Competition, technological change and productivity gains: a sectoral analysis

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Abstract

This paper addresses the empirical relationship between the level of competition and the rate of productivity growth across thirty sectors of the French production system during the period 1978-2015. It shows that there exists an optimal level of competition for each sector that is defined by the mark-up that maximizes the growth rate of labor productivity. The persistence of nonoptimal mark-ups in French sectors is associated with a 0.4% loss in aggregate average annual labor productivity growth during the period (1.86%). Hence, long-term productivity growth could have reached 2.25% if mark-ups had been at their optimal level. There is a strong significant positive correlation between the optimal mark-up and the rate of Hicks-neutral technical progress in each sector. This finding implies that sectors with high technical progress require higher mark-ups to maximize their rate of labor productivity growth. Overall, the aggregate economy would benefit from a decrease in the gap between nonoptimal and optimal mark-ups, as such an alignment would foster productivity growth.

Key Words: *Technical progress; productivity growth; mark-up*

JEL Classification: O11, O31, O47, L16

1 Introduction

This paper shows that the optimal mark-ups, namely, the mark-ups that maximize the growth of labor productivity in each sector of the French economy are strongly correlated with the sector rate of technical progress. Thus, a long-term disconnect between observed sector mark-ups and their optimal levels is detrimental to aggregate labor productivity growth. Hence, sectors that have higher rates of technical progress will have higher optimal mark-ups, meaning that such sectors will necessitate sufficiently high mark-ups in order to maximize their labor productivity growth.

To observe the correlation between technical progress and optimal mark-ups, and hence the long-term productivity growth that has been lost due to a permanent disconnect between observed mark-ups and

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optimal mark-ups, it is first necessary to estimate the actual level of mark-ups in each sector. Their optimal levels can then be calculated. Such a calculation is based on the estimated inverted U-shaped relationship between the rate of labor productivity growth and the mark-ups levels in each sector of the French economy.

Recent theoretical investigation has produced some evidence that the relationship between competition intensity and innovation is not linear but depends on the characteristics of markets and sectors. Hence, an increase in the level of competition in a given market can lead to diverging and opposite effects on the profit incentives to innovate, according to, notably, the initial level of competition, the characteristics of the sector in terms of production technologies, the sector's rate of innovation, the distance of firms to the technical frontier. In line with this prediction, this paper provides an empirical investigation of the relationship between the rate of hourly labor productivity growth and the intensity of competition in the French production system over the period 1978-2015, with the aim of showing that a disconnect between observed and optimal sector mark-ups weakens the rate of long-term aggregate productivity growth. The intensity of competition is captured by the mark-up over perfectly competitive prices in a sample of 30 French sectors. The objectives of this research are to obtain empirical insights into the following: first, whether the sector mark-ups and the growth of hourly labor productivity have a nonlinear relationship; second, whether there exists a threshold sector mark-up beyond which further increases in the level of competition would discourage investment and innovation, thus resulting in negative effects on the growth of hourly labor productivity.

The empirical results show that the mark-up threshold depends on the sector, and, more precisely, on the rate of technical progress in each sector. As a result, the higher the rate of technical progress, the higher the optimal mark-up. The rationale is that some sectors are more conducive to technical progress than others. Sectors with many opportunities for technical progress will require more investment and, as a result, higher mark-ups than will other sectors.

2 Literature review

The relationship between the intensity of competition and the rate of technical progress has been investigated in both theoretical and the empirical economic literature. The theoretical literature has so far evidenced the complexity and variety of the interrelations among market structure, competition, incentives to innovate and the results of investments on innovation. This body of evidence has led to the common view that market competition is not always a systematic driver of innovation or the related rate of productivity growth. Contrary to the view that any increase in the intensity of competition in a market will invariably lead to an improvement in efficiency and to the strengthening of incentives to innovate, a recent body of microeconomic literature suggests that the level of competition intensity and the economic incentives to invest in the production of innovation are interrelated in an ambiguous manner.

The theoretical relationship between the level of competition in a market and the rate of innovation has long been investigated in the microeconomic literature. Between the view that incentives to innovate depend on monopoly power because sufficient expected profits are crucial drivers of investment Schumpeter (1942), and the claim that innovations are essentially driven by competition Arrow (1962), a more recent strand of literature has produced new empirical evidence that beyond a certain level of competition intensity, incentives to innovate tend to decrease, meaning that a profit margin above the competitive price is needed to foster investment in innovation.

According to the seminal contribution of Aghion *et al.* (2005), the general cross-sector relationship between the "Schumpeter effect" and Arrow's "escape from competition" effect appears to follow nonlinear pattern. The empirical relationship between competition intensity measured as the Lerner index (i.e., the mark-up over the competitive price) and innovation measured as the number of patents follows an inverted U-shaped curve, meaning that any increase in competition above a certain defined level would slow the pace of innovation. In a market where the level of technology is unevenly distributed across firms, the incentives to invest in innovation are hindered above a threshold level of competition intensity. For Aghion *et al.* (2005), in such an area of competition intensity, laggard firms (the firms that are less able to innovate and generate productivity gains) are discouraged from investing in innovation, because post-innovation rents and the likelihood of catching-up with the leading innovators are reduced. As a result, a public policy that aims to foster innovation should consider the characteristics of sectors as regards the distribution of technology levels.

The study of the relationship between the rate of technical progress and the profitability of innovators has generally been focused on the profits that investments in R&D can generate. Other studies following Aghion *et al.* (2005)Aghion have provided further empirical evidence of an existing trade-off between competition intensity and endogenous innovation. Among the empirical findings, Askenazy *et al.* (2013) use a panel of French firms and find an inverted U-shaped relationship between competition (the Lerner index) and the R&D intensity of large firms with relatively low innovation costs (namely, the cost of R&D over the firm's value added). As the relative cost of R&D increases, the nonlinear relationship weakens, meaning that the impact of competition intensity on firms' decisions to invest in R&D is decreasing and vanishes for high relative costs of R&D. Public policy should then take into account the nature of innovations and their cost relative to the size of the firms. Moreover, for Schmutzler (2013), competition intensity can also influence investments that reduce production costs, according to such parameters as the preexisting level of competition and the initial level of productive efficiency, and the cost-reducing spillovers arising across firms. While an increase in the competition intensity will more likely have a positive effect on firms with higher initial productive efficiency (i.e., those with lower marginal costs), the interplay among such parameters leads to an overall ambiguous and context-sensitive effect of competition on innovation conceptualized as investment in cost-reducing technology.

A general theoretical result suggests that the relationship between the level of competition and the rate of innovation is nonmonotonic and nonunique Belleflamme & Vergari (2011). Such a nonlinear effect of competition on innovation implies that any public policy that aims to encourage investment in innovation should take into account the trade-off between static efficiency, achieved through decreases in mark-ups and dynamic efficiency supported by improvements in quality attributable to investments in innovation. Unambiguous empirical evidence of a nonlinear relationship between competition and investment in innovation has been provided by Houngbonon & Jeanjean (2016) using a large panel of national markets. The authors provide firm-level evidence of a trade-off between the Lerner index and the level of investment in the wireless telecommunications sector. The empirical results show that the level of capital expenditures in mobile networks and services deployment begins to decrease when the competition intensity exceeds an optimal level, which is defined by a sector-wide profit-margin ratio. In addition, Jeanjean (2015) finds empirical evidence that in the wireless telecommunications sector, the observed declining trend in the unit prices of data mobile services is essentially driven by investments in technology rather than by price competition or cost-reducing policies. The trend in productivity growth, captured as the rate of unit price decline, is driven by the contributions of dynamic effects (related to investment in technology), whereas the contributions of static effects (related to price competition and/or cost reduction) are limited. This study highlights that expected profit margins motivate investments in technology that drive declines in the retail unit prices over time. As competition and investment exhibit an inverted U-shaped relationship, increasing competition intensity above the optimal level might hinder investment. Hence, the rate of technical progress would decrease, which weakens the trend of unit price decline. From this result, it appears that a technology-intensive sector has to rely on sufficiently high profit margins to support investment in order to achieve continuous productivity gains. Our approach is similar to that of Bouis & Klein (2009), who studies the effect of competition intensity on labor productivity gains in a range of sectors using a panel of OECD countries. Competition is captured by sector mark-ups that are derived from the econometric estimation described by Roeger (1995) based on dual Solow residuals. The authors obtained an inverted U-shaped relationship between competition and productivity growth. They find that increasing competition (reducing mark-ups over competitive prices) only raises productivity in sectors where the level of competition is low, with no significant effect on competitive sectors. In addition, the effect of competition varies across sectors according to their cost specificity. Business services, which have lower sunk costs and less competition than manufacturing sectors, would benefit from an increase in competition;in contrast, manufacturing sectors do not experience improved productivity because of higher sunk cost and more intense competition.

More recently, Calligaris *et al.* (n.d.) use a panel of twenty-six OECD countries, over the period 2001-2014, to show that mark-ups tended to increase, on average, over the period and that mark-ups in digitally intensive sectors have been higher than mark-ups in less digitally intensive sectors. In addition, the difference between the mark-ups in digitally intensive sectors and those in less digitally intensive sectors have been increasing over the period. However, the study does not empirically identify possible factors underlying the tendency of mark-ups to increase or the differentials between sectors with higher and lower intensities in digital assets. The study does indicate potential sources for these trends, including the returns on intangible assets and network effects at the sector level. The purpose of the present paper is to provide evidence that rising levels of mark-ups in a sector are attributable to increased productivity and greater technical progress, which appears to be the case in sectors that intensively use digital technologies and assets.

3 The sample

The economic information necessary to carry out the estimations of sector mark-ups and sector productivity growth are retrieved from the OECD database for structural analysis (STAN database) and based on the 2008 national accounts system. The scope of the study is to estimate the relationship between competition and productivity across thirty sectors of the French production system, covering manufacturing, energy, construction, market services and public administration over the period 1978-2015. A table of the thirty sectors is presented in appendix 4. In addition, the price deflator for gross fixed capital formation for the French economy and the real long-term interest rate, which are used to compute the cost of capital, are retrieved from the AMECO macroeconomic database of the European Commission. The following variables are used to compute both sector mark-ups and sector hourly productivity:

PROD: Production (gross output) at current prices;

CPGK: Gross capital stock, volume, expressed in current prices for the reference year 2010;

EMPN: Total employment, measured as the number of persons engaged;

EMPE: Number of employees;

LABR: Labor compensation of employees at current prices;

VALU: Value added at current prices;

VALK: Value added, volume, expressed in current prices for the reference year 2010;

PIGT: Price deflator for gross fixed capital formation for the total economy in the reference year: 2010=100;

ILRV: Real long-term interest rate, GDP deflator.

4 Empirical evidence

This section provides empirical evidence that the relationship between the level of mark-up and the rate of hourly productivity growth depends on each sector and that this relationship can be represented as an inverted U-shaped curve. Moreover, it is shown that the optimal sector mark-ups are increasing with the growth rate of technical progress. To provide evidence of an inverted U-shaped relationship between competition and labor productivity, the mark-ups are estimated according to the methodology developed by Roeger (1995) and detailed in appendix 1. The mark-ups are estimated for each of the thirty sectors of the French economy for seven defined periods with an average duration of five years, which provides 210 estimated mark-ups. Seven periods are considered for the estimation: Period 1 (1978-1984); Period 2 (1985-1989); Period 3 (1990-1994); Period 4 (1995-1999); Period 5 (2000-2004); Period 6 (2005-2009); and Period 7 (2010-2015). The duration of each period was based on a trade-off between the accuracy of the mark-up estimations and the number of periods that provides more observations. Indeed, longer periods improve the accuracy of the mark-up estimations; however they reduce the number of observations. Thus, the compound annual growth rate of hourly labor productivity is computed for each of the 7 periods. The computation is detailed in appendix 2.

4.1 Empirical strategy

This section aims to characterize the relationship between mark-ups and hourly productivity growth. First, following Bouis & Klein (2009), we test a general quadratic relationship for all sectors. We find that this relationship does not hold for all sectors; however, it holds for some sectors that have relatively homogeneous mark-ups. This finding suggests that the relationship may depend on the sector. Hence, we try an inverted U-shaped specification in which the parameters depend on the sectors, and we find that this relationship is significant. This allows the calculation of the mark-up that maximizes the inverted U for each sector. Furthermore, we calculate the average level of Hicks-neutral technical progress for each sector, as described in appendix 3. We find that the optimal mark-ups are strongly positively correlated with technical progress. This finding suggests that greater technical progress requires a higher optimal mark-up.

Finally we use the previous results to estimate productivity growth losses due to unsuitable mark-ups.

4.2 Relationship between mark-ups and hourly labor productivity growth

First, the general relationship between mark-ups and variations in the hourly labor productivity growth rate of sectors is examined. Figure1 below provides a scatter-plot of the compound annual growth rate of hourly labor productivity and the mark-ups for sectors over the seven periods running from 1978 to 2015. Each point on the figure represents a sector observed during a specific period.

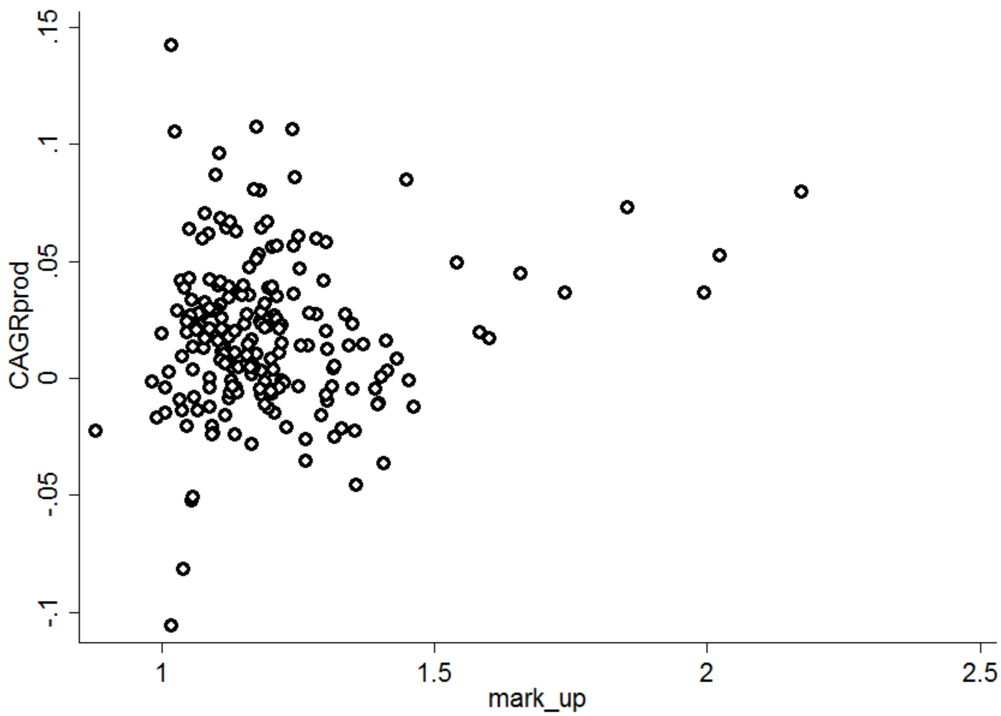

Figure 1: **Hourly productivity growth and mark-ups**

At a first glance, this figure fails to provide a obvious or robust result regarding the link between competition and productivity growth. However, by removing the sectors with the highest mark-up from the graph, it is possible to see that an inverted U-shaped relationship characterizes the effect of mark-ups on the rate of hourly labor productivity growth, as shown in figure2. Both graphic representations of the relationship between competition and labor productivity growth suggest, as previously noticed by Bouis & Klein (2008), that such a relationship is expected to vary across sectors and that sectors with higher levels of mark-ups may indeed behave differently than those with lower levels of mark-up. Hence, mark-ups over competitive prices or marginal costs could be related to specific sector characteristics, meaning that higher mark-ups do not necessary imply higher static monopoly rents. Figure 2 below provides a scatter-plot of the compound annual growth rates of hourly labor productivity and the mark-ups, with the two sectors with the highest mark-ups removed.

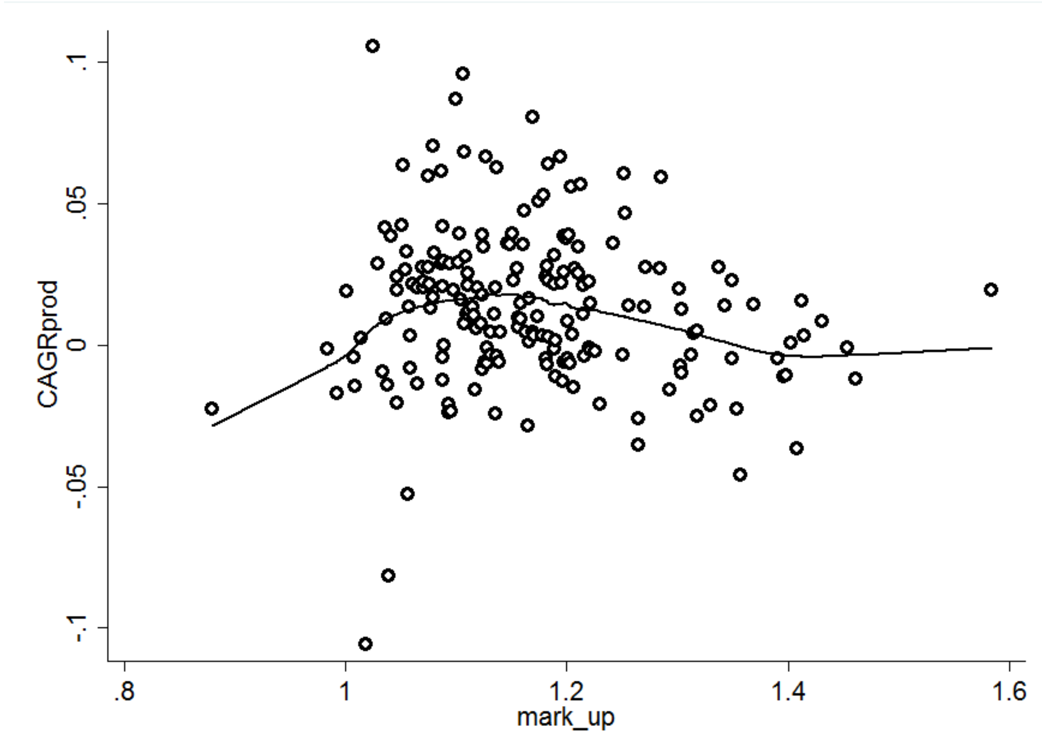

Figure 2: **Hourly productivity growth and mark-up, excluding sectors with the highest mark-ups**

In figure 2, both sector D61 (telecommunications services) and sector D35 (electricity, gas, steam and air conditioning supply) have been removed. The curve represents a lowess smoother of the scatter plot which exhibits an inverted U shape. The aim of the regression is to test whether the relationship between the mark-up and hourly labor productivity growth can be represented as an inverted U-shaped curve. The adequacy of the relationship with an inverted U-shape is tested by estimating the following equation:

$$CAGRprod_{ip} = c + \alpha \ markup_{ip}^2 + \beta \ markup_{ip} + \lambda \ d_p + \delta \ d_i + \varepsilon_{ip} \tag{1}$$

where i denotes the sector and p the period. $mark-up_{ip}$ is the mark-up of sector i over the period p, d_p is the period fixed effect, d_i is the sector fixed effects, c, is the constant, and ε_{ip} is the error term. If the relationship is described by an inverted U-shape, then α and β are both significant with $\alpha < 0$ and $\beta > 0$. In this case, the mark-up that optimizes productivity growth is $mark - up - max = -\widehat{\beta}/2\widehat{\alpha}$. Table 1 below summarizes the results of the regression.

The regressions in columns (1) and (2) are estimated using the whole sample, while in column (3) and column (4), a restricted sample, which excludes the sectors with the highest mark-ups is used. In column (3), telecommunications services (sector D31) and energy distribution (electricity, gas, steam and air conditioning supply, sector D35) are removed; in column (4), in addition to the sectors already removed, scientific research and development (sector D72) is excluded. Column (1) provides the estimation of a linear relationship between mark-up levels and hourly labor productivity growth. Columns (2), (3), and (4) provide the results for a quadratic relationship. The estimated coefficient in column (1) is not statistically significant and does not differ significantly from a null value, which does not support a linear, decreasing relationship between sector mark-ups and productivity growth. Hence, the result invalidates a monotonic, increasing relationship between productivity and competition. The estimated coefficients in column (2) are not significant either, ruling out any unique general quadratic relationship that is valid for all sectors in the sample. However, the coefficients of column (3), which are estimated for the restricted sample (excluding the two sectors with the highest mark-ups), become significant. Moreover, when the sector with third highest mark-up is removed, the significance of the estimated coefficients in column (4) increases further. Thus the robustness of the quadratic relationship depends on the sector. When the sectors with significantly higher mark-ups are removed from sample, the remaining sectors are sufficiently similar to exhibit a similar quadratic relationship. This result is illustrated by figure 2 where the inverted U-shaped relationship is clearly visible on the graph when two sectors are removed; this is not the case in figure 1 which uses the whole sample. As expected, the optimal mark-ups tend to decrease when the sectors with the highest mark-ups are removed; they also tend to be more precisely estimated. The optimal mark-up is estimated at 1.304 for the whole sample, 1.212 for the restricted sample (without the sectors with the two highest mark-ups), and 1.181 for the most restricted sample (without the sectors with the three highest mark-ups).

Table 1: Mark-up and Hourly Labor Productivity Growth

Dependent variable: Hourly Productivity growth CAGRprod				
Specification	(1)	(2)	(3)	(4)
markup	-0.00607	0.0596	0.6415*	1.098***
	(0.0203)	(0.0886)	(0.372)	(0.369)
markup^2		-0.0228	-0.265*	-0.465***
		(0.0299)	(0.154)	(0.152)
sector fixed effects	yes	yes	yes	yes
period fixed effects	yes	yes	yes	yes
constant	0.00194	-0.0444	-0.388*	-0.641***
	(0.0286)	(0.0670)	(0.222)	(0.221)
R^2	0.495	0.497	0.451	0.461
Observations	210	210	196	189
mark-up max		1.304***	1.212***	1.181***
		(0.482)	(0.0448)	(0.0275)

Significant at 1%(***), 5%(**) and 10%(*). Robust standard errors in parentheses.

4.3 Estimation of the optimal sector mark-ups

To test whether the optimal mark-ups depend on the sector, a dummy variable is associated with the squared mark-up term, which allows the estimated coefficient to vary across sectors. The following equation is then estimated:

$$CAGRprod_{ip} = c + \alpha_i \; d_i.markup^2_{ip} + \beta \; markup_{ip} + \lambda \; d_p + \varepsilon_{ip} \tag{2}$$

In this equation, the individual (sector) fixed effects have been removed to avoid interactions with the dummy indicator. The term d_i represents the dummy indicator of sector i, β is the coefficient of the mark-up that is common the all sectors, and α_i is the coefficient of the squared mark-up specific to sector i. The optimal mark-up for sector i is then determined by the following term: $markup\_max_i = -\frac{\widehat{\beta}}{2\widehat{\alpha_i}}$. As a result, the corresponding maximum level of hourly productivity growth is $CAGRprod\_max_i = \widehat{c} - \frac{\widehat{\beta}^2}{4\widehat{\alpha_i}}$. The results of the estimation are presented in table 2 below.

Table 2: Mark-up and Hourly Labor Productivity Growth

Dependent variable Hourly productivity growth CAGRprod				
Variable	coef	std.err	$markup_{max}$	$CAPRprod_{max}$
markup	0.232**	(0.0993)		
$markup^2$				
sector:				
1	-0.106***	(0.0395)	1.097	0.0053
2	-0.104***	(0.0395)	1.114	0.0073
3	-0.0850**	(0.0397)	1.365	0.0363
4	-0.0865**	(0.0397)	1.342	0.0337
5	-0.103**	(0.0498)	1.124	0.0085
6	-0.0795**	(0.0397)	1.459	0.0473
7	-0.0864**	(0.0396)	1.344	0.0339
8	-0.0939**	(0.0395)	1.236	0.0215
9	-0.0600	(0.0401)	1.935	0.1026
10	-0.0876**	(0.0408)	1.325	0.0318
11	-0.0826**	(0.0397)	1.406	0.0411
12	-0.0839**	(0.0404)	1.384	0.0386
13	-0.0801**	(0.0397)	1.448	0.0460
14	-0.0824**	(0.0371)	1.407	0.0413
15	-0.103**	(0.0402)	1.125	0.0086
16	-0.1008***	(0.0397)	1.071	0.0023
17	-0.0974**	(0.0394)	1.192	0.0163
18	-0.0857**	(0.0401)	1.354	0.0352
19	-0.114***	(0.0394)	1.018	-0.0039
20	-0.103***	(0.0394)	1.123	0.0083
21	-0.0671*	(0.0345)	1.729	0.0786
22	-0.107***	(0.0393)	1.080	0.0033
23	-0.0942**	(0.0394)	1.232	0.0210
24	-0.111***	(0.0391)	1.045	-0.0007
25	-0.102**	(0.0389)	1.139	0.0102
26	-0.103**	(0.0398)	1.124	0.0084
27	-0.114***	(0.0392)	1.021	-0.0035
28	-0.108***	(0.0397)	1.075	0.0027
29	-0.109***	(0.0396)	1.069	0.0020
30	-0.108***	(0.0408)	1.075	0.0027
period fixed effects	yes			
sector fixed effects	no			
constant	-0.128*	(0.0674)		
R^2	0.464			
Observations	210			

Significant at 1%(***), 5%(**) and 10%(*). Robust standard errors in parentheses.

The first column of the table provides the estimated coefficients of the sector-specific squared mark-up, the second column provides the associated standard error, the third column provides the optimal mark-up for each sector calculated on the basis of the estimated mark-up coefficients, and the last column provides the annual average growth rate of maximized hourly productivity. The estimated coefficient of the mark-up is significant, and the estimated coefficients of the squared mark-up terms are also significant for all sectors, with the exception of a single sector for which the coefficient is nevertheless, close to the 10% significance threshold. The estimated coefficients of the optimal mark-ups are all highly significant. As a result, the estimates validate a nonlinear, inverted U-shaped relationship between competition and labor productivity, which captures the actual rate at which technical progress is adopted in the production system.

4.4 The optimal mark-up is strongly correlated with the rate of technical progress

Figure 3 below allows the comparison of the the optimal mark-ups with the average rates of technical progress by sector, denoted θg_i. (See appendix 3 for the calculation of θg_i, the Hicks-neutral technical progress as the mark-up-adjusted Solow residual following Roeger (1995).) Formally, it represents the correlation between the optimal mark-up and the rate of technical progress for each sector.

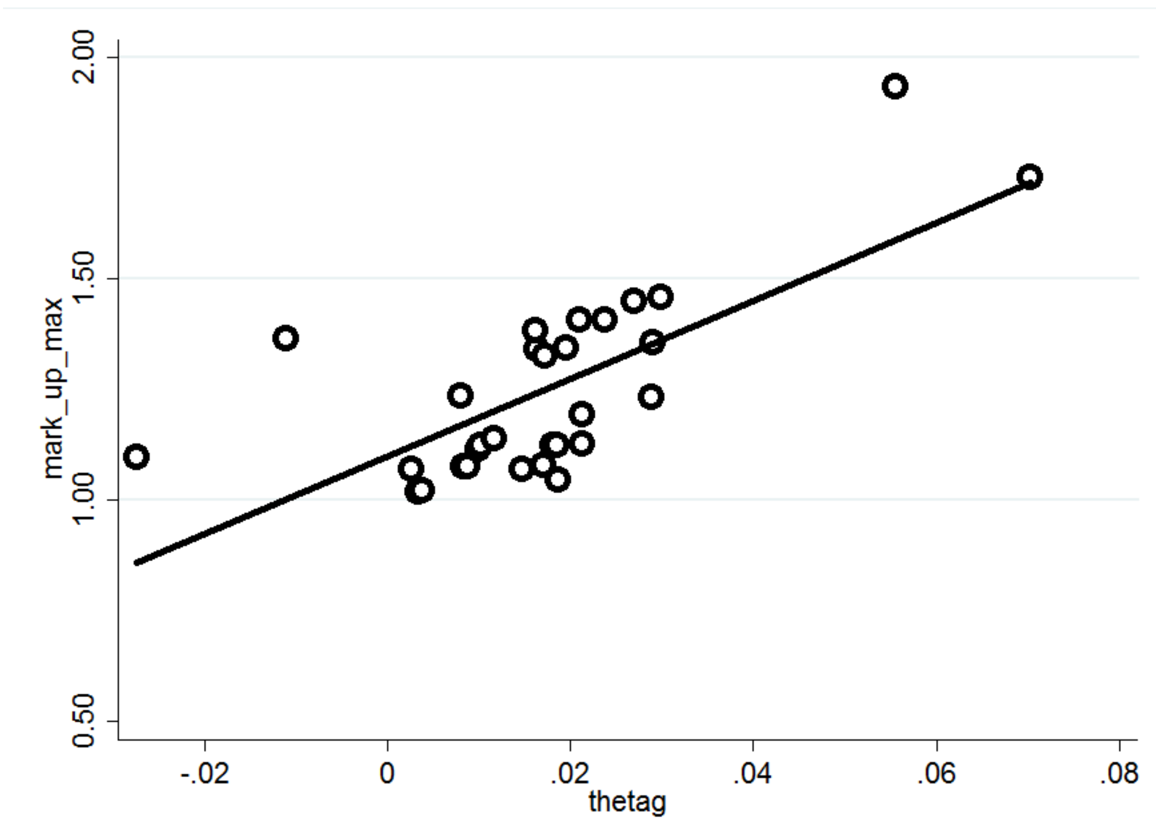

Figure 3: **Correlation between optimal mark-ups and total productivity growth**

The line indicates the linear fit of the scatter plot. The coefficient of correlation between the sector specific optimal mark-up and the rate of technical progress is 0.71, which is above the 1% significance threshold (0.463) for 30 observations. Note that the correlation between the average mark-up and the rate of technical progress is positive but not significant. The coefficient of correlation is 0.28 which is lower than the 10% significance threshold (0.306). Thus, average mark-ups are not (or weakly) correlated with technical progress, while optimal mark-ups are strongly correlated. Such a strong correlation suggests that the sectors experiencing higher rates of technical progress will require higher optimal mark-ups. As a result, a sector in which the rate of innovation is relatively high, will require relatively high mark-ups over competitive prices (or marginal costs) are needed in order to maximize productivity growth in that sector.

How can we explain this result? Labor productivity growth reflects improvements in production tools, which require investment. The mark-up, according to Aghion *et al.* (2005) or Aghion *et al.* (2014), has two contrary effects on investment. On the one hand, it tends to reduce investment, which is the escape competition effect. On the other hand, it tends to increase investment, which is the Schumpeterian effect. The mark-up that maximizes investment reflects a trade-off between those two effects for each sector. The escape competition effect depends on the pre-investment mark-up, while the Schumpeterian effect depends on the post-investment mark-up. Technical progress impacts the economy through investment; therefore, a higher rate of technical progress increases the Schumpeterian effect more than the escape competition effect. As a result, the trade-off in a sector with a higher rate of technical progress tends to shift toward a higher mark-up.

5 Productivity losses

5.1 Labor productivity losses due to unsuitable mark-ups

In the previous section, we calculated the optimal mark-up for each sector. This means that when the mark-up is above or below this level, productivity growth is not at its maximum. The gap between the observed productivity growth and the maximum productivity growth may be considered a productivity loss. To estimate the productivity losses for each sector at each time, it is necessary to compute, on the one hand, the difference in each period and for each sector, between the observed mark-up and the optimal mark-up:

$\Delta markup_{i,p} = markup_{i,p} - markupmax_i$

On the other hand, it is necessary to compute the difference between the hourly labor productivity growth rate and the maximum labor productivity growth rate, which is the difference between the hourly labor productivity growth and the rate of productivity growth that is achieved when the mark-ups coincide with their optimal levels in each sector:

$\Delta CAGRprod_{i,p} = CAGRprod_{i,p} - CAGRprodmax_i$

If $mark - upmax_i$ is the optimal mark-up $CAGRprod_i$, on can expect that the first difference $\Delta CAGRprod_{i,p}$ will be increasing when $\Delta mark - up_{i,p} < 0$ and decreasing when $\Delta mark - up_{i,p} > 0$. Hence an increase in the variation rate of markups leads to a decrease in the variation rate of labor productivity. Figure 4 below presents the variations in hourly labor productivity growth as a function of the mark-up over perfectly competitive prices.

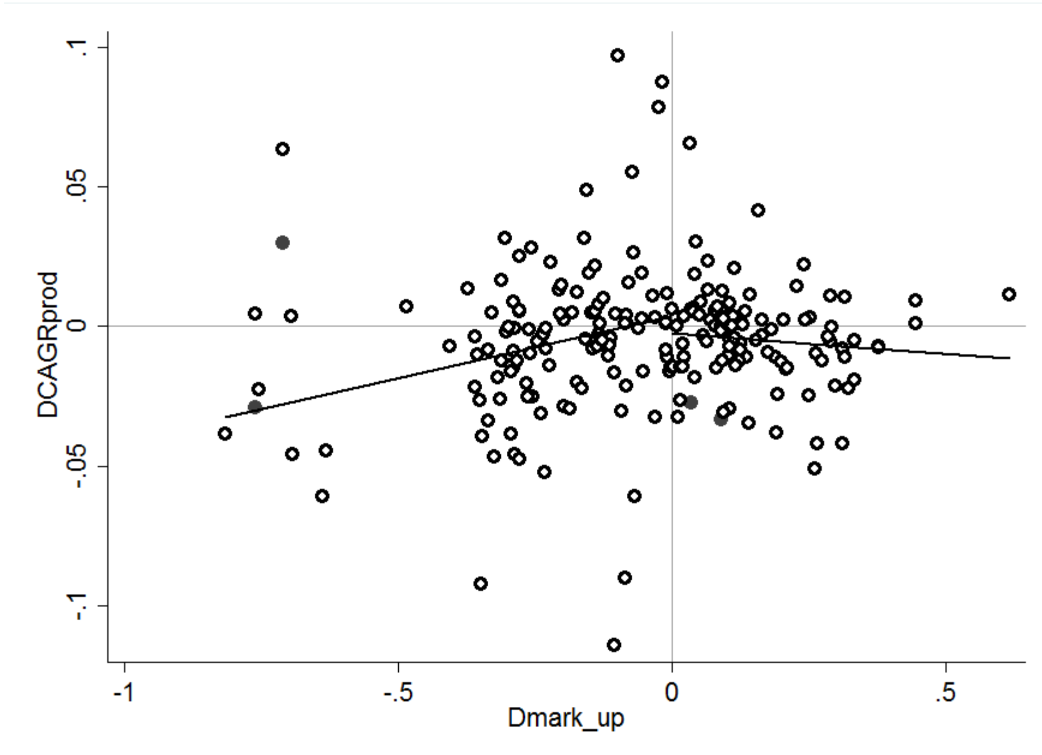

Figure 4: **Optimal mark-up and maximum hourly labor productivity growth**

The white scatter plot points show the impact of the difference between the sector mark-ups and the optimal mark-ups on the growth rate of labor productivity. The Internet bubble may have increased the productivity growth of the information technologies sector during the fifth period (2000-2004) independently of the mark-up. This can be corrected by a dummy variable, as explained in equation (3) below and the 4 gray points represent the 4 corrected information technology sectors in the fifth period. The two lines represents the statistically significant linear fit of the scatter plot when the mark-ups are above and below their maximum values. As expected, the values of the first difference $\Delta CAGRprod_{i,p}$ are increasing when the mark-up is below its optimal level and decreasing when the mark-up exceeds its optimal level. Moreover, the fitted values appear to be close to the null value when the mark-up approaches the optimal level. This result suggests that the optimal mark-up and the maximum values of hourly productivity growth are accurately estimated. As a result, one would expect that as soon as the mark-ups differ from their optimal levels, the rate of labor productivity growth begins to decrease. The following equation with first difference mark-ups and hourly labor productivity growth is then estimated:

$$\Delta CAGRprod_{ip} = c + \alpha\ \Delta markup_{ip}^2 + \beta\ \Delta markup_{ip} + intbub + \lambda\ d_p + \varepsilon_{ip} \quad (3)$$

The term *intbub* is a dummy variable that aims to capture the impact of the internet bubble, which might have affected the information technologies sector during the fifth period, 2000-2004. Hence, it is supposed that $intbub = 1$ during the fifth period for the four sectors included in the information technologies sector: D26 (computer, electronic and optical products), D58T60 (publishing, audiovisual and broadcasting activities), D61 (telecommunications), D62T63 (IT and other information services) $intbub = 0$ otherwise. If the optimal mark-ups are estimated accurately, the coefficient β would not be statistically different from zero and the coefficient α must be negative and statistically significant. The estimated coefficient of *intbub* is expected to be positive, as the Internet bubble should not have decreased productivity in the information technology sector, which invested heavily over the period. As an alternative, it is possible to estimate the following equation, which tests the extent to which the difference between the sector mark-ups and their optimal levels affects the rate of productivity growth (first difference):

$$\Delta CAGRprod_{ip} = c + \alpha\ |\Delta markup_{ip}| + \beta\ intbub + \lambda\ d_p + \varepsilon_{ip} \quad (4)$$

The term $\Delta markup_{ip}$ may be either positive or negative depending on the period. The absolute value of the difference between the sector markup and the optimal level allows for the comparison of the impact of the distance from these sector optimal mark-ups on labor productivity growth irrespective of the sign of such a difference. The equation is estimated for first differences of the dependent variable, i.e. the hourly labor productivity growth rate.

Table 3 below presents the results of the estimations of equations 3 and 4.

Table 3: Equations 3 and 4 Check of Optimal Mark-up estimations

Dependent variable: $\Delta CAGRprod$				
Specification	(1)	(2)	(3)	(4)
$\Delta markup$	0.0009	0.0011		
	(0.0065)	(0.0065)		
$\Delta markup^2$	-0.0344	-0.0462**		
	(0.0225)	(0.0189)		
$\lvert\Delta markup\rvert$			-0.0316**	-0.0367***
			(0.0139)	(0.0118)
intbub		0.0337*		0.0312*
		(0.0182)		(0.0179)
sector fixed effects	no	no	no	no
period fixed effects	yes	yes	yes	yes
constant	-0.0086**	-0.0080**	-0.0049	-0.0041
	(0.0034)	(0.0034)	(0.0042)	(0.0040)
R^2	0.125	0.152	0.140	0.164
Observations	210	210	210	210

Significant at 1%(***), 5%(**) and 10%(*). Robust standard errors in parentheses.

Columns (1) and (2) present the estimations of equation 3. Specification (1) does not include the dummy variable capturing the effect of the internet bubble whereas specification (2) does include it. Columns (3) and (4) present the estimations of equation 4. Specification (3) does not include the dummy for the Internet bubble while specification (2) does include it. As expected in specifications (1) and (2) the coefficient of $\Delta markup$ is not statistically different from the null value and the coefficient of $\Delta markup^2$ is negative, which validates the hypothesis of inverted U-shaped curve centered on zero. However, the coefficient is not significant in specification (1), although it is close to the 10% threshold. Conversely, the coefficient of the squared mark-ups is significant in specification (2), which includes the dummy capturing the effect of the Internet bubble. The coefficient of $|\Delta markup|$ is negative and significant in specifications (3) and (4) which confirms that hourly labor productivity growth decreases as soon as mark-ups deviate from the optimal levels estimated in the previous section. In both specifications (2) and (4), the Internet bubble dummy exhibits the expected positive and statistically significant coefficient. In figure 4, the four gray points represent the information technologies sector during the fifth period, from which the value of the intbub dummy coefficient (0.0337) has been subtracted from the productivity growth rate. As a result, there exists a mark-up that maximizes the growth rate of productivity. Hence, a difference between the actual mark-up and the optimal mark-up in a sector induces a divergence between observed labor productivity growth and its maximum growth rate. Figure 3 suggests that technical progress determines the potential productivity growth that is achieved for an optimal mark-up, and figure 4 shows that deviation from this optimal mark-up prevents the full realization of productivity growth.

5.2 Average annual productivity losses for each sector

Differences between effective and optimal levels of mark-ups entail losses in labor productivity growth. It is possible to estimate the average annual labor productivity growth that is lost due to unsuitable mark-up levels in each sector. It is first necessary to compute the mean of the differences between mark-ups and optimal mark-ups. However, as these differences may be of positive in some periods and negative in others, it is necessary to compute the first differences in absolute values:

$\Delta\Delta mkup_i = \sum_{p=1}^{7} |\Delta mark - up_{i,p}|/7$. On the other hand, we calculate the mean of the differences between observed productivity growth and maximum productivity growth: $\Delta\Delta CAGRprod_i = \sum_{p=1}^{7} \Delta CAGRprod_{i,p}/7$

Figure 5 below presents the productivity losses due to unsuitable mark-ups.

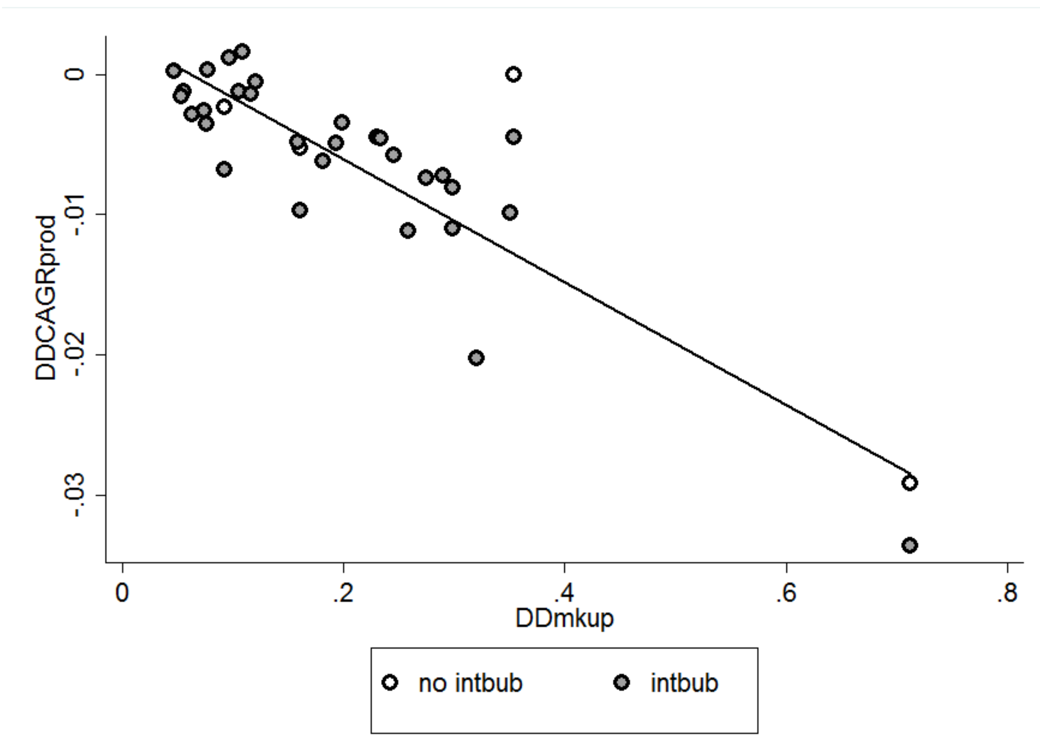

Figure 5: **optimal mark-up and maximum hourly productivity growth**

This graph shows that hourly labor productivity growth decreases when the mark-ups shift from their optimal levels. The gray scatter plot points represent losses in labor productivity growth after the Internet bubble is taken into account. The white points represent losses in productivity growth without the Internet bubble effect. In both cases, the correlation between the mark-up gap and the productivity loss is highly significant. The coefficient of determination is $R^2 = 0.78$ when the Internet bubble is taken into account and $R^2 = 0.74$ otherwise.

The impact on the global economy can be estimated by weighting each sector by its share of the global economy. It is estimated that between 1978 and 2015, the French economy lost 0.4% of its annual average growth rate of labor productivity because of unsuitable mark-ups (with an average difference of 0.152 from the optimal mark-up).

6 Conclusions and policy implications

This paper investigates the relationship between competition and productivity growth in thirty sectors of the French production system over the period 1978-2015. It provides empirical evidence that the relationship between mark-ups over competitive prices and the rate of labor productivity growth across sectors has an inverted U shape. This result implies that there exist an optimal mark-up for each sector. This optimal mark-up depends on each sector and, more precisely, on the sector-specific rate of technical progress. Hence, sectors with relatively high rates of technical progress will require sufficiently high mark-ups to maximize the growth rate of their labor productivity. As a result, a mark-up that differs from its optimal level tends to reduce the growth rate of labor productivity. The average annual loss of productivity growth due to unsuitable mark-ups in the French economy between 1978 and 2015 is estimated at 0.4%. As the average growth rate of French labor productivity over 1978-2015 was 1.86%, such growth could have reached 2.25% if mark-ups had been at their optimal levels.

A direct policy implication is that sectors with strong technical progress should be allowed to adjust their level of competition intensity to their actual rate of technical progress: otherwise, they could be prevented from achieving the productivity gains derived from the adoption of technologies. In particular, digital sectors (telecommunications services and IT equipment manufacturing), which have high productivity growth rates (i.e., high technical progress), necessitate sufficiently high mark-ups over competitive prices or marginal costs in order to maximize their labor productivity growth.

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Appendix

■ **Appendix 1: Calculation of the mark-ups Roeger (1995)**:

Starting from the neoclassical Cobb-Douglas production function:

$$Q_t = A_t\ N_t^{\alpha_{Nt}}\ M_t^{\alpha_{Mt}}\ K_t^{\alpha_{Kt}} \tag{5}$$

where Q_t is the output at time t, and N_t, M_t and K_t the factors of production, labor, intermediate consumption and capital, respectively.

Denote $\Delta q_t = ln(Q_t) - ln(Q_{t-1})$, $\Delta n_t = ln(N_t) - ln(N_{t-1})$, $\Delta k_t = ln(K_t) - ln(K_{t-1})$ and $\Delta m_t = ln(M_t) - ln(M_{t-1})$

The primal Solow residual is written:

$$SR_t = \Delta q_t - \alpha_{Nt}\Delta n_t - \alpha_{Kt}\Delta k_t - \alpha_{Mt}\Delta m_t \tag{6}$$

We can also calculate the dual residual based on prices:

$$SRP_t = \alpha_{Nt}\Delta w_t - \alpha_{Kt}\Delta r_t - \alpha_{Mt}\Delta z_t - \Delta p_t \tag{7}$$

where Δp_t represents the growth of production prices , Δw_t the growth of wages, Δr_t represents variation in the cost of use of capital and Δz_t variation in the price of intermediary consumption.

The Primal Solow residual can also be written:

$$SR_t = \left(1 - \frac{1}{\mu_t}\right)(\Delta q_t - \Delta k_t) + \frac{1}{\mu_t}\theta_t \tag{8}$$

where θ_t is Hicks-neutral technical progress. The dual residual can also be written:

$$SRP_t = \left(1 - \frac{1}{\mu_t}\right)(\Delta p_t - \Delta r_t) - \frac{1}{\mu_t}\theta_t \tag{9}$$

The difference between the primal residual and the dual residual provides:

$$y_t = \beta x_t + \varepsilon_t \tag{10}$$

where $\beta_t = \left(1 - \frac{1}{\mu_t}\right)$ is the Lerner index,

$y_t = (\Delta p_t + \Delta q_t) - \alpha_{Nt}(\Delta w_t + \Delta n_t) - \alpha_{Mt}(\Delta z_t + \Delta m_t) - \alpha_{Kt}(\Delta r_t + \Delta k_t)$

and $x_t = (\Delta p_t + \Delta q_t) - (\Delta r_t + \Delta k_t)$

β, thus, the mark-up μ can be estimated by using the ordinary least square estimator. In all equations that depend of time, the index t represents the given period according to the definition provided in the previous section. The confidence interval of the estimation increases with the duration of the period; however, the duration of the period also reduces the number of periods. Thus, the duration of the period as previously defined results from a trade-off between the number of periods and the accuracy of the estimated mark-ups. The estimation of the mark-ups is run for each sector for each of the seven periods. Each member of both equations is defined as follows:

$\Delta p_t + \Delta q_t = ln(PROD) - ln(PROD(-1)$

$\Delta k_t = ln(CPGK) - ln(CPGK(-1)$

$R = PIGT(ILRV/100 + \delta)$ (δ is the capital depreciation rate. It is assumed that $\delta = 5\%$)

$\Delta r_t = ln(R) - ln(R(-1))$

$\Delta n_t = ln(EMPN) - ln(EMPN(-1))$

$\Delta w_t = ln(LABR/EMPE) - ln(LABR(-1)/EMPE(-1))$

$\Delta z_t + \Delta m_t = ln(PROD - VALU) - ln(PROD(-1) - VALU(-1))$

$\alpha_{Nt} = (EMPN * LABR/EMPE)/PROD$

$\alpha_{Mt} = (PROD - VALU)/PROD$

$\alpha_{Kt} = 1 - \alpha_{Nt} - \alpha_{Mt}$

The Lerner index for sector i in period p is estimated from equation 10: $y_{i,p} = \beta_{i,p} x_{i,p} + \varepsilon_{i,p}$ using the OLS estimator, and the mark-up is $\mu_{i,p} = \frac{1}{1-\beta_{i,p}}$.

■ Appendix 2: Calculation of the compound annual growth rate of hourly labor productivity:

Hourly productivity can be calculated for each sector i and each year t : $HPROD_{it} = VALK_{it}/EMPN_{it}$ The compound annual growth rate can be calculated for each period, where t_1 is the first year of the period, t_0 is the last year of the previous period, and t_f is the last year of the period. The compound annual growth rate of sector i at period p is given by:

$$CAGRprod_{ip} = \left(\frac{HPROD_{i,t_f}}{HPROD_{i,t_0}}\right)^{(t_f - t_0)} \tag{11}$$

■ **Appendix 3: Calculation of technical progress**:

Technical progress is given by equation (6) and equation (8).

$$\theta_{it} = \mu_{it} SR_{it} - (\mu_{it} - 1)(\Delta q_{it} - \Delta k_{it}) \tag{12}$$

The annual technical progress rate is: $\theta g_{it} = e^{\theta_{it}} - 1$

The average annual technical progress rate of sector i is the mean technical progress of this sector over time:

$$\theta g_i = \sum_{t=1979}^{2015} \theta g_{it}/37 \tag{13}$$

Technical progress is exogenous and sector specific. It reflects the propensity to innovate, which depends on the sector.

■ Appendix 4: List of the thirty sectors

Table 4: List of the thirty sectors

Number	OECD code	Sector
1	D05T09	Mining and quarrying
2	D10T12	Food products, beverages and tobacco
3	D13T15	Textiles, wearing apparel, leather and related products
4	D16T18	Wood and paper products, and printing
5	D19	Coke and refined petroleum products
6	D20T21	Chemical and pharmaceutical products
7	D22T23	Rubber and plastics products, and other non-metallic mineral products
8	D24T25	Basic metals and fabricated metal products, except machinery and equipment
9	D26	Computer, electronic and optical products
10	D27	Electrical equipment
11	D28	Machinery and equipment n.e.c.
12	D29T30	Transport equipment
13	D31T33	Furniture; other manufacturing; repair and installation of machinery and equipment
14	D35	Electricity, gas, steam and air conditioning supply
15	D36T39	Water supply; sewerage, waste management and remediation activities
16	D41T43	Construction
17	D45T47	Wholesale and retail trade, repair of motor vehicles and motorcycles
18	D49T53	Transportation and storage
19	D55T56	Accommodation and food service activities
20	D58T60	Publishing, audiovisual and broadcasting activities
21	D61	Telecommunications
22	D62T63	IT and other information services
23	D64T66	Financial and insurance activities
24	D69T71	Legal and accounting activities; activities of head offices; management consultancy activities architecture and engineering activities; technical testing and analysis
25	D72	Scientific research and development
26	D73T75	Advertising and market research; other professional, scientific and technical activities; veterinary activities
27	D77T82	Administrative and support service activities
28	D84T88	Public administration and defence; compulsory social security; education; human health and social work activities
29	D90T93	Arts, entertainment and recreation
30	D94T96	Other service activities