A Firm Level Investigation of the Complementarity between Information and Communication Technologies and New Organizational Practices

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Abstract

In this paper, we investigate the interaction between firm use of information and communication technologies (ICT) and firm adoption of new organizational practices (NOP) and we attempt to assess their joint impact on productivity. Our analysis is mainly based on rich information provided by a French matched employer-employee survey, the 1997 C.O.I. survey. We have built a large collection of indicators on organizational change and computerization for a sample of 3386 manufacturing firms with more than 50 employees and synthesized them into two dichotomous variables at two dates, 1994 and 1997: high or low intensity in ICT use (HI or LI), high or low intensity in use of NOP (HO or LO). Looking at descriptive statistics, we show that firms possibly coordinate their decisions in the fields of ICT use and of use of NOP. We also find that firms coordinate these choices over time because of an irreversibility: they cannot move backward, from a high intensity in use to a low intensity in use. We thus propose a framework where static complementarities (between stable I and stable O) are taken into account as well as dynamic complementarities (between changing I and changing O). We find econometric evidence of a positive static complementarity and a negative dynamic complementarity. We also find evidence of an asymmetry between choices in the field of ICT and NOP uses: It is easier to yield productivity growth results from changes in ICT use alone than from changes in NOP use alone.

Introduction

We do not need any statistical surveys or econometric studies to get convinced that computerization and organizational change interactively contribute to firms' performance. However, we need statistical surveys to assess quantitatively their contribution and evaluate their degree of complementarity. During these past ten years, statistics and empirical studies have made great progress in quantity as well as in quality.

Our knowledge has increased and improved. But in many aspects, assessments remain fragile. In this paper, we try to use the great richness of a French statistical survey on organizational change and IT use conducted at the end of 1997 (the C.O.I. survey – enquête "Changements Organisationnels et Informatisation") to analyze the joint contribution of computerization and organizational change to firms' productivity.

1) Background discussion

Empirical studies that focus on complementarity between computerization and organizational change are of two types: either they assess directly complementarity or they assess it indirectly[1].

When they assess it directly, they include an interaction term between a measure of computerization and a measure of organizational change in a production function. In table 1, we report the results of three direct assessments: Bresnahan, Brynjolfsson and Hitt (2003), Caroli and Van Reenen (2001) and Zwick (2003). Bresnahan, Brynjolfsson and Hitt (2003) work with a measure of productivity and a measure of information technology (IT) capital during the 1987-1994 period whereas work organization is a standardized sum of dummies indicating whether the establishment used 6 different types of new organizational practices in 1995 or 1996[2]. They find that firms that more intensively used new organizational practices in 1995 or 1996 had higher productivity over the 1987-1994 period. This cross section estimation also includes an interaction term between IT capital and work organization whose coefficient is positive and significant at the 10% level. Contrary to Bresnahan, Brynjolsson and Hitt, Caroli and van Reenen (2001) as well as Zwick (2003) do not succeed in estimating a significant interaction term between their measures of new technology and

[1] Black and Lynch (2001, 2004) study the impact of information technology and of workplace innovations on productivity but they do not try to assess their complementarity.

[2] These practices are (1) team use, (2) team-building activities, (3) teamwork as a promotion criterion, (4) employee involvement groups or quality circles, (5) the fact that workers decide the pace of work and (6) the fact that workers decide the methods of work.

their measures of organizational change[3]. Zwick (2003) runs estimations in cross section as well as in the time dimension over the 1998-2000 period, whereas Caroli and Van Reenen (2001) focus on productivity growth between 1992 and 1996. This rapid survey shows how fragile is the evidence of a complementarity between computerization and organizational change. This fragility could be explained by measurement errors in computerization and organizational change variables and by a time horizon in the estimation, which is not appropriate.

[Insert table 1]

Brynjolfsson and Hitt (2003) and Hempell (2003) use an indirect approach to assess complementarity issues. They measure IT capital as precisely as possible over a long time period, respectively 8 years and 6 years and assess its output elasticity using different estimation strategies. Brynjolfsson and Hitt (2003) work in the time dimension only. They use varying time lengths and different control variables and they also instrument IT capital with external variables, which describe firms in the cross section. They find great differences in the estimated IT capital elasticity ranging from identical to other equipment to high excess return. The shorter the time period considered, the lower the elasticity. They refer to time consuming complementary organizational change as one potential explanation for these differences. Hempell (2003) finds a very high IT capital elasticity in the cross section (0.24) and tries to control for different sources of biases: unobserved heterogeneity (using fixed effects), measurement errors in IT capital stock and simultaneity in input and output choices (using GMM with internal instruments on first differences and SYS-GMM) and omitted variables (including indicators of skills). His preferred estimation yields an IT capital elasticity of 0.06. According to him, in the cross section, one of the main sources of spurious correlation lies in unobserved complementary expenses made by firms while investing in IT capital.

In this paper, we are going to tackle the IT/organization complementarity issue, following a line of research inspired by Ichniowski, Shaw and Prennushi (1997), Athey and Stern (1998) and Griliches and Mairesse (1998). Ichniowski, Shaw and Prennushi (1997) do not measure the IT/organizational complementarity, but they assess the complementarity between new organizational practices (NOP)

[3] Caroli and van Reenen (2001) measure new technologies with the proportion of workers using new technologies in 1992 and organizational change with a dummy indicating if the establishment had reduced the number of hierarchical layers between 1989 and 1992. In the production function estimation, establishment level information has been aggregated at the firm level. Zwick (2003) uses dummies indicating changes in 1996 or 1997: one indicating whether the firm has invested in ICT and three indicating if the firm has introduced teamwork, autonomous work groups or reduced its hierarchy.

in the finishing lines of the steel industry. The quality of their assessment lies in a very careful measurement methodology grounded on their deep knowledge of production processes acquired through fieldwork. A large list of NOP is considered and their use is followed up over time. Thus, unlike the empirical studies previously surveyed, Ichniowski, Shaw and Prennushi (1997) give some insights into the dynamics of organizational change. Following them, we are going to use a large set of information to measure computerization and organizational change rather than focusing on a small number of dummy variables that lead to very imprecise measures and we are going to seize some aspects of the dynamics of organizational change. Athey and Stern (1998) propose an empirical framework for testing complementarities in organizational design decisions. We are going to use their formalization of the organizational design production function and propose a definition of dynamic complementarity that extend their definition. Griliches and Mairesse (1998) discuss how cross section estimates may lie on spurious correlations whereas estimations in the time dimension are not completely satisfactory because they take away too much information. Balance lies in an intermediate approach where endogenous or imprecisely measured explanatory variables are instrumented by external variables (i.e. variables that explain the selection process or add precision to measurement) rather than internal variables (i.e. lagged variables or differences). We are going to follow this point of view when selecting instruments.

2) Measurement strategy

Our measurement strategy lies in the availability of a matched employer/employee survey on organizational change and IT use (C.O.I.) conducted in French manufacturing firms in 1997. The COI survey is a business survey matched with a labor force survey. A representative sample of about 4000 manufacturing firms employing over fifty workers has been questioned. It is a self-administered survey. A firm representative chosen by the headquarters of the firm gives the firm response. In addition, a few employees have been randomly selected within each firm and interviewed in the context of their home. The survey benefited from high response rates both on the firm side (82%) and on the employees' side (71%). The questionnaire of the business section of the C.O.I. survey is built on a precise description of the computerization process and on a large list of organizational practices at two dates: 1994 and 1997 (see appendix 1 for the detailed questions).

Following Greenan and Mairesse (1999, 2003), we rely on multiple correspondence analyses to synthesize information. We ran two analyses to measure computer use, one in 1994 and one in 1997. Fifteen discrete variables with 2 to 5 items are included in the computer use analysis. They describe IT equipment characteristics (whether the firm uses a mainframe computer, non networked

PCs or networked PCs in management and production activities), intensity of computerized data transfers (within the firm, with suppliers or subcontractors, with corporate clients, with public authorities), Internet use (with the assumption that it is nil in 1994) and the organization of the IT function. Table 2 gives their distribution.

[Insert table 2]

Symmetrically, we ran two multiple correspondence analyses using 15 variables with 2 to 4 items to measure the use of NOP in 1994[4] and 1997. Variables describe the use of three groups of NOP: practices contributing to quality management, practices aiming at a thorough management of time constraint and practices shaping internal and external transaction through market mechanisms. The analysis also includes variable measuring employee implication in ten indirect tasks on the shop floor (with a distinction between management, specialists and operators) and variables describing the structure of the organization (number of department / divisions and number of hierarchical layers). Table 3 gives their distribution.

[Insert table 3]

The first factor of each analysis can be clearly interpreted as measuring intensity in use. As far as ICT use is concerned, the first factor separates firms with new IT equipment, intense computerized data transfers, internet use, an IT and a phone and network department from firms with no new equipment, no computerized data transfers and no IT department. NOP also cluster on the first factor of the correspondence analysis: firms using just-in time practices, total productive maintenance, value analysis and with a complex structure are opposed to firms with a simple structure, no just in time practices and no quality certification.

However, when we compare analyses for 1994 and 1997, we observe some distortions. In 1994, a high level of computerized data transfers could not be obtained with a mainframe computer but this has evolved in 1997, in conjunction with the arrival on the market of new generations of mainframe computers. The diffusion of just in time practices between 1994 and 1997 has changed the way

[4] Some questions are formulated symmetrically for 1994 and 1997 but others are not. For example, questions on the use of new organizational devices (4.1 to 4.8, see appendix 1) are formulated in the following fashion: does your company use the following organizational device in 1997? (yes/no) What is the change in the % of employee affected since 1994? (+,=,-). In this case, we estimate the data for 1994 with the assumption that if the firm uses the device in 1997 and declares that the share of employees affected has increased since 1994 then the device was not used by the firm in 1994. More variables have been estimated in the new organizational practices use analysis (10) than in the computer use analysis (3, including the assumption that internet use was nil in 1994). Figures for these estimated variables appear with a star in tables 2 and 3.

firms structure the intensity of use of NOP. In 1994, the use of just in time practices was highly correlated with high intensity; in 1997 the use and the absence of use structure intensity. The distortions we observe are connected to the fact that each new tool diffuses at its own pace and that some tools evolve and open new uses, changing their relationship with other tools. As a result, the measures of intensity in use stemming from the first factors of our analyses are not homogeneous across time. In order to measure a change in the intensity of use, we need to measure it at the two dates, using an identical metric. We chose the 1997 metric: the weights used in 1994 to measure the intensity in use of ICT and NOP are those built from the correspondence analyses that we ran with data describing 1997.

The synthetic measures we obtain sum up a sizeable amount information, but they remain imprecise, for two main reasons. First, they are grounded on qualitative information that coarsely describe ICT and NOP uses. For example, we know if the firm produces just-in-time, but we do not know what share of production is concerned. Second, the questionnaire is about "modernization" and this could generate a bias towards positive answers. Instead of working with a continuous indicator if intensity, we prefer to dichotomize this variable and to distinguish firms with a high level of intensity from firms with a low level of intensity. This information is coarser but potentially more precise. We take 0 as the threshold value to separate low and high intensities in ICT and NOP uses. In 1994, 14% of firms have a high intensity in ICT use and we find the same figure for a high intensity in use of NOP. In 1997, respectively 50% and 48% of firms are classified as intense users of ICT or NOP. Figure 1 and 2 cross tabulate these variables in 1994 and 1997. We observe that no firm has moved from a position of high intensity to a position of low intensity. There are only three states of nature: low at the two dates (LILI for ICT use and LOLO for use of NOP), transition between low and high (LIHI and LOHO) and high at the two dates (HIHI and HOHO). The distribution of the two types of use are quite similar: half of the sample was low in 1994 and remains low, a large third moves from low in 1994 to high in 1997 and 14% are high at both dates.

[Insert figures 1 and 2]

We can easily build up variables showing how ICT use and use of NOP are combined within each firm. In 1997, 35% of firms used ICT and NOP intensively whereas 37% used both with a low intensity. The rest of the sample groups firms in mixed situation: 15% had an intense ICT use coupled with a low intensity in use of NOP, 13% were low intensity users of ICT but high intensity users of NOP.

[Insert table 4]

Table 4 shows the firm level dynamics of ICT and NOP use between 1994 and 1997. As we have already mentioned above, no transition entails a move backward from a high intensity use to a low intensity use. Thus, 7 cells are empty in table 4. The sample of firms is shared evenly between two types of situations: stability (48%) and increase in the intensity of uses (52%). In the following section, we are going to try and understand what the patterns of transitions observed in table 4 mean in terms of complementarity between ICT and NOP uses.

3) Static and dynamic complementarity

When we observe the distribution of ICT and NOP uses in 1997, we see that more firms are either high intensity users of both or low intensity users of both (35%+37%=72%) than in mixed situations with a high use combined with a low use (15%+13%=28%). This could be a symptom of complementarity between ICT and NOP: firms reach a higher level of productivity when they intensively use both categories of tools than when they choose to use only one category with a high level of intensity. Thus, the two extreme situations (HIHI and LOLO) are accumulation points whereas mixed situations (HILO and LIHO) are rarer.

In 1994, earlier in the diffusion process, we also observe a complementarity pattern, but it is not as strong: a large number of firms in the sample (76%) are low users of the two types of tools and firms in a mixed situation, HILO and LIHO are both more numerous (10% and 10%) than firms with an intense use of the two types of tools (4%).

Complementarity patterns can also be identified when we observe how firms evolve between 1994 and 1997. There is a complementarity pattern in the population of firms with stable situations between 1994 and 1997 (9%, 7%, 7%, 77%) and another one in the population of firms that change over time from a starting point with a low level of both ICT and NOP (23%, 15%, 15%, 49%).

In other words, we find positive correlations between the fact of using intensively ICT and NOP in 1997 (0.45), we also find a positive correlation between the fact of being stable in time with a high ICT use and the fact of being stable in time with a high use of NOP (0.53) and we find a positive correlation between the fact of changing in time towards a high level of ICT use and the fact of changing in time towards a high level of NOP use (0.25). The correlation between intense use of ICT and intense use of NOP in 1994 is also positive, but it is not as strong : 0.17.

Positive correlations between two types of uses are a symptom of complementarity but not a measure of it: other reasons than the search for high productivity can drive an investment towards a high use of two practices, for example the fact that the same supplier sells them. Complementarity can only be assessed through a productivity analysis.

We can model complementarity with the framework proposed by Athey and Stern (1998) where the production function is augmented by a discrete choice organizational design function. The firm i produces at t output Y_{it} using k inputs $Z_{it}^{k} = (Z_{it}^{1}, Z_{it}^{2}...., Z_{it}^{k})$. The firm combines its inputs efficiently with the help of two sets of tools: Information and Communication Technologies (ICT) and New Organizational Practices (NOP). It chooses to use each set of tools at either a high intensity (H) level or a low intensity level (L). We note I_{it} and O_{it} these two discrete choices from the set $\{H, L\}$. Production is determined as a function of I_{it}, O_{it} and Z_{it}^{k}:

$$[1] \qquad Y_{it} = F(I_{it}, O_{it}, Z_{it}^{k})$$

Organizational choices made by the firm at t lead to one of the following situation: HIHO, HILO, LIHO or LILO. However, in our data, we have found that situation at date t depended on choices made previously. There is some irreversibility in structural choices of equipment or of organizational practices, at least during a phase of rapid diffusion of ICT and NOP within firms. Thus, complementarity results from a dynamic process that we want to describe.

We are going to assume (as observed in our data) that if a firm has chosen a high level of either I or O at t-1, then it cannot switch to a lower intensity at t. In other words, a firm cannot move backward between t-1 and t. The choice (I_{it}, O_{it}) results from a sequence of decisions following the diffusion process of I and O over time. Lets consider the time period between t-1 and t. We assume that firm coordinates choices of I and O at date t and that it also coordinates sequences of choices over time so that (I_{it}, O_{it}) also depends on (I_{it-1}, O_{it-1}). In this setting, a firm has two options at date t: either to evolve or to remain stable in its choices. We note S_i the choice of stability between t-1 and t. This choice leads to four different situations at t, according to the decision (I_{it-1}, O_{it-1}) : S_{iHIHO}, S_{iHILO}, S_{iLIHO} and S_{iLILO}. We note D_i the choice of evolving between t-1 and t. This choice leads to five different situations at t: changing I and O together (D_{iDIDO}), changing I only, with either a high intensity in use of NOP (D_{iDIHO}) or a low intensity (D_{iDILO}), changing O only, with either a high intensity in use of ICT (D_{iHIDO}) or a low intensity (D_{iLIDO}).

Assuming that F is separable in Z_{it}^k and in organizational design choices, we can rewrite the production function as:

$$[2] \quad \begin{aligned} Y_{it} = g(Z_{it}^k - \overline{Z}_t^k) + (q_{11} - q_{00})S_{iHIHO} + (q_{10} - q_{00})S_{iHILO} + (q_{01} - q_{00})S_{iLIHO} + \\ (j_{11} - q_{00})D_{iDIDO} + (j_{10} - q_{00})D_{iDILO} + (j''_{10} - q_{00})D_{iDIHO} + \\ (j_{01} - q_{00})D_{iLIDO} + (j''_{01} - q_{00})D_{iHIDO} + q_{00} \end{aligned}$$

with:

$S_i = S_{iHIHO} + S_{iHILO} + S_{iLIHO} + S_{iLILO}$,

$D_i = D_{iDIDO} + D_{iDILO} + D_{iDIHO} + D_{iLIDO} + D_{iHIDO}$,

$S_i + D_i = 1$,

and $\overline{Z}_t^k$ the average use of input Z^k at date t on the whole population of firms.

Four different complementarity indicators can be defined on the basis of equation [2]:

$$k_S = q_{11} - q_{10} - q_{01} + q_{00}$$

$$k_{D1} = j_{11} - j_{10} - j_{01} + q_{00}$$

$$k_{D2} = j''_{10} - j_{10}$$

$$k_{D3} = j''_{01} - j_{01}$$

κ_S defines complementarity in I/O choices within firms that do not change their intensity in uses between t-1 and t. This definition is equivalent to the one proposed by Athey and Stern (1998) in a static framework. The three other definitions refer to dynamic kinds of complementarity. κ_{D1} defines how returns to increasing intensity in use of ICT between t-1 and t evolve when intensity in use of NOP also increases. κ_{D2} compares returns to increasing ICT use between t-1 and t when intensity in use of NOP changes from high to low. Symetrically, κ_{D3} compares returns to increasing use in NOP between t-1 and t when intensity in use of ICT changes from high to low.

We can rearrange [2] so as to identify these four parameters:

$$[3]\quad Y_{it} = g(Z^k_{it} - \overline{Z}^k_t) + k_S S_{iHIHO} + (q_{10} - q_{00})S_{iHI} + (q_{01} - q_{00})S_{iHO} + k_{D1} D_{iDIDO} + (j_{10} - q_{00})D_{iDI} + (j_{01} - q_{00})D_{iDO} + k_{D2} D_{iDIHO} + k_{D3} D_{HIDO} + q_{00}$$

with :

$S_{iHI}=S_{iHILO}+S_{iHIHO,}$

$S_{iHO}=S_{iLIHO}+S_{iHIHO,}$

$D_{iDI}=D_{iDIDO}+D_{iDILO}+D_{iDIHO,}$

and $D_{iDO}=D_{iDIDO}+D_{iLIDO}+D_{iHIDO.}$

4) Econometric results

We matched the C.O.I. data with two government data files giving company accounts in great details: the BRN-SUSE file ("Bénéfice Réèl Normal de SUSE") for 1990-1993 and the FICUS file ("Fichier Complet Unifié de SUSE") for 1994-2001. Both files keep the records of firms subject to the "normal" tax system. We match firms from different data files using the SIREN firm identification number. From these files, we obtain value added at factor cost (Y), gross book value of fixed assets (K), total number of employees (L) and total wage bill (W). The structure of our panel is such that all firms are present in 1997, when the C.O.I. survey was conducted. It is an unbalanced panel, with firms being continuously present over different time sequences between 1990 and 2001. Our final results are obtained on a sub-sample of 2,513 firms continuously present over 1991-1998, with strictly positive gross book value of fixed assets in 1992, 1995, 1998, and with an average increase per year of value added per head (Y/L), wage bill per head (W/L), capital intensity (K/L) and total number of employees (L) not exceeding 25%.

Adding an error term to [2] and [3], we can estimate these expressions in the cross section in 1997[5]. However, Athey and Stern (1998), echoing results obtained by Marschak and Andrews (1944), argue that complementarity estimates stemming from a production function are only valid when we control for most of the sources of performance variation. Productivity estimates obtained in the time dimension are preferable because they control time invariant unobserved heterogeneity that could

[5] Table 4 describes the dynamics of ICT and NOP uses. Each cell in the table is related to the notations we use to describe I and O choices over time in expression [2].

be correlated with both I/O choices and productivity, such as management quality or industrial relations. But what time horizon should we choose? In the C.O.I survey, we measure the intensities in ICT and NOP uses in 1997 and their variation between 1994 and 1997. This intensity in uses in 1997 is the result of changes that occurred within firms in the medium term, reflecting the fact that the survey focuses on innovative tools. A six year time period seems to be in line with these considerations. What time period should we choose? On one hand, we do not know at what precise dates firms invested (we just know what was used in 1994 and what was used in 1997) and on the other Brynjolfsson and Hitt (2003) show that the productivity effect of investment in IT capital takes time, at least 5 years. We thus ran our regressions on four different six years time periods: 1991-1997, 1992-1998, 1993-1999 and 1994-2000. Our best results are obtained with 1992-1998 and our second best with 1991-1997.

We estimate long differenced production function (1992-1998), with a variant [2'] stemming from [2], and another one [3'] stemming from [3]:

$$\begin{aligned}\Delta \ln(Y/L)_{it} = {} & \alpha[\Delta \ln(K/L)_{it} - \overline{\Delta \ln(K/L)}] + (\alpha+\beta-1)[\Delta \ln L_{it} - \overline{\Delta \ln L}] + \\ & (\theta_{11}-\theta_{00})S_{iHIHO} + (\theta_{10}-\theta_{00})S_{iHILO} + (\theta_{01}-\theta_{00})S_{iLIHO} + \\ & (\varphi_{11}-\theta_{00})D_{iDIDO} + (\varphi_{10}-\theta_{00})D_{iDILO} + (\varphi''_{10}-\theta_{00})D_{iDIHO} + \\ & (\varphi_{01}-\theta_{00})D_{iLIDO} + (\varphi''_{01}-\theta_{00})D_{iHIDO} + \theta_{00} + \varepsilon_{it}\end{aligned} \qquad [2']$$

$$\begin{aligned}\Delta \ln(Y/L)_{it} = {} & \alpha[\Delta \ln(K/L)_{it} - \overline{\Delta \ln(K/L)}] + (\alpha+\beta-1)[\Delta \ln L_{it} - \overline{\Delta \ln L}] + \\ & \kappa_S S_{iHIHO} + (\theta_{10}-\theta_{00})S_{iHI} + (\theta_{01}-\theta_{00})S_{iHO} + \\ & \kappa_{D1} D_{iDIDO} + (\varphi_{10}-\theta_{00})D_{iDI} + (\varphi_{01}-\theta_{00})D_{iDO} + \\ & \kappa_{D2} D_{iDIHO} + \kappa_{D3} D_{HIDO} + \theta_{00} + \varepsilon_{it}\end{aligned} \qquad [3']$$

We estimate five different specifications: (1) α=0, β=1, (2) α=0.20, β=0.80, (3) α estimated, $\alpha+\beta$=1, (4) α estimated, $\alpha+\beta$-1 estimated, (5) α estimated, $\alpha+\beta$-1 estimated and 15 industry dummies. Table 5 reports our results. The figures obtained from the first specification indicate that except for S_{LIHO}, all situations yield higher productivity results than S_{LILO}. Firms with low intensity in use of ICT and NOP in 1994 and in 1997 have lower productivity growth over 1992-1998 and this is also the case for firms which kept a low intensity in ICT use and a high intensity in use of NOP over 1994-1997. On the other hand, firms with high intensity in use of ICT and NOP over the whole period (S_{HIHO}) are clearly the most efficient ones.

[Insert table 5]

Estimated static complementarity (κ_S) is positive, but it is not significant at a 10% level. The reason for this is that firms with a stable high intensity in use of ICT and low intensity in use of NOP yield quite a good productivity result. Contrary to static complementarity, dynamic complementarity (κ_{D1}) is negative and significant. This is because the productivity of firms that changed both I and O use over time (D_{DIDO}) is comparable to the productivity of firms that only increased their ICT use (D_{DILO}), while firms that only increased their use of NOP (D_{LIDO}) have a lower but not negligible productivity growth. Static and dynamic complementarity results show an asymmetry between I change alone and O change alone: It seems more efficient to have a high intensity in ICT use only than a high intensity in use of NOP only ($S_{HILO}>S_{LIHO}$ and $D_{DILO}>D_{LIDO}$). We find the same kind of asymmetry when we look at κ_{D2} and κ_{D3}: there is no productivity growth difference between firms that increase their intensity in ICT use with a stable high O or with stable low O, but there is a positive productivity growth difference between firms that increase their intensity in use of NOP with a stable high I compared with firms that did it with a stable low I. In total, it seems that it is easier to yield productivity growth results from the fact of moving to a high intensity in ICT use than from the fact of moving to a high intensity in use of NOP.

What happens to these results when some controls are included in the regressions? All the coefficients shrink and become less significant. In our last specification, including capital intensity growth, employment growth and 15 industry dummies, only two situations remain significantly different than S_{LILO} in terms of productivity: S_{HIHO} and D_{DILO}. Mixed stable situations are no more productive, their coefficients being negative but very close to zero and not significant. As a result, the static complementarity coefficient increases and becomes more significant. Dynamic complementarity coefficients lose their significance as soon as the growth in capital intensity enters the regression. κ_{D1} remains negative but gets closer to zero, κ_{D2} becomes negative but very close to zero and κ_{D3} remains positive but shrinks. It is not clear that the asymmetry between changes in I alone and changes in O alone remains once controls are included in the regressions.

The lack of robustness in our results may be due to measurement errors in our intensity in ICT use and use of NOP variables, which may induce a downward bias in the OLS estimates. If variables measuring intensity in use are subject to measurement errors, then the problem will be amplified in interaction terms. We tried to limit the incidence of measurement errors by transforming our continuous intensity variables into a dichotomous variables but this may be insufficient to get rid of the measurement errors. Because it is a matched employer/employee survey, C.O.I. has the advantage of supplying a second source of measures through the interviews of small samples of

randomly selected employees within each firm. From the answers given by the 1, 2 or 3 interviewed employees belonging to each firm, we estimate the share of employees whose workstation exhibit some characteristics connected either with ICT use or with the use of NOP (see appendix 2). Mairesse and Greenan (1999) show that these estimations, although very imprecise, can be usefully used as instrumental variables in firm level regressions. Tables 6 reports two-stage least square regressions where or I/O indicators have been instrumented with variables stemming from the labor force section of the survey. Because some firms have no responding employees, our sample falls to 1939 units.

[Insert table 6]

As anticipated, estimated coefficients are larger, some of them like D_{DIDO} and D_{DILO} having a questionable magnitude, and they are very imprecise. Consequently, estimated complementarities coefficients remain imprecise. These instrumental variable results are still preliminary and need to be improved.

Conclusion

We have built a large collection of indicators on organizational change and computerization for a sample of 3386 manufacturing firms with more than 50 employees and synthesized them into two dichotomous variables at two dates, 1994 and 1997: high or low intensity in ICT use (HI or LI), high or low intensity in use of NOP (HO or LO). Looking at descriptive statistics, we show that firms possibly coordinate their decisions in the fields of ICT use and of use of NOP. We also find that firms coordinate these choices over time because of an irreversibility: they cannot move backward, from a high intensity in use to a low intensity in use. We thus propose a framework where static complementarities (between stable I and stable O) are taken into account as well as dynamic complementarities (between changing I and changing O). We find econometric evidence of a positive static complementarity and a negative dynamic complementarity. We also find evidence of an asymmetry between choices in the field of ICT and NOP uses: It is easier to yield productivity growth results from changes in ICT use alone than from changes in NOP use alone.

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Table 1: Complementarity between ICT and organizational practices in the empirical literature

Authors, year, country	Sample and period	Measures	Cross section	Time dimension
Bresnahan, Brynjolfsson and Hitt (2002) United States	300 firms 1987-1994 Direct assessment	Productivity: 1987-1994 IT capital 1987-1994 Work organization: standardized sum of dummies (1995, 1996)	Non IT capital elasticity: 0.15 IT capital elasticity: 0.033-0.035 WO: 0.0218 WOXLog(IT stock): 0.0162	
Brynjolfsson and Hitt (2003) United States	527 firms 1987-1994 Indirect assessment	Productivity: 1987-1994 IT capital 1987-1994		IT excess return : none in the short term (1 year), yes after 5-7 years Time consuming complementary organizational change
Caroli and Van Reenen (2001) France	289 establishments 1992-1996 Direct assessment	Productivity: 1992-1996 Change between 1989 and 1992 Proportion of workers using new technologies (TECH) Delayering (OC)		Growth 1992-1996 Capital elasticity: 0.23 OC: 0.02 (NS) TECH: 0.008 (NS) OCXTECH: 0.022 (NS)
Hempell (2003) Germany	1100 service firms 1994-1999 Indirect assessment	Productivity: 1994-1999 IT capital: 1994-1999	Non IT capital elasticity: 0.15 IT capital elasticity: 0.24	Much lower IT elasticity. GMM estimations on first differences yield a significant IT elasticity of : 0.06 Spurious correlation in the cross section due to unobserved complementary expenses
Zwick (2003) Germany	2500 establishments 1997-2000 direct assessment	Productivity: 1998-2000 Dummies: investment in ICT (1996, 1997) introduction of teamwork, reduction of hierarchies, autonomous work groups Factor analysis: Reorganizations	Capital elasticity: 0.15 - CRS ICT: 0.02-0,05 (S 2000 only) ICT IV : 0.50-0.79 Reorganizations: 0.01 (NS) Very weak interactions effects between ICT investments, training and reorganizations	Capital elasticity: 0.02 - DRS ICT impact on fixed effect: 0.02 ICT IV: 0.98 Reorganization: 0.14 Reorganization IV: -0.02 (NS)

Note: NS (S) means non significant (significant) at a 10% level

Table 2: ICT use in 1994 and 1997

%		1994	1997
Equipment characteristics			
2	Mainframe computer in management activities	54	59
2	Mainframe computer in production activities	40	47
2	Non networked PCs in management activities	48	46
2	Non networked PCs in production activities	34	36
2	Networked PCs in management activities	31	66
2	Networked PCs in production activities	22	49
Intensity of computerized data transfers			
5	No within firm transfers	54	30
	Intense within firm transfers	7	16
3	No transfers with suppliers or subcontractors	89	73
	Intense transfers with suppliers or subcontractors	2	6
3	No transfers with corporate clients	86	66
	Intense transfers with corporate clients	3	10
2	Transfers with public authorities	11	22
Internet use			
4	No use of Internet	100*	60
	Complex use of Internet (E-mail, Web site, E-search)	0*	13
Organization of IT function			
2	Existence of a IT manager appointed full time	25	45
2	Outsourcing of IT activities	24*	40
2	Existence of a phone and network manager appointed full time	6	13
2	Outsourcing of phone and network activities	22*	31

Source: C.O.I survey, 1997, business section, MEFI-SESSI, MAP-SCEES
Note: This table gives the percents computed on the sample of 3286 manufacturing firms with more than 50 employees. * Indicates that the figure has been estimated. The first column gives the number of items per discrete variables.

Table 3: Use of NOP in 1994 and 1997

%		1994	1997
	Quality		
2	ISO 9001, ISO 9002 or EAQF certification	19*	49
2	Other certification or Total Quality Management	15*	35
2	Value analysis, functional analysis or AMDEC method	14*	26
	Just-in-time		
2	System of just in time delivery	21*	39
2	System of just in time production	20*	38
2	5S method or Total Productive Maintenance	7*	16
	Market devices		
2	Organization in profit centres	20*	31
2	Formal in-house customer / supplier contracts	16*	29
3	Outsourcing of more than 3 tasks	33*	47
2	Subcontracting of production	36*	54
	Employee implication		
4	High implication of production workers (7 to 10 tasks)	14	22
4	High implication of specialists (7 to 10 tasks)	17	18
4	Low implication of management (0 to 3 tasks)	18	20
	High implication of management (8 to 10 tasks)	27	24
	Structure		
3	From 0 to 2 departments / divisions	35	14
	9 and more departments / divisions	15	36
4	From 0 to 2 hierarchical layers	27	28
	From 5 and 9 hierarchical layers	21	17

Source: C.O.I survey, 1997, business section, MEFI-SESSI, MAP-SCEES
Note: This table gives the percents computed on the sample of 3286 manufacturing firms with more than 50 employees. * Indicates that the figure has been estimated. The first column gives the number of items per discrete variables.

Figure 1: ICT use intensity in 1994 and 1997

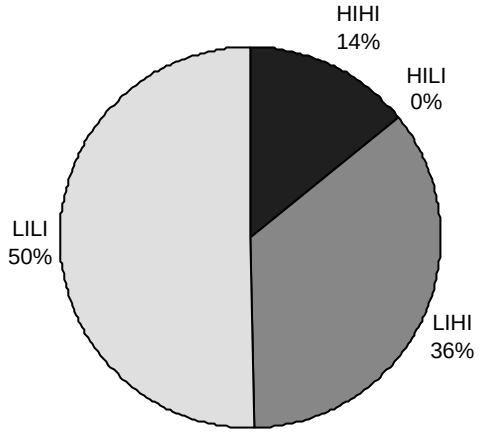
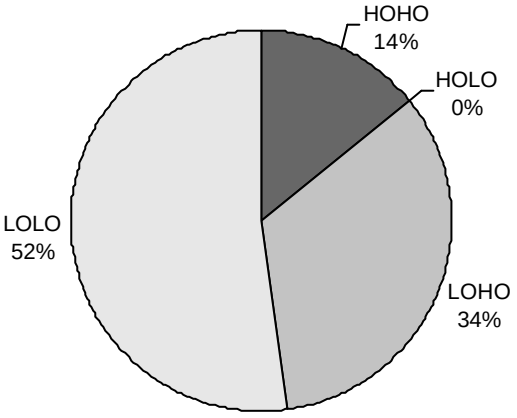


Figure 2: Intensity in use of NOP in 1994 and 1997



Source: C.O.I survey, 1997, business section, MEFI-SESSI, MAP-SCEES
Sample of 2513 firms matched with BRN and FICUS files and present over 1991-1998

Table 4: ICT and NOP : firm level dynamics of uses between 1994 and 1997

Frequency Row percent **Name of the cell variable**		**1997**				
		HIHO	**HILO**	**LIHO**	**LILO**	**Total**
1994	**HIHO**	107 (100) S_{HIHO}	0 (0)	0 (0)	0 (0)	107 (100)
	HILO	162 (65) D_{HIDO}	87 (36) S_{HILO}	0 (0)	0 (0)	249 (100)
	LIHO	170 (68) D_{DIHO}	0 (0)	79 (32) S_{LIHO}	0 (0)	249 (100)
	LILO	443 (23) D_{DIDO}	281 (15) D_{DILO}	243 (13) D_{LIDO}	941 (49) S_{LILO}	1908 (100)
	Total	882 (35)	368 (15)	322 (13)	941 (37)	2513 (100)

Source: C.O.I survey, 1997, business section, MEFI-SESSI, MAP-SCEES
Sample of 2513 firms matched with BRN and FICUS files and present over 1991-1998

Table 5: Regression estimates of value added per head growth (1992-1998) on dynamic complementarity indicators

Specification **capital elasticity** **returns to scale** **Controls**	(1) 0 constant none	(2) 0.20 constant none	(3) 0.24* constant none	(4) 0.24* 1.04* none	(5) 0.23* 1.04* 15 industries
S_{HIHO} $q_{11} - q_{00}$	0.462*** (0.069)	0.342*** (0.062)	0.317*** (0.062)	0.239*** (0.064)	0.188*** (0.063)
S_{HILO} $q_{10} - q_{00}$	0.218*** (0.076)	0.138** (0.068)	0.121* (0.067)	0.077 (0.069)	-0.007 (0.067)
S_{LIHO} $q_{01} - q_{00}$	0.069 (0.079)	0.005 (0.071)	-0.008 (0.070)	-0.024 (0.070)	-0.026 (0.069)
D_{DIDO} $j_{11} - q_{00}$	0.241*** (0.039)	0.145*** (0.035)	0.125*** (0.035)	0.069* (0.037)	0.040 (0.037)
D_{DILO} $j_{10} - q_{00}$	0.225*** (0.046)	0.167*** (0.041)	0.155*** (0.041)	0.121*** (0.041)	0.080** (0.041)
D_{DIHO} $j''_{10} - q_{00}$	0.248*** (0.056)	0.155*** (0.053)	0.136*** (0.050)	0.087* (0.051)	0.056 (0.051)
D_{LIDO} $j_{01} - q_{00}$	0.149*** (0.049)	0.084** (0.043)	0.070 (0.043)	0.050 (0.043)	0.033 (0.043)
D_{HIDO} $j''_{01} - q_{00}$	0.303*** (0.057)	0.180*** (0.051)	0.155*** (0.051)	0.089* (0.053)	0.052 (0.053)
k_S $q_{11} - q_{10} - q_{01} + q_{00}$	0.175 (0.125)	0.199* (0.12)	0.205* (0.112)	0.186* (0.111)	0.221** (0.109)
k_{D1} $j_{11} - j_{10} - j_{01} + q_{00}$	-0.134* (0.071)	-0.106* (0.063)	-0.100 (0.063)	-0.101 (0.063)	-0.025 (0.058)
k_{D2} $j''_{10} - j_{10}$	0.023 (0.066)	-0.012 (0.059)	-0.019 (0.058)	-0.034 (0.058)	-0.025 (0.058)
k_{D3} $j''_{01} - j_{01}$	0.154** (0.068)	0.097 (0.061)	0.085 (0.061)	0.039 (0.062)	0.019 (0.061)
$\mathbf{R^2}$ **(MSE)**	0.037 (0.455)	0.022 (0.364)	0.268 (0.353)	0.270 (0.351)	0.285 (0.340)

Source: C.O.I survey, 1997, business section, MEFI-SESSI, MAP-SCEES
Sample of 2513 firms matched with BRN and FICUS files and present over 1991-1998
Note: in specifications 3, 4 and 5 the value given for capital elasticity and returns to scale has been estimated when * is mentioned.

Table 6: Instrumented regression estimates of value added per head growth (1992-1998) on dynamic complementarity indicators

Specification **capital elasticity** **returns to scale** **Controls**	(1) 0 constant none	(2) 0.20 constant none	(3) 0.21* constant none	(4) 0.22* constant* none	(5) 0.22* constant* 15 industries
S_{HIHO} $q_{11} - q_{00}$	0.505 (0.675)	0.252 (0.545)	0.234 (0.539)	0.330 (0.557)	0.194 (0.530)
S_{HILO} $q_{10} - q_{00}$	-0.526 (0.911)	0.000 (0.735)	0.051 (0.720)	0.118 (0.722)	0.142 (0.695)
S_{LIHO} $q_{01} - q_{00}$	0.266 (1.052)	0.008 (0.848)	-0.010 (0.840)	0.045 (0.835)	0.058 (0.748)
D_{DIDO} $j_{11} - q_{00}$	1.059*** (0.386)	0.742** (0.311)	0.723** (0.313)	0.777** (0.329)	0.635** (0.315)
D_{DILO} $j_{10} - q_{00}$	2.121*** (0.538)	1.598*** (0.434)	1.563*** (0.435)	1.590*** (0.441)	1.213*** (0.428)
D_{DIHO} $j''_{10} - q_{00}$	0.809 (0.692)	0.312 (0.558)	0.284 (0.561)	0.255 (0.566)	0.275 (0.528)
D_{LIDO} $j_{01} - q_{00}$	1.271* (0.758)	0.592 (0.611)	0.543 (0.612)	0.589 (0.615)	0.405 (0.564)
D_{HIDO} $j''_{01} - q_{00}$	0.809 (0.692)	0.816* (0.443)	0.780* (0.489)	0.843* (0.452)	0.669 (0.418)
k_S $q_{11} - q_{10} - q_{01} + q_{00}$	0.765 (1.502)	0.244 (1.211)	0.193 (1.194)	0.166 (1.189)	-0.007 (1.096)
k_{D1} $j_{11} - j_{10} - j_{01} + q_{00}$	-1.872* (0.979)	-1.168 (0.789)	-1.124 (0.790)	-1.069 (0.798)	-0.852 (0.782)
k_{D2} $j''_{10} - j_{10}$	-0.850 (0.909)	-1.007 (0.733)	-1.017 (0.726)	-1.001 (0.726)	-0.808 (0.655)
k_{D3} $j''_{01} - j_{01}$	0.485 (0.923)	0.504 (0.744)	0.495 (0.736)	0.588 (0.754)	0.394 (0.689)
R^2 **(MSE)**	0.031 (0.874)	0.022 (0.568)	0.175 (0.556)	0.180 (0.563)	0.237 (0.459)

Source: C.O.I survey, 1997, business section, MEFI-SESSI, MAP-SCEES
Sample of 1939 firms matched with BRN and FICUS files and present over 1991-1998
Note: in specifications 3, 4 and 5 the value given for capital elasticity and returns to scale has been estimated when * is mentioned.

Appendix 1: The Business section of the C.O.I. survey

In this appendix, we give the questions from the business section of the survey that we used to measure computerization and organizational change. The question numbers are those of the questionnaire: our presentation does not follow the order of the questionnaire. Frequency counts from the business part of the C.O.I. survey are published in Favre, François and Greenan (1998). The whole questionnaire and some descriptive results have been translated in English. They are available upon request.

Computerization:

Does your company outsource any of the following tasks? (OUT)		In 1997		Change since 1994		
3.9	Telephony/networks					
3.10	IT					

Are/were your company's management and production departments equipped with the following IT resources ?

		MANAGEMENT		PRODUCTION	
		1997	1994	1997	1994
16.1	Mainframe computer				
16.2	Non-Networked microcomputer				
16.3	Networked microcomputer				

Has your company used, or does it use IT interfaces (computer network, EDI links, etc.) for data transfers ?		1997		1994	
		Yes	No	Yes	No
19.1	within management departments (purchasing, sales, marketing, accounting etc.)				
19.2	between management and production departments (process engineering, production management, manufacturing etc.)				
19.3	between management and suppliers, subcontractors or service providers				
19.4	between management and corporate clients				
19.5	between management and social organizations, public authorities				
19.6	between design departments (research, development and design) and production				
19.7	between design departments and suppliers, subcontractors or service providers				
19.8	within production departments or between manufacturing units				
19.9	between production departments and suppliers, subcontractors or service providers				
19.10	Between production departments and corporate clients				

Did your company use Internet for any of the following in 1997 ?		Yes	No
20.1	Accessing e-mail		
20.2	Disseminating information (e.g. Web pages)		
20.3	Searching for information		

New organizational practices:

Does your company outsource any of the following tasks? (OUT)		In 1997		Change since 1994		
		Yes	No	+	=	-
3.1	Research/development/design					
3.2	Purchasing					
3.3	Production engineering/production management/scheduling					
3.4	Manufacturing/production					
3.5	Quality assurance					
3.6	Maintenance					
3.7	Sales					
3.8	Marketing/advertising					
3.11	Human resources/staff training					

3.12	**Accounting/management control**					
3.13	**Finance/cash management**					
3.14	**Legal affairs**					
3.15	**Environment/health and safety**					

Does your company use the following organizational device?		**In 1997**		**Change in the % of employees affected since 1994**		
		Yes	**No**	**+**	**=**	**-**
4.1	**ISO 9001, ISO 9002, EAQF certification**					
4.2	**Other certification or total quality management**					
4.3	**Value analysis, functional analysis or "AMDEC" method**					
4.4	**5S method or TPM (Total Productive Maintenance)**					
4.5	**Organization in profit centers**					
4.6	**Formal in-house customer/supplier contracts**					
4.7	**System of just-in-time delivery**					
4.8	**System of just-in-time production**					

In general, who is/was authorized to do the following in your company workshops? (more than one answer possible)		**In 1997**			**In 1994**		
		Management **(MAN)**	Production worker **(PW)**	Specialist **(SPE)**	Management **(MAN)**	Production worker **(PW)**	Specialist **(SPE)**
6.1	**Adjust installations**						
6.2	**Perform 1st level maintenance**						
6.3	**Allocate tasks to production workers**						
6.4	**Inspect quality of supplies**						
6.5	**Inspect quality of production**						
6.6	**Participate in performance improvements**						
6.7	**Participate in projects teams**						
6.8	**Stop production in case of an incident**						
6.9	**Troubleshoot in case of an incident**						
6.10	**Start production again in case of an incident**						

7. How many hierarchical layers are/were there between production workers (level 0) and the head of the company (level N)? (HL) and (EVHL)			
In 1997		**In 1994**	

Appendix 2: The labour force section of the C.O.I. survey

Small samples of two or three employees per firm have been interviewed in the context of the C.O.I survey. They were asked to describe their work at the date of the survey (end of 1997). From their answers, we build the following firm level estimations:

ICT use

Share of PC users
Share of mainframe users
Share of portable PC users
Share of spreadsheet software users
Share of computer users specialized in data entry
Share of intranet users
Share of Internet users
Share of Minitel users
Share of automated machine users
Share of employees allowed intervening on electric installations

Use of NOP

Share of employees with very intense communication with outside the firm
Share of employees with intense communication with outside the firm
Share of employees with very intense communication with colleagues
Share of employees with intense communication with colleagues
Share of employees with medium communication intensity with colleagues
Share of employees with more than 17 meeting per year
Share of employees with 11 to 16 meeting per year
Share of employees with 3 to 10 meetings per year
Share of employees with 1 or 2 meetings per year
Share of employees with very high technical constraints
Share of employees with high technical constraints
Share of employees that very often work outside the firm's premises
Share of employees that often work outside the firm's premises
Share of employees with a very high scope of initiative
Share of employees with a high scope of initiative
Share of employees with a medium scope of initiative
Share of employees with a low scope of initiative
Share of employees that have to comply with precise quality norms
Share of employees making proposals for process improvements
Share of employees in a hierarchical position
Share of employees with no hierarchical position but who occupied such a position in the past.