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Computerization, labor productivity and employment: impacts across industries vary with technological level

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Informatisation, productivité du travail et emploi : des effets différenciés entre industries selon le niveau technologique

Résumé

Le progrès technique, notamment au travers de l'informatisation, pose des enjeux pour le devenir de certains emplois. En parallèle, les gains de productivité se sont essoufflés dans de nombreux pays développés et l'usage de l'informatique ne semble pas se traduire nécessairement dans les statistiques de productivité, en particulier dans les industries manufacturières non productrices de capital informatique aux États-Unis (Acemoglu, Autor, Dorn, Hanson, et Price, 2014). Afin d'étudier si les diminutions d'effectifs et les faibles gains de productivité du travail associés à l'informatisation surviennent séparément dans différents secteurs, cette étude adopte une approche méso-économique pour la France entre 1994 et 2007. Le travail pouvant être soit substituable soit complémentaire au capital informatique, selon que les tâches correspondantes sont routinières ou non, une attention privilégiée est portée au niveau technologique et au degré de qualification des emplois. Les principaux résultats sont les suivants. Contrairement aux États-Unis, les secteurs producteurs de capital informatique ne montrent pas de gains de productivité liés à l'informatisation. Cependant, pour les secteurs non producteurs, elle est associée à des effets positifs mais fragiles sur la productivité du travail, et à des baisses d'effectifs sans équivoque. Celles-ci se concentrent dans les industries de faible technologie, principalement parmi les travailleurs peu qualifiés, avec *in fine* des gains de productivité particulièrement nets. Dans les industries de moyenne-haute technologie, de tels effets ne sont pas identifiés. L'informatisation n'y est pas associée à des baisses d'effectifs quelle que soit la catégorie d'emploi, mais est reliée à une part de l'emploi qualifié plus élevée. Au final, l'informatisation pourrait accompagner des changements sectoriels structurels, avec une amélioration de la productivité pour les secteurs en déclin et un enrichissement en travail pour ceux en essor.

Mots-clés : productivité du travail, informatisation, substitution/complémentarité capital-travail

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Computerization, labor productivity and employment: impacts across industries vary with technological level

Abstract

Technical progress notably through computerization raises concerns about the future of labor. In parallel, productivity became sluggish in many developed countries and computers are everywhere but not in *all* productivity statistics, especially not among non IT producing manufacturing industries in the United States (Acemoglu, Autor, Dorn, Hanson, and Price, 2014). To observe whether job losses and missing labor productivity gains from computerization are localized in the same part of the manufacturing sector, this paper delves into targeted disaggregated focuses in France between 1994 and 2007. As computers can be used as complements or substitutes for labor depending on the (non-) routine nature of tasks, we concentrate on low-tech vs. mid/high tech industries and on high-skilled vs. low-skilled workers. Our main results are the following. Contrary to the United States, labor productivity is not driven to a large extent by IT-producing industries. Yet, for the whole IT-using manufacturing sector, computerization is associated with positive but fragile effects on labor productivity, and to unambiguous declines in employment. Actually, a labor saving effect of computerization is massively concentrated among industries relying on low production technology. For mid/high-tech IT-using industries, evidence is less straightforward on labor productivity. Among them, computerization is not associated to job cuts whatever the job type, and is related to a rise in the share of high-skilled workers. In the end, computerization could go in hand in hand with economy wide structural changes, with strong productivity improvements in declining sectors and labor deepening in rising ones.

Keywords: labor productivity, computerization, capital-labor substitution and complementarity

Classification JEL : J2, L60, O3

Introduction

Technical progress notably through computerization raised concerns about the future of labor. Many jobs could be exposed to substitution by machines in the following decades: in particular, the *Conseil d'Orientation pour l'Emploi* finds that 10 percent of existing jobs in France are threatened (COE, 2017). In parallel, productivity became sluggish in many developed countries, and computers are everywhere but not in *all* productivity statistics, to rephrase Robert Solow[1]. Acemoglu, Autor, Dorn, Hanson, and Price (2014) recently revived the "Solow paradox" by illustrating for the United States and after the 1990s that labor productivity gains are still missing for computer-intensive manufacturing industries when information technology (IT) producers are ruled out.[2] All these facts seem paradoxical: why would jobs be substituted by machines if not for productivity improvements?

Against this background, this paper sheds light on this puzzling aggregate view by delving into targeted disaggregated focuses at the industry level and for different groups of occupations. The aim is to observe whether job losses and missing labor productivity gains from computerization are localized in the same part of the manufacturing sector. Indeed, simple theoretical mechanisms suggest that both facts could be outcomes in separate industries. Labor can be either substitutable or complementary to computers depending on the routine or non routine content of the corresponding tasks, as evidenced by Autor, Levy, and Murnane (2003).[3] Typical examples are automation in textiles or R&D in chemicals.[4] Computerization could thus lead to either a fall or a rise of labor demand in production. In the end, the effect of computerization on employment and labor productivity might depend on the industry mix between these alternative uses of computers.

In this paper, we concentrate on effects among manufacturing industries and investigate two major and related dimensions of disaggregation: technological levels and occupations, which both participate in the (non-)routine nature of labor. We show that distinguishing

[1] At the end of the 1980s, Robert Solow noticed that "computers [were] everywhere but in the productivity statistics" (1987, New York Times Book Review). Since then, many studies showed a positive effect of information technology on labor or total productivity, with widely varying size and interpretations (Cardona, Kretschmer, and Strobel, 2013).

[2] Similarly Brynjolfsson and McAfee (2011) argued that "total factor productivity in non-IT producing industries has not been improving along with increased IT services use."

[3] Autor et al. (2003) found that computerization can be associated with reduced labor input of routine manual and routine cognitive tasks and increased labor input of non-routine cognitive tasks.

[4] Albeit clearly associated to the automation phenomena in particular, our ICT variable does not grasp it thoroughly, such as information more targeted on robots in Acemoglu and Restrepo (2017) for instance.

between low-tech and mid/high tech industries and between high-skilled and low-skilled workers provides a sufficient level of heterogeneity to sharply characterize distinct outcomes for productivity and employment where computerization is more intensive.

This work relies on series built for 228 manufacturing industries in France between 1994 and 2007, using administrative data from the "Bénéfices Réels Normaux" (BRN), for production, total firm level employment and computer investment, and the "Déclarations annuelles de données sociales" (DADS) for employment by skill groups. Following Acemoglu et al. (2014), we use panel regressions at the sector level to explain productivity (ratio between sales and total employees) and employment with year-specific elasticities for computer intensity (defined as the share of computer investment). This allows to gain insight into long-term trends in a context of progressive computerization, and to compare our results with equivalent ones for the United States using data from Acemoglu et al. (2014). Starting from the whole manufacturing sector, this econometric approach is then applied separately for IT-using industries, and within this category for low- and mid/high tech ones. Results are then refined using employment for high-skilled and low-skilled workers, and compared to outcomes obtained for the services sector.

Our main results are the following. Contrary to the United States, labor productivity in France has not been driven to a large extent by IT-producing industries, revealing the potential underdevelopment of the "French tech". Yet, for the whole IT-using manufacturing sector, computerization is associated with positive but fragile effects on labor productivity, and to unambiguous declines in employment. Actually, a labor saving effect of computerization is massively concentrated among industries relying on low production technology. For mid/high-tech IT-using industries, evidence is less straightforward on labor productivity. Among them, computerization is related to more employment for all job types relative to low-tech industries, and notably to a rise in the share of high-skilled workers. In comparison, computerization in services favors employment and sales significantly, with no distinguishable impact on labor productivity yet. In the end, computerization seems to foster economy wide structural changes, with strong labor productivity improvements in declining sectors and labor enrichment in rising ones.

This paper is related to the link between computerization, employment and firm labor demand in terms of skills and tasks, following the seminal work by Autor et al. (2003).

Computer investment can drive diverging employment dynamics with respect to economic sectors: Biscourp, Crépon, Heckel, and Riedinger (2002) found a strong effect of the decline in computer prices on the relative demand for unskilled and skilled workers, with varying sensitivities in services and manufacturing.[5] In addition, Pak and Poissonnier (2016) show that technology has a negative contribution on changes in employment concentrated on low-skilled workers, while the contribution is positive for high-skilled.[6] Using the same data as ours, Harrigan, Reshef, and Toubal (2016) show that firms with more technology[7] saw greater polarization, which suggests similar outcomes at the industry level. Further emphasizing the substitution between IT capital and labor in a general equilibrium framework, Acemoglu and Restrepo (2017) obtain negative effects of robots on employment and wages across U.S. commuting zones. This impact is yet distinct from those they obtain with other types of IT capital, which is consistent with our results using data on computers and displaying more complementarity with labor. Finally, Spieza, Polder, and Presidente (2016) estimate on OECD countries that the decrease in IT user cost has short-term effects on labor demands whatever the skill level, but is neutral in the long-run.

This study is also related to works on R&D, innovation, productivity and employment. Hall, Lotti, and Mairesse (2012) notably test the potential complementarity between IT and R&D on a panel of Italian manufacturing firms. They find that IT and R&D separately affect strongly productivity but are not complements. Our results at the industry level and using R&D intensity categories are consistent with an absence of complementarity but also suggest a negative interaction, as they depict IT-driven productivity effects among low-tech industries but not mid/high-tech ones. Behind these empirical findings, there could be two different underlying uses of computers when R&D is low or high as mentioned by Hall et al. (2012). First, "[IT] enables "organizational" investment, mainly business processes and new work practices which, in turn, lead to cost reductions and improved output and, hence, productivity gains". Second, "[in] a less traditional view, [IT] is an input for producing new

[5]More precisely, at the general level, a 15 percent fall in computer prices leads to a decline of marginal costs for firms by 0.7 percent and a rise of the ratio between skilled and unskilled workers in employment by 3.5 percent; and demand for skilled relative to unskilled workers seems stronger in manufacturing than in services, especially for firms within the first size quintile (cf. Biscourp et al., 2002, Figure 8, p.18).

[6]Pak and Poissonnier (2016) decompose employment variations with respect to different qualification levels over 30 years and with an accounting input-output approach.

[7]The propensity of a firm to adopt new technologies is proxied by its employment of "techies", i.e. technically qualified managers and technicians.

goods and services (like internet banking), new ways of doing business [...] and new ways of producing goods and services (integrated management)".[8] Here, we associate both views of IT uses to IT-labor substitution and complementarity respectively. More theoretically, Acemoglu and Restrepo (2016) highlight that R&D can be oriented to the automation of current tasks or the creation of new ones, and that some balance between the former and the latter can be reached endogenously such that in equilibrium "the endogenous response of [R&D] restores the labor share and employment back to their initial level". Our results could be interpreted as signs of the presence of these alternative compensating mechanisms at stake with technological change, and also suggest further analyzing labor shares among different industry groups within manufacturing.

The rest of the paper is organized as follows. Section 1 develops preliminary simple theoretical insights on the potential substitution and complementarity effects of computerization on employment and labor productivity. Section 2 describes our data sources, their treatments and the definition of the industry and skill groups at the core of our empirical analysis. Section 3 presents the economic approach and its application to different broad manufacturing industry groups. Finally, Section 4 extends these estimates on major employment categories and in services.

1 Preliminary theoretical insights

Should computerization enhance labor productivity? Besides improving total factor productivity gains, computers may also favor labor deepening of production. In order to figure out this potential effect, a simple model is derived where computers can be either substitutes or complements for labor. It follows the models by Autor et al. (2003) and Harrigan et al. (2016), which enclose computer price evolutions and the skill composition of firms labor demand, and adds decreasing returns to scale. A fall in computer prices can then induce differing dynamics for employment and labor productivity.[9] The model by Autor et al. (2003) rationalized their finding that computerization can be associated with reduced labor input of routine manual and routine cognitive tasks and increased labor input of non-routine cognitive

[8] In France, higher R&D spendings are indeed associated with more product innovation notably (Lelarge, 2006).

[9] In particular, this model abstracts from margin adjustments by firms to gain market shares and from total factor productivity improvements (TFP A below is constant), which may also be influenced by ICT use.

tasks. By routine tasks, Autor et al. (2003) mean for instance record-keeping, calculation, repetitive customer service, or picking, sorting, repetitive assembly, for which substitution with computers can be expected (see Table 1 in Autor et al., 2003). Examples of non routine tasks are forming/testing hypotheses, medical diagnosis, legal writing, persuading/selling, managing others, for which strong complementaries with computers are more likely.

A firm is represented by a production function using routine and non-routine tasks T_r and T_n with decreasing returns to scale ($\alpha < 1$ and $0 < \beta < \alpha$):

$$Q = A\left(\frac{T_r}{\alpha-\beta}\right)^{\alpha-\beta}\left(\frac{T_n}{\beta}\right)^{\beta},$$

where production Q implies an intensity of non-routine tasks β, and A is a scale parameter.[10] The tasks T_r (resp. T_n) are achieved with both labor H_r (resp. H_n) and computers C_r (resp. C_n) following:

$$T_r = \left[\theta_r^{\frac{1}{\sigma_r}} C_r^{\frac{\sigma_r-1}{\sigma_r}} + (1-\theta_r)^{\frac{1}{\sigma_r}} H_r^{\frac{\sigma_r-1}{\sigma_r}}\right]^{\frac{\sigma_r}{\sigma_r-1}} \text{ and } T_n = \left[\theta_n^{\frac{1}{\sigma_n}} C_n^{\frac{\sigma_n-1}{\sigma_n}} + (1-\theta_n)^{\frac{1}{\sigma_n}} H_n^{\frac{\sigma_n-1}{\sigma_n}}\right]^{\frac{\sigma_n}{\sigma_n-1}},$$

where θ_r and θ_n are parameters indicating the computer intensity of each type of task, with $0 < \theta_r, \theta_n < 1$. We distinguish here two possible types of computer uses which might differ for routine and non routine tasks. Non-routine labor is assumed to be complementary to computers, with $0 < \sigma_n < 1$, while routine labor is substitutable with them, with $\sigma_r > 1$.

The demands for routine and non-routine tasks are derived from the equality between marginal benefits and costs:

$$P_r T_r = (\alpha-\beta)Q \text{ and } P_n T_n = \beta Q, \tag{1}$$

where P_r and P_n are the composite prices for each type of task. These composite prices depend on the price of computers p and on the associated type of labor, w_r or w_n. The quantities of tasks T_r (resp. T_n) are made up by optimal quantities of computers C_r (resp. C_n) and labor H_r (resp. H_n), at prices P_r (resp. P_n), p et w_r (resp. w_n) so that the composite price is given by:

$$P_r = \left[\theta_r p^{1-\sigma_r} + (1-\theta_r) w_r^{1-\sigma_r}\right]^{\frac{1}{1-\sigma_r}} \text{ and } P_n = \left[\theta_n p^{1-\sigma_n} + (1-\theta_n) w_n^{1-\sigma_n}\right]^{\frac{1}{1-\sigma_n}}. \tag{2}$$

[10] Production Q is in nominal terms. The firm considers exogenous sales prices. This corresponds to the absence of margin adjustment as mentioned in footnote 9.

For a specific level of tasks, the corresponding labor demand depends on the relative cost of labor in the composite price and the labor intensity of these tasks, according to:

$$\left(\frac{w_r}{P_r}\right)^{\sigma_r} H_r = (1-\theta_r)T_r \text{ and } \left(\frac{w_n}{P_n}\right)^{\sigma_n} H_n = (1-\theta_n)T_n. \tag{3}$$

Associating equations (1) and (3), we have:

$$H_r = (1-\theta_r)(\alpha-\beta)Q\frac{P_r^{\sigma_r-1}}{w_r^{\sigma_r}} \text{ and } H_n = (1-\theta_n)\beta Q\frac{P_n^{\sigma_n-1}}{w_n^{\sigma_n}}. \tag{4}$$

Finally, labor productivity $\Gamma = Q/(H_r + H_n)$ has the following form:

$$\Gamma = \left[(1-\theta_r)(\alpha-\beta)\frac{P_r^{\sigma_r-1}}{w_r^{\sigma_r}} + (1-\theta_n)\beta\frac{P_n^{\sigma_n-1}}{w_n^{\sigma_n}}\right]^{-1}. \tag{5}$$

Within this framework, consider two simplified industry cases, s and c, where only one type of tasks is used, that is with $\beta = 0$ or $\beta = \alpha$. Then, labor productivity in each of them follows:

$$\Gamma_s = \frac{w_r}{\alpha}\left[\frac{\theta_r}{1-\theta_r}\left(\frac{p}{w_r}\right)^{1-\sigma_r} + 1\right] \text{ and } \Gamma_c = \frac{w_n}{\alpha}\left[\frac{\theta_n}{1-\theta_n}\left(\frac{p}{w_n}\right)^{1-\sigma_n} + 1\right]. \tag{6}$$

Assume then that the price p of computers falls, all else being equal in terms of wages w_r or w_n. The effects on labor productivity are such as:

$$\frac{\partial \Gamma_s}{\partial p} \propto \frac{\theta_r}{1-\theta_r}\underbrace{(1-\sigma_r)}_{<0} \text{ and } \frac{\partial \Gamma_c}{\partial p} \propto \frac{\theta_n}{1-\theta_n}\underbrace{(1-\sigma_n)}_{>0} \tag{7}$$

In industry s, routine labor and computers are substitutes so that $1-\sigma_r < 0$ and labor productivity increases. In industry c, non-routine labor and computers are complements, so that $1-\sigma_n > 0$ and labor productivity decreases.

These effects on labor productivity are the result of the combination of two standard mechanisms. First, there is a substitution effect within tasks T_r or T_n since, for a given production level, computer and labor uses depend on relative factor prices. All things being equal, in both industries s and c the substitution effect induces a fall in labor, whose magnitude depends on the constant elasticity of substitution: weak for low levels of the elasticity (i.e. for complementary such as with $\sigma_n < 1$), strong for high levels of the elasticity (i.e. for substitutability such as with $\sigma_r > 1$). The fall in labor mechanically implies a rise in the labor productivity.[11]

[11] This effect is embedded in the coefficients "$-\sigma_r$" and "$-\sigma_n$" in Equations (7), through which a fall in p implies a rise in both Γ_s and Γ_c.

Second, a drop in computer prices p implies a fall in total production costs (P_r or P_n) and then a revenue effect in the profit maximization of the firms. In both industries s and c, it induces a rise in quantities of tasks T_r or T_n, that is in both quantities of computers and labor. Due to decreasing returns to scale, the output does not increase as much and, more precisely, the revenue effect implies a decrease in the labor productivity.[12]

In industry s ($\sigma_r > 1$), the substitution effect is higher than the revenue effect whereas the revenue effect is higher in industry c ($\sigma_n > 1$).[13] Moreover, as $\theta/(1-\theta)$ is increasing in θ, the effects on labor productivity in Equations (7) are even stronger in both industry cases when the computer intensity of production is higher. Note that in this simple model, the two types of labor r and n only differ according to their degree of substitutability with computers. In particular, there is no specific labor efficiency which could influence the aggregate labor productivity.

In the general case in Equation (5), the productivity Γ can be then rewritten in terms of the previous labor productivities Γ_s and Γ_c: $\Gamma = [(1-\beta)/\Gamma_s + \beta/\Gamma_c]^{-1}$, so that the total productivity effect of a drop in the computer price is undetermined and depends upon the tasks intensities (through β) on top of θ_n, θ_r, σ_n and σ_r.[14]

In the end and at least, as manufacturing industries largely differ in their demands of routine and non-routine tasks, the impact of their computer intensity on their employment and labor productivity, as suggested by Equations (4) and (5), is ambiguous. In the next section, data are designed to reflect the main features presented here.

2 Data sources and treatments

Data are taken from the "Bénéfices Réels Normaux" (BRN) and the "Déclarations annuelles de données sociales" (DADS), two French administrative databases, between 1994 and 2007, and are merged at the firm level. This time window is chosen for two reasons: first, after 2007, the computer expenditures variable in BRN data has been gathered with unrelated

[12]This effect is embedded in the number "1" in Equations (7), through which a fall in p results in a fall in both Γ_s and Γ_c. Note that, from Equation (1), in case s, $Q/T_r = P_r/\alpha$, and in case c, $Q/T_n = P_n/\alpha$.

[13]To shed more light on these polar productivity outcomes, two alternative models including a single task production technology are developed in the Appendix.

[14]Note that $\partial\Gamma/\partial\beta = \Gamma^2/(\Gamma_c\Gamma_s)(\Gamma_c - \Gamma_s)$. So if partial productivity is higher for non routine tasks than routine ones ($\Gamma_c > \Gamma_s$), then an increase of non routine tasks intensity in production β is total productivity enhancing.

items; second, major revisions of used industry codes occurred in 1993 and 2008.[15] Manufacturing firms are gathered into 228 industries at the 4-digit level based on the Statistical classification of economic activities in the European Community (NACE). NACE codes were slightly revised in 2002 with a separation of several industries into new subcategories. NACE codes are harmonized over the sample to rely only on the 1990-2001 NACE Rev.1 version.[16] For descriptive statistics, aggregates are also computed at the higher 2-digit NACE level (NACE divisions) in order to deal with a tractable number of entities (23 in manufacturing ranging from "15" for "food products and beverages" to "37" for "recycling"). IT-producing industries are made up by the three following 2-digit divisions in line with the definition by Acemoglu et al. (2014): "office machinery and computers"; "radio, television and communication equipment"; and "medical, optical and watch instruments". Codes changed for some firms in IT-producing industries as their activity became mostly made up by services rather than hardware merchandises. To avoid mixing these firms with others in services, we use the earlier codes. Finally, to allow for comparisons with the United States for productivity and total employment, we also rely on the NBER-CES Manufacturing database used by Acemoglu et al. (2014) which includes 387 manufacturing industries at the 4-digit SIC codes level.

To measure computer use, we rely on "office and computing machinery" investment as reported in the BRN. Crépon and Heckel (2000) and Barbesol, Heckel, and Quantin (2008) used this variable for France, and Autor, Katz, and Krueger (1998) relied on a similar one for the United States. We define computer intensity as the ratio between computer investment and total investment as in Acemoglu et al. (2014), but also Berman, Bound, and Griliches (1994) and Autor et al. (1998). Our labor productivity measure is the ratio between sales and total employees. Sales are preferred to value added as productivity is then unaffected by the choice of deflators for intermediate inputs and IT in particular. Note that all variables are in nominal terms. Yet, results are very similar to Acemoglu et al. (2014) which also use nominal outcome variables as alternative regressions.

[15]This period also allows direct comparison with Harrigan et al. (2016) which study the impacts of computerization on polarization with the same data between 1994 and 2007 but at the firm level.

[16]NACE Rev.1.1 contains very few additional items. In manufacturing, one of the main changes is a breakdown of NACE 2940 (manufacture of machine tools) into three classes, portable hand held, metalworking and others. In services, an example is the breakdown into two new wholesale classes NACE 5164 (wholesale of office machinery and equipment) and NACE 5165 (wholesale of machinery for use in industry, trade and navigation).

Table 1 – Classification of manufacturing industries into categories based on R&D intensities

SIC	**name**	**NACE**	**name**	**grp**
20	Food and kindred products	15	Food products and beverage	*low*
21	Tobacco products	16	Tobacco products	*low*
22	Textile mill products	17	Textiles	*low*
23	Apparel and other textile prod.	18	Wearing apparel	*low*
24	Lumber and wood products	20	Wood and wood products	*low*
25	Furniture and fixtures	36	Furnitures	*low*
26	Paper and allied products	21	Pulp, paper and paper products	*low*
27	Printing and publishing	22	Publishing, printing	*low*
28	Chemicals and allied products	24	Chemicals and chemical products	*mid/high*
29	Petroleum and coal products	23	Coke, refined petroleum products	*mid/high*
30	Rubber and misc. plastics prod.	25	Rubber and plastic products	*mid/high*
31	Leather and leather products	19	Leather and leather products	*low*
32	Stone, clay, and glass products	26	Non-metallic mineral products	*mid/high*
33	Primary metal industries	27	Basic metals	*mid/high*
34	Fabricated metal products	28	Fabricated metal products	*mid/high*
35	Industrial machinery and equip.	29	Machinery and equipment	*mid/high*
		30	Office machinery and computers	-
36	Electronic and oth. electric equip.	31	Electrical machinery and app.	*mid/high*
		32	Radio, TV and com. equip.	-
37	Transportation equipment	34	Transport equip.	*mid/high*
38	Instruments and related products	33	Medical, precision and optic. inst.	-
39	Misc. manufacturing industries	37	Miscellaneous (recycling)	*low*

Source: 1987 SIC Code List from the U.S. Census Bureau, Eurostat, Hatzichronoglou (1997). Note: "Chemicals" (NACE 2-digit code 24) are associated to medium-high technology by the OECD excepting pharmaceuticals (NACE 3-digit code 244) which include hight-tech industries. Similarly, "transport equipment" (NACE 34 / NACE 35) is within the medium-high category apart from "aircraft and spacecraft" (NACE 353) made up by high-tech industries. In the category "publishing, printing" "NACE 22", the sub-part "publishing" is set as a high-tech set of industries in our own classification, as under NACE rev.2, "publishing" is in Section J for "information and communication services".

We follow the OECD classification of industries with respect to R&D intensity (cf. Table 1). In this classification, the ranking takes into account both the level of technology specific to the sector (measured by the ratio of R&D expenditure to value added) and the technology embodied in purchases of intermediate and capital goods (Hatzichronoglou, 1997).[17] Based on the distinction of four groups by the OECD, we divide manufacturing IT-using industries within two categories: low-technology industries[18] and mid/high-tech ones. Mid/high tech industries include the OECD groups "medium-low", "medium-high" and "high" apart from IT-producing industries[19]. The aim is to broadly distinguish industries with respect to their use of routine vs. non-routine tasks. R&D intensity is expected to be associated with more non-routine labor and computers to be more complementary to labor in this case. The number of industries in our categories is relatively balanced (80 low-

[17] The classification by Hatzichronoglou (1997) relies on R&D intensity measures using the OECD ANBERD, STAN, Input-Output and BILAT databases for 1980 and 1990.

[18] The only exception is "publishing" within "wood, pulp, paper products, printing, publishing" which is excluded from manufacturing.

[19] "High" tech industries apart from IT-producing industries correspond to "aircraft and spacecraft" and "pharmaceuticals".

tech industries vs. 130 mid/high-tech industries), and focusing on two categories provides parsimony and statistical power.

Services include wholesale, hotels and restaurants, transport and communication, business services and personal services.[20] In particular, business services are made up by major activities where computers can be expected to be used extensively, with consultancy related to IT, research and development on natural sciences and engineering, management consultancy, real estate, renting of equipments, advertising and legal activities for instance. This set of service industries also allows to abstract from industries where the public sector is present, such as for education or health, where the measure of productivity through sales would be inappropriate.

Total employment is split into two categories gathering high- and low-skilled workers. They are intended to reflect discrepancies in the routine nature of their work, to be sufficiently homogeneous with respect to their potential exposure to computers, and to form a balanced partition (Table 2). High-skilled encompass social and occupational groups (SOG) 2, 3 and 4, that is "craftsmen, shopkeepers and heads of businesses", "higher managerial and intellectual occupations" and "mid-level occupations". In manufacturing, this category amounts to 38.9 percent of total employment (in full time equivalent). Then, the second category, low-skilled workers, is made up by 1-digit SOG codes 5 and 6, or "employees" and "workers", It corresponds to 59.6 percent of total employment in manufacturing.[21]

3 Main estimations

From these data, between 1994 and 2007, and omitting IT-producers, 2-digit divisions with the highest labor productivity gains are not necessarily those with the highest computer intensity at first glance (Figure 1). With a similar computer intensity around 4 percent, textiles (17), transports (34) and furnitures (36) had quite different productivity gains at 12, 24 and 15 percent respectively. The wearing apparel division (18) reached productivity gains equivalent to transports (34) at around 23 percent while its computer intensity is twice higher at 9 percent. Employment is not correlated with computer intensity also. For

[20] These sectors correspond to NACE 2-digit codes 50/52, 55, 60/64, 65/67, 70/74 and 90-92/93. Sector related to public services are excluded: public administration and defense (75), education (80), health (85), activities of membership organizations (92).

[21] We rely on the assumption that the share of routine tasks is on average significantly higher in occupations requiring lower qualifications.

Table 2 – Classification of social and occupational groups (SOG) into general categories

SOG	description	share	grp	PCS	description	share	grp
21	Small business owners and w.	0.0	*high*	47	Technicians	10.6	*high*
22	Shopkeepers	0.0	*high*	48	Supervisors and foremen	4.2	*high*
23	Heads of businesses	0.6	*high*	52	Public service employees	0.0	*low*
31	Liberal professions	0.0	*high*	53	Security workers	0.2	*low*
33	Top public managers	0.0	*high*	54	Office workers	5.9	*low*
34	Scientific & educational prof.	0.1	*high*	55	Retail workers	1.1	*low*
35	Creative professionals	0.8	*high*	56	Personal service workers	0.2	*low*
37	Top managers and prof.	5.5	*high*	62	Skilled industrial workers	30.2	*low*
38	Technical managers and eng.	9.9	*high*	63	Skilled manual laborers	2.4	*low*
42	Teachers	0.1	*high*	64	Drivers	1.2	*low*
43	Mid-level health professionals	0.2	*high*	65	Transport & wholesale work.	3.2	*low*
45	Mid-level office public emp.	0.0	*high*	67	Unskilled industrial workers	14.7	*low*
46	Mid-level managers and prof.	7.4	*high*	68	Unskilled manual laborers	1.0	*low*

Source: DADS. Note: Shares are proportions of the SOG into total manufacturing employment in 2007.

instance, employment can drastically fall in textiles (17) but remain stable for chemical (24), although computer intensity is similar at 3 percent. To get a sharper view in what follows, estimations use the 4-digit industry level and distinguish between different technological levels and employment categories as outlined above.

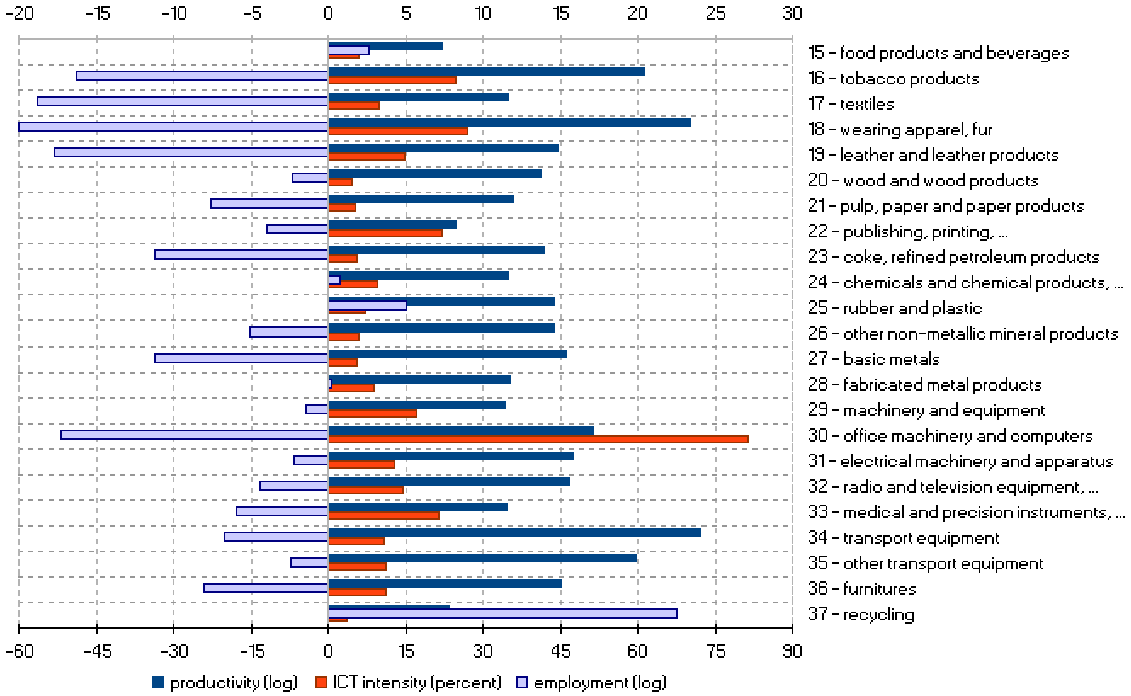
To estimate the relationship between labor productivity or employment and computer intensity, our main specification is similar to Acemoglu et al. (2014) and follows:

$$\log Y_{jt} = \gamma_j + \delta_t + \sum_{t'=1994}^{2007} \beta_{t'} \mathbb{1}_{t'=t} IT_j + \epsilon_{jt}, \tag{8}$$

where j stands for industry, t for year, Y_{jt} is the dependent variable (labor productivity, production or employment); γ_j and δ_t are industry and year fixed effects; IT_j is the average computer intensity in industry j between 1994 and 2007; the coefficients $\beta_{t'}$ are the elasticities related to IT intensity and ϵ_{jt} are residuals.[22] In this specification, labor productivity is assumed to depend on a static measure of computer intensity, with elasticities varying over time to gain insight on long-term trends in a context of progressive IT diffusion. β_{1994} is normalized to 0 so that $\beta_{t'}$ for $t' > 1994$ have to be interpreted as differences to the effect in 1994. This approach proved robust to alternative time windows in Acemoglu et al. (2014), and the average computer intensity can be seen as a smoothed measure of long-term industry behavior.

[22] While the model presented outcomes induced by ICT price shocks, this empirical strategy directly relies on ICT intensity at the industry level, which is assumed to reflect both ICT importance in industries' production technologies and ICT overall rising affordability across decades. The model does not include capital which makes impossible to exactly associate IT_j to any corresponding ratio. Yet, IT_j should be thought as including computers for routine tasks H_r and non routine ones H_n.

Figure 1 – IT intensity and evolutions of productivity and employment, 1994-2007



Note : Manufacturing industries are considered at the 2-digit level using NACE codes between 15 (food) to 37 (recycling). Productivity and IT intensity values correspond to the upper scale while employment to the lower one.

Concentrating on IT-using industries might shed light on productivity evolutions in France. As in the United States, labor productivity gains in France seemed to slow down between 2005 and 2009 compared to the 1995-2005 period, with a major contribution of IT-using sectors within manufacturing and services (Sode, 2016). In addition, between 1987 and 1998, the contribution of IT capital accumulation on growth was substantial, at 0.7 point for a mean growth of 2.3%, but was mostly concentrated in IT-producing industries (0.4 point) and in services for IT-using ones[23] (0.3 point) (Crépon and Heckel, 2000).

First, we estimate Equation (8) for the manufacturing sector with and without IT-producing industries, and compare France and the United States using a methodology identical to Acemoglu et al. (2014) for the later. The aim is to test whether IT related labor productivity gains in manufacturing are mostly driven by IT-producers in France as in the United States and whether some return of the Solow paradox could be seen for French IT-

[23]In services, the corresponding IT-using industries are wholesale, retail trade, business services and rental and leasing services.

using industries also.

Figure 2 plots the elasticities $\beta_{t'}$ through time t' and the corresponding confidence intervals at the 5 percent level. Here, computer intensity is related to significant labor productivity gains for the whole manufacturing sector in France in the late 2000s (Panel *a*, left). For the United States, we replicate the strong and significant effects by Acemoglu et al. (2014) (Panel *b*, left). When excluding IT-producers in France, the outcomes are similar but are less clear-cut. The elasticities either for labor productivity or employment have the same small order of magnitude but become significant at the 5 percent level in the late 2000s (Panel *a*, right). This contrasts with the United States for which no more labor productivity gains are identified and coefficients are closer to zero (Panel *b*, right). Yet, employment also declines with higher computer intensity in the United States.

This comparison might first illustrate the lower weight of IT-producers in the French economy, while the high-tech sector, including GAFAs (Google, Apple, Facebook, Amazon,...), dramatically rose in the United States. Indeed, the market value of new technological leaders created in France represents only 6 percent of the European total[24], as there is in France a high rate of start-up creation but scarce situations of substantial firm growth (France Stratégie, 2016). Second, without IT-producers, there are slightly significant labor productivity gains in France contrary to the United States. To a small extent, this stands in contrast with the results by Acemoglu et al. (2014) suggesting a potential return of the Solow paradox. For France, the puzzle consists in little rather than no labor productivity gains out of computerization. To understand these differences, we now delve into similar analyses disaggregating the IT-using manufacturing sector.

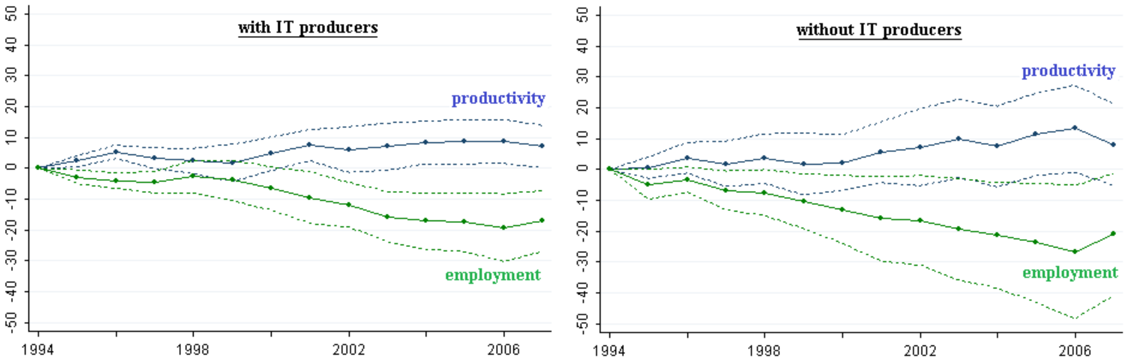
The relations between IT intensity and labor productivity previously observed may reflect heterogeneities among different categories of industries, as it has been illustrated by excluding IT-producing ones. Yet, industries also differ with respect to their production technology, and computers may not bring about identical labor productivity gains whether an industry mainly relies on routine tasks likely to be automated or on non-routine ones, notably when R&D is prominent (see Section 1). Here, we distinguish between low-techs (food, textile, furnitures,...) and mid/high techs (chemicals, machinery, transports,...) (see Section 2).

Equation (8) is separately estimated for low-tech and mid/high tech industry categories.

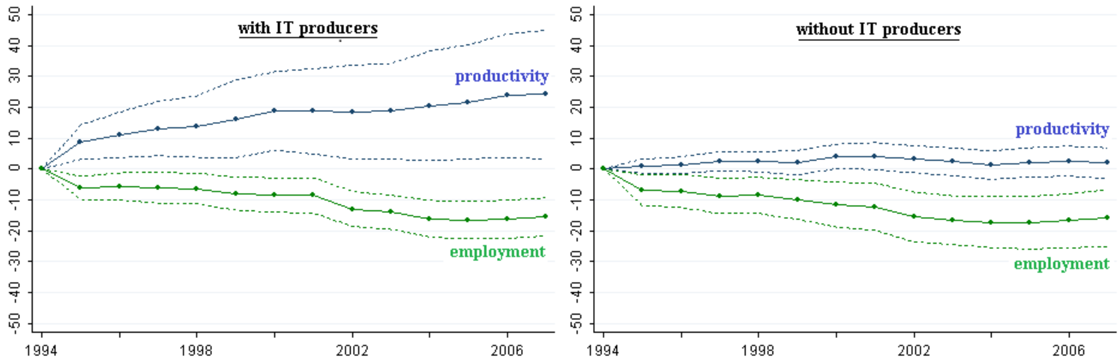
[24]Compared to 38 percent for the United Kingdom, 25 percent for Sweden and 17 percent for Germany (France Stratégie, 2016).

Figure 2 – IT intensity and labor productivity/employment in manufacturing industries including IT producers (left) or excluding them (right)

(a) in France



(b) in the United States

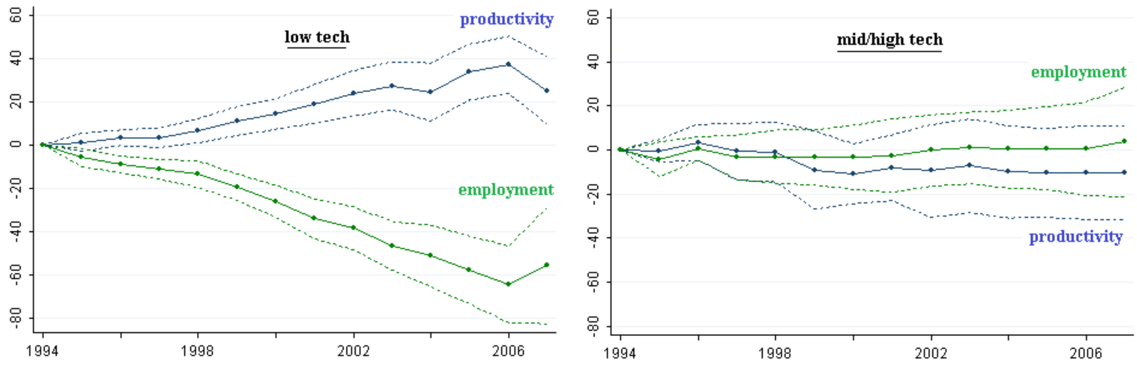


Note: Doted lines correspond to confidence intervals at the 5 percent level. Each point corresponds to a coefficient $\beta_{t'}$ for a specific year t'. For the United States, $n = 387$ manufacturing industries ($n = 359$ when excluding IT-producing ones). For France, $n = 228$ manufacturing industries ($n = 218$ when excluding IT-producing ones). Regressions are weighted by mean employment shares. Standard errors are clustered by industry.

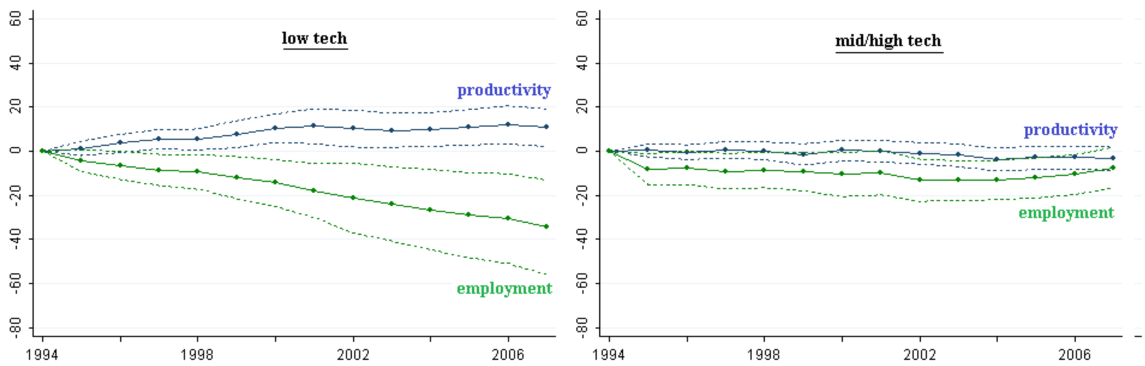
The samples are relatively balanced, as they include 96 and 150 observations each year respectively. In France, low-tech and mid/high-tech industries display sharply distinct behaviors. The most stringent pattern is the strong employment drop for low-tech industries with higher computer intensity (Figure 3, Panel *a*, left). On the contrary, mid/high-tech industries do not seem exposed to such massive computer related employment drops (Panel *a*, right). Labor productivity gains related to computerization are even stronger in low-tech industries than those previously obtained for the whole U.S. manufacturing including IT-producers. To test whether this divide is not specific to France, we replicate the same approach for the United States, following the correspondence between the 2-digit division labels in both countries (see Section 2). In the end, the patterns are exactly identical to those observed for France (Panel b), indicating that common drivers may be at stake.

Figure 3 – IT intensity and employment
in low-tech industries (left) and mid-tech ones (right)

(a) in France



(b) in the United States



Note: Doted lines correspond to confidence intervals at the 5 percent level. Each point corresponds to a coefficient $\beta_{t'}$ for a specific year t'. Over the whole time period, for France (resp. for the United States), the number of low-tech manufacturing industries is 96 (resp. 150) while there are 122 (resp. 209) mid/high-tech ones.

For low-tech industries, labor productivity gains through substantial IT related labor cuts are consistent with computers allowing for an automation process reducing the use of routine labor. For mid/high tech industries, our results confirm the possibility of a return of the Solow paradox as underlined by Acemoglu et al. (2014) and refine it to these specific industries. For them, computers might be used for other purposes than automation, and these alternative uses might imply a compensating impact in terms of employment. As these industries are more R&D intensive, these alternative uses might involve more non routine work by high skilled workers. To shed light on this hypothesis, we next derive the same econometric approach for employment in different skill groups.

4 Extensions

In this Section, we provide additional results allowing to depict computer-related employment dynamics in manufacturing in terms of skill groups, and in comparison to services. First, the absence of effects of IT intensity among mid/high tech industries could be the outcome of distinct and opposite employment effects for different categories. Indeed, Table 3 displays that between 1994 and 2007, employment in manufacturing increased for all high-skilled 1-digit groups (craftsmen, shopkeepers and heads of businesses; higher managerial and intellectual occupations; and mid-level occupations) while it declined to a large extent for low-skilled ones (employees; and workers). Computerization since the late 1990s might have contributed to these different trends, and in particular the one affecting more qualified categories. Second, we extend the analysis to services to put our results on mid/high tech industries into perspective. Indeed, general employment evolutions differ between manufacturing and services: all declining SOG within manufacturing rose in services between 1994 and 2007.[25]

Table 3 – Evolutions of main SOG categories in manufacturing and services, full time equivalent jobs, 1994-2007

		manufacturing			*services*		
PCS	**description**	**1994**	**2007**		**1994**	**2007**	
2	Craftsmen, shopkeepers and heads of businesses	17 729	17 927	≃	49 619	56 187	≃
3	Higher managerial and intellectual occupations	305 434	455 368	↑	561 454	1 220 060	↑
4	Mid-level occupations	654 296	660 729	≃	1 042 371	1 629 835	↑
5	Employees	313 407	200 257	↓	1 218 221	1 716 317	↑
6	Workers	1 820 172	1 570 193	↓	1 186 071	1 806 336	↑

Source: *Déclarations Annuelles de Données Sociales.*

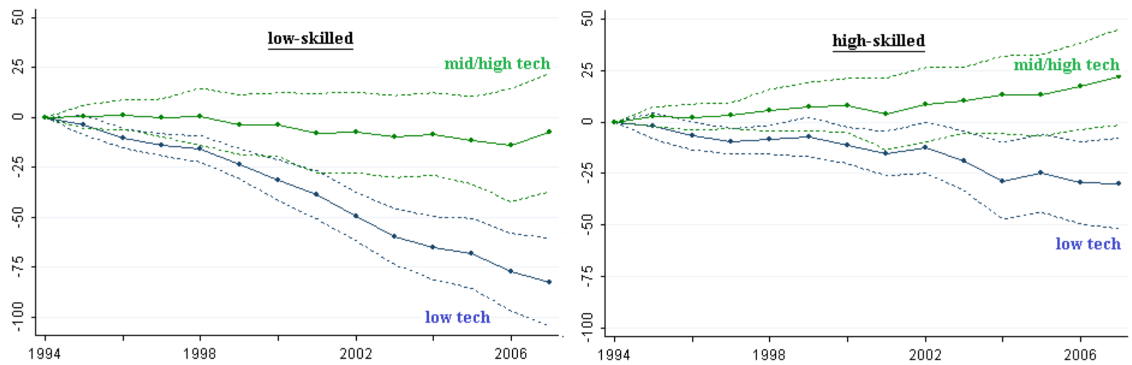
We estimate Equation (8) using the employment levels of high-skilled and low-skilled workers, and also their ratio as an alternative explained variable (see Section 2 for the composition of these categories). Figure 4 shows that results for total employment are the sum of differing evolutions for various categories. Among low-tech industries, computerization is associated with labor cuts concentrated among low-skilled but affecting also high-skilled to a lower extent. Among mid/high tech industries, the effects of computerization are not significant for low-skilled and positive and almost significant for high skilled. This picture is

[25]Relatedly, Spieza et al. (2016) show that, between 1996 and 2011 among OECD countries, while the employment share of manufacturing declined by 5 points, it rose in business services by 4 points.

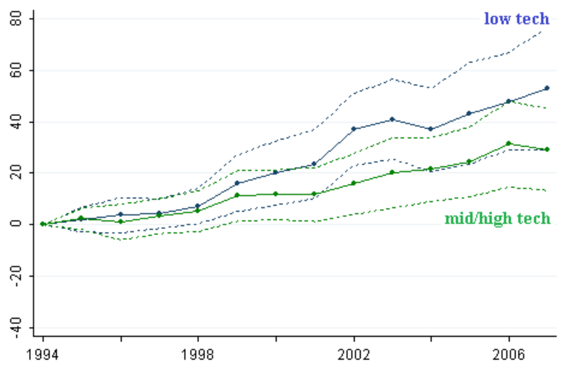
blurred in levels, but the impact of computer use on the ratio between these two categories is unambiguous over the whole time period and got stronger and stronger: computer-intensive industries relied more and more on high-skilled compared to low-skilled, both among low-tech and among mid/high tech industries. Yet, behind this common trend, the patterns in terms of levels suggest that substitution may intervene more among low tech industries, while complementarity might dominate among mid/high tech ones.

Figure 4 – IT intensity and employment in manufacturing
with respect to technological level and employment categories

(a) levels for high- and low skilled workers



(b) high- over low-skilled employment ratio

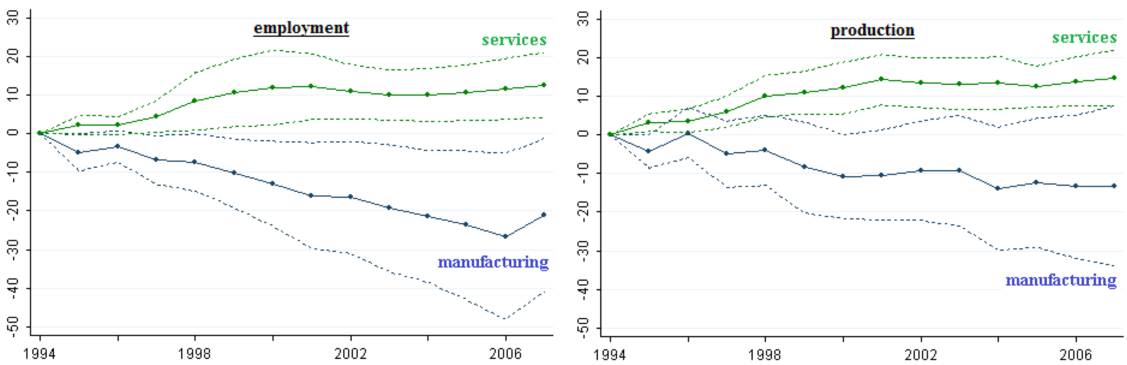


Note: Doted lines correspond to confidence intervals at the 5 percent level. Each point corresponds to a coefficient $\beta_{t'}$ for a specific year t'. Over the whole time period, for France (resp. for the United States), the number of low-tech manufacturing industries is 96 (resp. 150) while there are 122 (resp. 209) mid/high-tech ones.

In the previous Section, computerization had no labor productivity enhancing effect among mid/high tech industries. Here, we show that higher computer intensity is associated with a rise in the share of high-skilled workers. Both results are not incompatible in view of the simple mechanisms presented in Section 1: a drop in the computer price might lead to a rise in non routine work and to a labor enrichment of production. We let an extended analysis of this conjecture for further work, while many other factors[26] outside this model might also intervene within these industries, and notably outsourcing.[27]

Similar exercises are carried out beyond the manufacturing sector in order to put the corresponding results into a broader perspective. Beforehand, Equation (8) is estimated for productivity in services. No significant effects are observed (unreported). Figure 5 displays the coefficients of Equation (8) using the productivity components, employment and production, as the explained variables. The dynamics of both of them are significant, and the signs of elasticities are opposite to those observed within IT-using manufacturing: positive for both in services, negative for both in manufacturing. This symmetry could be rationalized by outsourcing, computers providing means both to benefit from external business services and to supply them.

Figure 5 – IT intensity and employment and production
in IT-using manufacturing and service industries



Note: Doted lines correspond to confidence intervals at the 5 percent level. Each point corresponds to a coefficient $\beta_{t'}$ for a specific year t'. For manufacturing (resp. services), the number of IT-using industries is 218 (resp. 70).

In the end, our last results indicate that computerization was associated to workforce reallocation over a long time span in France. They also broaden the perspective provided by

[26]This simple theoretical framework abstracts from considerations relating IT use (i) to competition and concentration within an industry, (ii) to innovation types (process or products) affecting quantity or quality improvements, (iii) to wage differentials between high- and low-skilled workers, and (iv) to rising outsourcing, that could all affect production levels and costs at the firm and industry scales.

[27]Between 1970 and 2013 in the manufacturing sector, intermediate consumptions of services rose twice as rapidly as total intermediate consumptions (Rignols, 2016). This phenomenon also explains why regulations in services, and more generally in non-manufacturing "upstream" industries, can influence productivity in manufacturing (Cette, Lopez, and Mairesse, 2013).

similar estimates for low-tech and mid/high-tech industries, in the sense that computerization may destroy jobs in specific sectors while having neutral or positive effects in other parts of the economy.

Conclusion

This work employs a methodology between the micro- and macroeconomic scales at the industry and skill levels. It suggests heterogeneities of computerization effects among industries with respect to their situation as producer or user of IT, their technological level, their intensity in various task types, and their position within the manufacturing or services sector: in France, IT-producers marginally weight on aggregate estimates; in both France and the United States, low-tech industries experience tremendous labor savings associated with computerization ; in France, in mid/high-tech manufacturing industries and services display signs of labor enrichment of production as computer investment rises. All our results suggest that computerization seems to foster economy-wide structural changes, with strong labor productivity improvements in declining industries and labor enrichment in rising ones. Further works could consist in analyzing wages for the industry and employment categories underlined in this paper: it would allow for developing a targeted analysis of polarization in France; it may also provide necessary empirical reference to structurally interpret our elasticities of labor demands in particular. Finally, preliminary estimates without clustered standard errors and using a sample of surviving firms indicate our results by technologies and skills hold true at the firm level also and might deserve further developments. Further work may also consist in exploring whether ICT use in mid/high-tech sectors could be associated to market power gains. This way, a somehow offensive ICT use could be distinguished from a defensive one oriented towards productivity improvements.

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Appendix

Case with a single task.

Here, a model with a single task is developed in order to obtain similar productivity expressions as for the polar cases in the theoretical section. In this context, the algebra is much simpler. The production function follows

$$Q = \left[\theta^{\frac{1}{\sigma}} C^{\frac{\sigma-1}{\sigma}} + (1-\theta)^{\frac{1}{\sigma}} H^{\frac{\sigma-1}{\sigma}}\right]^{\alpha\frac{\sigma}{\sigma-1}}$$

and let be X such that $Q = X^{\alpha\frac{\sigma}{\sigma-1}}$. The first order conditions are given by:

$$w = \alpha(1-\theta)^{\frac{1}{\sigma}} H^{-\frac{1}{\sigma}} X^{\alpha\frac{\sigma}{\sigma-1}-1}$$
$$\text{and } p = \alpha\theta^{\frac{1}{\sigma}} C^{-\frac{1}{\sigma}} X^{\alpha\frac{\sigma}{\sigma-1}-1}$$

Rearranging these equations, the demands for labor and computers are then such that:

$$H = \tfrac{(1-\theta)\alpha^{\sigma}}{w^{\sigma}} X^{\sigma\alpha\frac{\sigma}{\sigma-1}-\sigma}$$
$$\text{and } C = \tfrac{\theta\alpha^{\sigma}}{p^{\sigma}} X^{\sigma\alpha\frac{\sigma}{\sigma-1}-\sigma}$$

Using these expressions for production factors H and C within Q, X is determined as a function of the exogenous production paramaters and factor prices. Indeed:

$$X^{\sigma(\alpha-1)} = \alpha^{1-\sigma}\Lambda^{\sigma-1},$$
$$\text{where } \Lambda = \left[\theta p^{1-\sigma} + (1-\theta) w^{1-\sigma}\right]^{1/(1-\sigma)}$$

Finally, as both Q and H only depends on the endogenous variable X, labor productivity Q/H has the following simple closed-form formula:

$$Q/H = \tfrac{1}{1-\theta}\tfrac{1}{\alpha} w^{\sigma}\Lambda^{1-\sigma} \text{ (A1)}$$

Case with a positive mark-up also.

Previously, the production price was exogenous and set at one. The corresponding results actually can be extended to the case were the firm set this price with a small positive mark-up.

Let us now consider NQ rather than Q as sales, where N is the production price. And assume that $N = Q^{-\nu}$ (this form can be microfunded with Dixit-Stiglitz preferences where ν is the elasticity demand for each good, as used by Autor et al., 2003).

The same steps as in the previous case can be used and the intermediary results are marginally affected. The first order conditions and the equation determining X are slightly modified:

$$H = \tfrac{(1-\theta)\tilde{\alpha}^{\sigma}}{w^{\sigma}} X^{\sigma\tilde{\alpha}\frac{\sigma}{\sigma-1}-\sigma}$$
$$X^{\sigma(\tilde{\alpha}-1)} = \tilde{\alpha}^{1-\sigma}\Lambda^{\sigma-1}$$
$$\text{where } \tilde{\alpha} = \alpha(1-\nu)$$

The mark-up ν exactly intervenes as if the coefficient α became $\alpha(1-\nu)$. The consecutive results are thus identical to the ones in the previous case so that nominal labor productivity NQ/H follows Equation (A1) with $\tilde{\alpha}$ rather than α.

Labor productivity now depends on the markup, but can be written as previously with additional multiplicative terms:

$$Q/H = \tfrac{1}{1-\theta}\tfrac{1}{\tilde{\alpha}} w^{\sigma}\Lambda^{1-\sigma} N^{-1}$$
$$\text{where } N = \tilde{\alpha}^{-\mu}\Lambda^{\mu} \text{ and } \mu = -\tfrac{\alpha\nu\sigma}{\sigma(\tilde{\alpha}-1)}.$$