysis is extended to the 1992-1996 period. Basically, under the reasonable assumptions:

a) the investments in ICT during this period are strongly correlated with the investments in 1992 (as the investments in 1992 were correlated to those in 1982 or in 1987),

b) the volume of the ICT investments has strongly increased (as shown by aggregated data for manufacturing, Oliner and Sichel (2000) or Jorgenson et al. (2000)),

the synergy between ICT investments and job reorganization between 1992 and 1996 should be even larger than during the previous decade.

Columns (1) to (7) in tables 4A and 4B lists the tests for productivity growth between 1992 and 1996 as dependent variable. Compared to the outputs of tables 2A and 2B, the figures are quite different for controls (basic characteristics in 1992). The TFP growth between 1992 and 1996 is now strongly correlated to the TFP increase during the previous decade. The connection between productivity growth and the span of control has vanished while the TFP increase is negatively correlated to initial labor productivity.

Despite these changes, the connections between industry performance, ICT and job reorganization still hold. As expected, the combination of job reorganization and computer investments are dramatically and positively correlated to the TFP growth between 1992 and 1996. The coefficient associated to the investments in computer and data processing is again significantly negative. The estimated effects are larger than those obtained for the previous decade. The correlation between $I \times R$ and TFP improvements is robust to the adjunction of the productivity growth between 1982 and 1992 (columns (4) to (7)). Moreover, basically, these results clearly support that the direction of the causality comes from the combination of ICT and job reorganization to improvements of total productivity. Finally, the job reorganization and TFP performance are now positively correlated (columns (5) and (7), the coefficient is however non-significant), suggesting that the costs of reorganization were completely absorbed during the eighties and the early nineties.

To sum up, the result of a synergy between investments in computer and data processing equipment and job reorganization is robust to various specifications or estimation methods[11]. The job reorganization is a necessary condition for an efficient adoption of computers.

3.3 The birth and death of the Solow paradox revisited

The connections between job reorganization and technology give a simple solution to the so-called Solow paradox (during the eighties and the beginning of the nineties) for the manufacturing (except hardware producers) but also for the whole economy if we admit that our conclusions can be extended to tertiary activities. Indeed, the small aggregated effect of computers on productivity should be in fact split into two opposite terms:

1) computer and data processing equipment enhances total factor productivity in industries with large job reorganization.

2) heaviness of capital stock induces decrease of TFP (without altering the output per worker[12]).

[11] We have also tried to include the hardware industries in the previous regressions; the qualitative results have not been altered; however, as expected, because hardware industries are massive investors in ICT and in the same time as known job reallocations, the estimated coefficient for the combination of computer investments and job reorganization is larger and more statistically significant.

[12] We have performed regressions for the increase of labor productivity during the 1982-1992 and 1992-1996 periods; in this case, the combination of computerization and job reorganization is strongly correlated to the labor productivity growth while the computer investments are now

This mechanism can also explain the conclusions of some micro-studies; empirical works at firm or industry level find no systematic connections between improved performance and use of IT (Brynjolfsson and Yang (1996) for a survey, or Morrisson (1997)). New technology has seen failure in many firms; the efficiency gain may be low and the costs of computerization may be higher than the improvements in productivity (Schrage, 1997).

Our results also offer an attractive interpretation of a part of the recovery of aggregated labor productivity during the late nineties. Indeed, Oliner and Sichel (2000) find that, compared to the previous periods, the TFP growth is about 0.7% higher since 1995; they decompose this increase in TFP growth in ITC producing industries, and in a "residual" 0.3% acceleration of TFP in other industries including services (Jorgenson and Stiroh (2000) get quite similar figures). This unexplained growth can result from the evaporation of the costs of job reallocation in previously reorganized manufacturing industries and the extension of this job reorganization to non-manufacturing sectors inducing a more efficient use of ICT. This view can be again compared to the adoption of innovative practices; Osterman (2000) shows that the latter has deepened during the nineties, especially in tertiary activities.

This interpretation of the recent performance of the US economy is mainly food for thought. We advocate for further investigations on this topic.

4 Conclusion

We have explored the consequences of job reorganization and diffusion of computer and data processing systems on total factor productivity in American manufacturing. Numerous theoretical approaches suggest that the expansion of the information and communication technology has to be associated with job creation-destruction in order to adapt the workers and the workplace organization to the new technological environment and then to extract productivity gains from these technologies.

unrelated to this growth.

Exploiting the NBER productivity database merged with job reallocation data, we have tests this synergy for detailed manufacturing industries, except the hardware producers which have enjoyed exceptional performance. We have tried to correct for the heterogeneity among these industries and for endogeneity biases. Using various specifications and econometric approach, the complementarity remains significant and robust. The computerization is efficient for TFP in high-reorganized industries while it reduces the total factor productivity in others because it weights the capital stock without increasing enough the output performance. This mechanism can lead to significant total factor productivity growth differentials between detailed industries and gives intuitions for understanding the new economy decade. For medium computer investments, differences in job reorganizations can result in as high as 0.5% per annum difference in total factor productivity growth during the 1982-1996 period.

CNRS and CEPREMAP, PARIS

REFERENCES

Aghion P., P. Howitt, 1998, *Endogenous Growth Theory*, Cambridge: MIT Press.

Autor, D. H., Katz, L. F. et Krueger, A. B., (1998), " Computing Inequality: Have Computers Changed the Labor Market? ", *Quarterly Journal of Economics*113 (4), pp.1169-1214.

Bartelsman Eric, Wayne Gray, 1996, Census Manufacturing Industry Productivity Database, NBER Technical Working Paper 205, Oct.

Berg Peter, Eileen Appelbaum, Thomas Bailey, Arne L. Kalleberg, 1996, " The Performance Effects of Modular Production in the Apparel Industry ", *Industrial Relations*, vol 35, N° 3, pp. 356-373.

Berman Eli, John Bound, Zvi Griliches, 1994, " Changes in the demand for skilled labor within U.S. manufacturing: Evidence from the Annual Survey of Manufactures ", *Quarterly Journal of Economics*, May, pp.376-397.

Black S., L. Lynch, 2001, " How to Compete: The Impact of Workplace Practices and Information Technology on Productivty ", *The Review of Economics and Statistics*, vol. 83 (3), pp. 434-445..

Blinder A., R. Quandt, 1997, Waiting for Godot: Information Technology and the Productivity Miracle, Princeton Working Paper, may.

Boyer R., E. Charron, U. Jürgens, S. Tollidays eds, (2000), *Between Imitation and Innovation: The Transfer and Hybridisation of Productive Models in the International Automobile Industry*, Oxford University Press: Oxford.

Bresnahan Timoty F., Erik Brynjolfsson, Lorin M. Hitt, 1998, How do Information Technology and Work Place Organization Affect Labor Demand? Firm Level Evidence, mimeo MIT January.

Bresnahan Timoty F., Erik Brynjolfsson, Lorin M. Hitt, 2001, Information Technology, Workplace Organization and the Demand for Skilled Labor: Firm-level Evidence, forthcoming *Quarterly Journal of Economics*.

Brynjolfsson Erik, Lorin M. Hitt, 1998, Information Technology and Organizational Design: Evidence from Micro Data, mimeo MIT January.

Brynjolfsson, E., Yang, S., 1996, Information Technology and Productivity: A Review of the Literature, *Advances in Computers*, Academic Press, Vol. 43, pp. 179-214.

Cappelli P., D. Neumark, 1999, Do « High Performance » Work Practices Improve Establishment-Level Outcomes?, NBER WP N°7374, October.

Caroli E., J. Van Reenen, 2001, Skill biased organizational change? Evidence from a panel of British and French establishments, forthcoming *Quarterly Journal of Economics*.

David P. A., 1990, " The Dynamo and the Computer: A Historical Perspective on the Modern Productivity Paradox ", *American Economic Review*, vol. 80 (2), pp. 355-361.

David P.A., 2000, "Understanding Digital Technology's Evolution and the Path of Measured Productivity Growth: Present and Future in the Mirror of the Past", in E. Brynjolfsson and B. Kahim eds., *Understanding the Digital Economy*, Cambridge: MIT Press, pp. 49-98.

Davis S. J., J. C. Haltiwanger, S. Schuh, 1996, *Job Creation and Destruction*, Cambridge : MIT Press.

Dunlop John T., David Weil, 1996, "Diffusion and Performance of Modular Production in the U. S. Apparel Industry, ", *Industrial Relations*, vol. 35, N° 3, July, pp. 334-356.

Evans Philip B., Thomas S. Wurster, 1997, " Strategy and the new economics of information ", *Harvard Business Review* Sept-Oct, pp. 71-82.

Feenstra Robert C., 1996, "NBER Trade Database, Disk1: U.S. Imports, 1972-1994: Data and Concordances", NBER Working Paper no. 5515.

Feenstra Robert C., 1997, "NBER Trade Database, Disk 3: U.S. Exports, 1972-1994, with State Exports and Other U.S. Data", NBER Working Paper no. 5990.

Robert C. Feenstra, Gordon H. Hanson, 1999, "The Impact of Outsourcing and High-Technological Capital on Wages: Estimates for the United Sates", *Quarterly Journal of Economics*, August, pp. 907-940.

Gordon R.J., 1999, US Economic Growth Since 1970: One Big Wave?, *American Economic Review,* vol. 89 (2), pp. 123-127.

Gordon R.J., 2000, Has the "New Economy" Rendered the Productivity Slowdown Obsolete?, mimeo Northwestern University.

Gordon R.J., 2001, Technology and Economic Performance in the American Economy, mimeo Northwestern University.

Greenwood J., M. Yorukoglu, 1997, "1974", *Carnegie-Rochester Conference Series on Public Policy* vol. 46 June, pp. 49-95

Huselid Mark A., Brian E. Becker, (1996), " Methodological Issues in Cross-Sectional and Panel Estimates of the Human Resource-Firm Performance Link ", *Industrial Relations*, vol. 35 (3), pp. 400-423.

Ichniowski, Casey, Thomas A. Kochan, David I. Levine, Craig Olson, George Strauss, 1996, " What Works at Work: Overview and Assessment ", *Industrial Relations*, vol. 35, N° 3, pp. 299-333.

Ichniowski C., K. Shaw, G. Prennushi, 1997, " The effects of human resource management practices on productivity: A study of steel finishing lines ", *American Economic Review*, vol. 87 (3), pp. 290-313.

Jorgenson D.W., K.J. Stiroh, 2000, "Raising the Speed Limit: U.S. Economic Growth in the Information Age", *Brookings Papers on economic Activity*, 1, pp. 125-235.

Kling R., R. Lamb 2000, "IT and Organizational Change in Digital Economies: A Sociotechnical Approach", in E. Brynjolfsson and B. Kahim eds., *Understanding the Digital Economy*, Cambridge: MIT Press, pp. 49-98.

Kremer M., E. Maskin, (1996), Segregation by Skill and the Rise in Inequality, NBER Working Paper N° 5718.

Lindbeck A., D. J. Snower, 1996, “ Reorganization of Firms and Labor-Market Inequality ”*, American Economic Review*, 86 (2), pp. 315-321.

Milgrom P. J. Roberts, 1995, “ Complementarities and fit strategy, structure, and organizational change in manufacturing ”, *Journal of Accounting and Economics*, 19 (1), 179-208.

Morrison Catherine J., 1997, “ Assessing the Productivity of Information Technology Equipment in U.S. Manufacturing Industries ”, *The Review of Economics and Statistics*, Sept., pp. 471-481.

OECD, (1999), “Les nouvelles modalités de travail et leurs conséquences pour le marché du travail », OCDE *Perspectives de l'emploi* (OECD *Employment Outlook*), juin, Chap. 4, pp. 195-241.

Oliner S. D., D.E. Sichel, 2000, “The Resurgence of Growth in the Late 1999s: Is Information Technology the Story”, mimeo Federal Reserve Board, Washington.

Osterman P., 1994, “ How Common is Workplace Transformation and Who Adopts it ? ”, *Industrial and Labor Relations Review*, Vol. 47, N°2, Jan, pp.173-188.

Osterman P., 2000, “Work Reorganization in an Era of Restructuring: Trends in Diffusion and Effects on Employee Welfare”, *Industrial and Labor relations Review*, vol. 53, N°2, pp. 179-196.

Schrage Michael, 1997, “ The Real Problem with Computers ”, *Harvard Business Review,* Sept-Oct, pp.178-188.

Solow R., 1987, “ We'd better Watch Out ”, *New York Times Book Review*, 12 July.

Thesmar David, Mathias Thoenig, 2000, The End of Fordism: Macroeconomic Consequences of Endogenous Organisational Responses, *Quarterly Journal of Economics* vol. 115 (4).

Thoenig M., E. Verdier, 2001, Trade Induced Technical Bias and Wage Inequalities : a Theory of Defensive Innovation, mimeo DELTA.

Tripplet J. E., 1999, “The Solow productivity paradox: what do computers do to productivity?”, *Canadian Journal of Economics* 32, No. 2, pp. 309-334.

Venables A.J., 2001, “Geography and International Inequalities: the impact of new technologies”, World Bank Conference on Development Economics, Washington May.

Yorukoglu M., 1998, “ The Information Technology Productivity Paradox ”, *Review of Economic Dynamics*, vol. 1, pp. 551-592.

Womack, J. P. , D. T. Jones, 1996, “ Beyond Toyota: How to Root Out Waste and Pursue Perfection ”, *Harvard Business Review*, Sept-Oct, pp.140-158.

Table 1 : Summary statistics

	Weighted		Unweighted	
	1982	**1992**	**1982**	**1992**
Job reorganization*		1.07		1.04
		(0.22)		(0,24)
Computer and data processing	0.61#	0.94	0.46#	0.89
investments per 10 000 $ equipment stock	(0.65)	(1.29)	(0.67)	(1.20)
Labor productivity	5.91	11.13	4.72	8.53
(current 0 000 $)	(3.35)	(7.46)	(2.60)	(5.79)
Capital stock per capita	7.52	9.18	6.81	8.15
(0 000 $ 1987)	(7.50)	(9.45)	(7.19)	(8.25)
Nominal wage of production workers	1.86	2.77	1.63	2.40
(0 000 $)	(0.50)	(0.81)	(0.47)	(7.11)
Nominal wage of non-production	2.58	4.08	2.41	3.80
workers (0 000 $)	(0.46)	(0.73)	(0.39)	(0.63)
Span of control (number of production	2.67	2.69	3.24	3.16
workers per non-production worker)	(1.59)	(1.71)	(1.76)	(1.78)
Degree of openness =	0,15	0,21	0,16	0,24
(imports+exports)/(shipments+imports)	(0,12)	(0,18)	(0,14)	(0,21)

Mean (Standard deviation in parenthesis)
The weight is the average share in total value added in 1982 and 1992.
* see text for definition
Whole sample expect # sub-sample of 323 observations (see text for details)
Sources: NBER productivity database, Census of Manufactures, Davis et al. (1996) data on job reallocation, Feenstra (1996) data set on imports and exports.

Table 2A : Job reorganization, computerization and productivity (without controls for 2-digit sectors)

	Dependant variable Annual total factor productivity growth between 1982 and 1992 in %						
	OLS						IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Computerization in 1992	-0.24	-0.04	-0.04	-0.91	-0.71	-1.20	-1.39
	(0.06)	0.06	(0.06)	(0.30)	(0.27)	(0.36)	(0.40)
Job reorganization	_	_	0.07	_	_	-0.86	_
			(0.31)			(0.42)	
Job reorganization * computerization in 1992	_	_	_	**0.60**	**0.59**	**1.05**	**0.90**
				(0.26)	**(0.24)**	**(0.32)**	**(0.33)**
TFP growth between 1972 and 1982	_	_	0.00	_	-0.00	-0.01	0.02
			(0.04)		(0.04)	(0.04)	(0.05)
Degree of openness in 1982	_	1.17	1.17	_	1.26	1.31	1.44
		(0.57)	(0.58)		0.57	0.57	0.62
Wage of production workers in 1982	_	-0.50	-0.49	_	-0.52	-0.51	-0.89
		(0.29)	(0.29)		(0.29)	(0.29)	(0.33)
Wage of non-production workers in 1982	_	0.50	0.49	_	0.45	0.49	0.51
		(0.29)	(0.29)		(0.29)	(0.29)	(0.31)
Labor productivity in 1982	_	-0.04	-0.04	_	-0.03	-0.05	-0.03
		(0.03)	(0.03)		(0.03)	(0.03)	(0.03)
Capital stock per worker	_	0.07	0.07	_	0.07	0.07	0.06
		(0.01)	(0.01)		(0.01)	(0.01)	(0.01)
Span of control	_	0.24	0.24	_	0.24	0.24	0.13
		(0.05)	(0.05)		(0.05)	(0.05)	(0.06)
N	345	345	345	345	345	345	323
R^2	0.06	0.26	0.26	0.07	0.28	0.29	

See table 1 and the core text for the definitions of the variables.
The estimations are weighted by the average share in total value added in 1982 and 1992.
Column (7) the computerization in 1992 is instrumented by the computerization in 1982.
Sources: NBER productivity database, Census of Manufactures, Davis et al. (1996) data on job reallocation, Feenstra (1996) data set on imports and exports.

Table 2B: Job reorganization, computerization and productivity (including dummies for 2-digit SIC sectors)

	Dependant variable Annual total factor productivity growth between 1982 and 1992 in %						
	OLS						IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Computerization in 1992	-0.15 (0.07)	-0.02 (0.07)	-0.02 (0.06)	-0.91 (0.30)	-0.68 (0.28)	-1.18 (0.36)	-2.03 (0.55)
Job reorganization	_	_	0.02 (0.31)	_	_	-0.90 (0.41)	_
Job reorganization * computerization in 1992	_	_	_	**0.60** **(0.26)**	**0.60** **(0.24)**	**1.07** **(0.32)**	**1.24** **(0.39)**
TFP growth between 1972 and 1982	_	_	0.02 (0.04)	_	-0.02 (0.04)	0.00 (0.04)	0.04 (0.05)
Degree of openness in 1982		0.61 (0.67)	0.60 (0.67)		0.74 (0.66)	074 (0.66)	1.33 (0.79)
Wage of production workers in 1982	_	-0.37 (0.36)	-0.35 (0.37)	_	-0.45 (0.36)	-0.46 (0.36)	-1.41 (0.50)
Wage of non-production workers in 1982	_	-0.02 (0.35)	-0.00 (0.35)	_	-0.01 (0.34)	0.00 (0.35)	0.52 (0.43)
Labor productivity in 1982	_	-0.07 (0.04)	-0.07 (0.04)	_	-0.07 (0.04)	-0.08 (0.04)	-0.03 (0.04)
Capital stock per worker	_	0.09 (0.01)	0.10 (0.01)	_	0.10 (0.01)	0.10 (0.01)	0.10 (0.02)
Span of control	_	0.23 (0.06)	0.23 (0.06)	_	0.23 (0.06)	0.23 (0.06)	0.05 (0.09)
N	345	345	345	345	345	345	323
R^2	0.21	0.39	0.39	0.22	0.40	0.41	

See table 1 and the core text for the definitions of the variables.
The estimations are weighted by the average share in total value added in 1982 and 1992.
Column (7) the computerization in 1992 is instrumented by the computerization in 1982.
Sources: NBER productivity database, Census of Manufactures, Davis et al. (1996) data on job reallocation, Feenstra (1996) data set on imports and exports.

Table 3: Estimated TFP growth differentials between 1982 and 1992 in annual %

		Degree of job reorganization						
		0.8	0.9	1.07	1.2	1.3	1.4	2
Computer investments in 1992 per 10 000 $ capital stock	0.05	0.02	0.02	0.03	0.03	0.04	0.04	0.06
	0.5	-0.06	-0.04	0.01	0.05	0.08	0.11	0.29
	0.7	-0.11	-0.06	0.01	0.06	0.10	0.15	0.40
	0.94	-0.15	-0.10	Reference	0.07	0.13	0.19	0.53
	1.50	-0.26	-0.17	-0.02	0.10	0.19	0.28	0.82
	2.10	-0.38	-0.26	-0.04	0.12	0.25	0.38	1.14
	3.00	-0.56	-0.38	-0.07	0.17	0.35	0.53	1.61
	7.00	-1.35	-0.92	-0.21	0.34	#	#	#

Estimations based on test (5) table 2B. See text cautions.
Lecture: if the degree of reorganization is 0.8 and the computer investments are 0.05, then the annual productivity growth is 0.02% above the reference (job reorganization = 1.07, computer investments = 0.94).
we do not report the estimations for these values of the parameters because there is no observed industries with both very high investments in computers and data processing systems and high job reorganization.

Table 4: Productivity in the nineties

	Dependant variable Annual total factor productivity growth between 1992 and 1996 in %						
	OLS						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Computerization in 1992	-0.08	-2.60	-1.86	-2.16	-1.87	-1.68	-1.40
	(0.12)	(0.50)	(0.51)	(0.51)	(0.67)	(0.51)	(0.66)
Job reorganization	_	_	_	_	0.46	_	0.46
					(0.70)		(0.70)
Job reorganization * computerization in 1992	_	**2.14**	**1.74**	**1.75**	**1.49**	**1.59**	**1.39**
		(0.44)	**(0.45)**	**(0.44)**	**(0.60)**	**(0.44)**	**(0.59)**
TFP growth between 1982 and 1992	0.28	_	_	0.25	0.25	0.24	0.24
	(0.09)			(0.09)	(0.09)	(0.09)	(0.09)
Degree of openness in 1992	1.31	_	1.40	1.18	1.11	1.24	1.22
	(0.90)		(0.86)	(0.73)	(0.74)	(0.85)	(0.85)
Wage of production workers in 1992	-0.18	_	0.14	-0.18	-0.20	0.11	0.08
	(0.31)		(0.32)	(0.24)	(0.24)	(0.32)	(0.32)
Wage of non-production workers in 1992	0.70	_	0.20	0.49	0.51	0.16	0.18
	(0.30)		(0.33)	(0.27)	(0.27)	(0.33)	(0.33)
Labor productivity in 1992	-0.09	_	-0.11	-0.12	-0.12	-0.09	-0.09
	(0.03)		(0.03)	(0.02)	(0.02)	(0.03)	(0.03)
Capital stock per worker in 1992	0.02	_	-0.02	0.019	0.018	0.02	0.02
	(0.02)		(0.02)	(0.015)	(0.015)	(0.02)	(0.02)
Span of control in 1992	0.09	_	0.17	0.00	0.01	0.12	0.01
	(0.09)		(0.09)	(0.08)	(0.08)	(0.09)	(0.08)
2-digit SIC dummies	**Yes**	**No**	**Yes**	**No**	**No**	**Yes**	**Yes**
N	345	345	345	345	345	345	345
R^2	0.40	0.08	0.41	0.27	0.27	0.42	0.42

See table 1 and the core text for the definitions of the variables.
The estimations are weighted by the average share in total value added in 1992 and 1996.
Sources: NBER productivity database, Census of Manufactures, Davis et al. (1996) data on job reallocation, Feenstra (1996) data set on imports and exports.