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Competition, technological change and productivity gains: a European sectoral analysis

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Abstract

We show that the relationship between the level of competition (the price markup) and the growth of labor productivity in 28 sectors of a panel of 8 euro area countries between 1995 and 2018 is consistent with an inverted U-shaped curve. We calculate an optimal price markup that maximizes productivity growth in each sector and show that sectors with the highest rates of technical progress are the ones that maximize their growth of productivity at the lowest levels of competition (the higher price markup). For the European panel of sectors, during this period, the average loss in productivity growth attributable to deviations from their optimal levels of competition was 0.31%. From a policy perspective, public authorities should aim to enable optimal price markups, particularly in high-innovation sectors, to reap the most benefits from their potential for productivity.

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1 Introduction

The relationship between the intensity of competition and the rate of innovation has long been investigated in both theoretical and empirical literature. The most recent research, from the seminal contribution of Aghion *et al.* (2005) to the theoretical insights from Askenazy *et al.* (2013) and Schmutzler (2013), has demonstrated that rather than being monotonic and linearly increasing, this relationship is ambiguous and depends upon a set of industry-specific characteristics. Aghion *et al.* (2005) first showed that the relationship between competition and innovation fits an inverted U-shaped curve, meaning that any increase in competition above an optimal threshold will slow the pace of innovation. Jeanjean (2021) shed light on the role of technical progress in the relationship between competition and innovation by showing how the level of competition that maximizes investment is lower in industries that have a higher level of technical progress. Ciriani & Jeanjean (2020) used data from thirty sectors of the French economy during 1978-2015 to demonstrate an inverted and U-shaped relationship between competition intensity (captured by the sector-specific price markup) and labor productivity growth. They showed that price markups that maximize productivity growth in each sector are strongly correlated with the rate of technical progress for the sector, implying that sectors with high innovation necessitate higher markups (lower competition intensity) to maximize their labor productivity rate. Moreover, the persistence of suboptimal markups in the French economy is associated with a 0.4% average annual loss in productivity growth over the whole period. We extend the analysis to a panel of 8 euro area countries, observed from 1995 to 2018. First, it provides estimations of markups that maximize the rates of productivity growth at the level of 28 sectors in a panel of 8 euro area countries. We then provide estimations for the losses in sector labor productivity that are attributable to unsuitable markups; hence, the gap between the observed labor productivity growth and the maximum productivity growth in each sector in every period, due to a gap between the observed markup and the optimal level of markup. Overall, our result confirms the robustness of the inverted U-shaped relationship between competition intensity and productivity growth at the sector and country levels and the positive correlation between technical progress and markups. As a result, sectors that are more intensive in their technical progress require higher markups to maximize their rate of productivity growth.

2 The theoretical foundations of the inverted U-shaped relationship and the issue of reverse causality between competition and investment

In Aghion *et al.* (2005), the relationship between competition and innovation is proved to follow an inverted-U shaped curve in the context of the UK economy. Aghion *et al.* (2014) specifies that two opposites competitive forces are at work: the "Escape competition effect" and the "Schumpeterian effect". The first relates to "neck-and-neck" competition. Firms have the same technology and invest to acquire monopoly power through gaining technological leadership, and invest more when competition, initially low, intensifies. In the latter effect, there are leading and laggard firms. The latter need to invest to catch-up with the technological leaders. The gain from catching up diminishes when competition intensifies, then laggards tend to lower their investment. In a particular sector, both effects coexist, and the overall impact of their interplay depends on which one dominates. When competition is low (high) the “Escape competition effect” (the “Schumpeterian effect”) dominates. In the first (latter) effect, investment increases (decreases) with the degree of competition. Investment reaches its maximum level when both effects are balanced, and the relationship is flat. Hence this relationship is globally inverted-U shaped.

Jeanjean (2020) studies the impact of technical progress on the inverted-U relationship and provides theoretical and numerical proofs that technical progress increases incentives to invest in both effects, however not in a symmetrical way. The slope of the U-shaped curve is preserved with the “Escape competition effect” while it is steeper with the “Schumpeterian effect”. This is because incentives to invest directly depends on competition and firms consider the level of competition before investment in the ”escape competition effect” and the level of competition after investment in the ”Schumpeterian effect”. Since competition is not impacted by investment in the ”escape competition effect”, technical progress uniformly increases incentives to invest, while in the ”Schumpeterian effect” technical progress increases more incentives to invest for low than for high levels of competition. This differential impact between the two effects decreases the slope of the inverted U curve in all points, therefore the level of competition that maximizes investment decreases.

From a policy perspective, our results show that is advisable that sectors which have higher technical progress can adjust their competition intensity to maximize their investment or productivity growth. Such recommendation builds on the result that the degree of competition influences investment. In the present work and in the cited papers, the empirical specifications used to estimate the relationship between competition and investment as well as the effect of technical progress do not formally account for the issue of simultaneity, which includes an impact of investment on the actual degree of competition. However, both the existence of the U-shaped relationship between competition and investment and the shift of the U-shaped curve maximum are supported by theoretical proofs. The empirical validations in the present paper, along with the theoretical proofs from the economic literature cited above allow to establish the causal effect of the degree of competition on the level of investment in innovation or equivalently on the growth of productivity at the level of sectors.

3 Empirical evidence

3.1 The sample: A panel of 28 sectors in 8 European economies.

The economic information necessary to carry out the estimations of sector markups and sector productivity growth was 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 twenty-eight sectors in 8 European countries, covering manufacturing, energy, construction, market services and public administration, from 1995 to 2018. A table of the twenty eight sectors and eight countries is presented in appendix 4. In addition, the price deflator for gross fixed capital formation in the eight countries and the real long-term interest rates, which are used to compute the cost of capital, were retrieved from the AMECO macroeconomic database of the European Commission. The following variables are used to compute both sector markups 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.

3.2 Empirical strategy

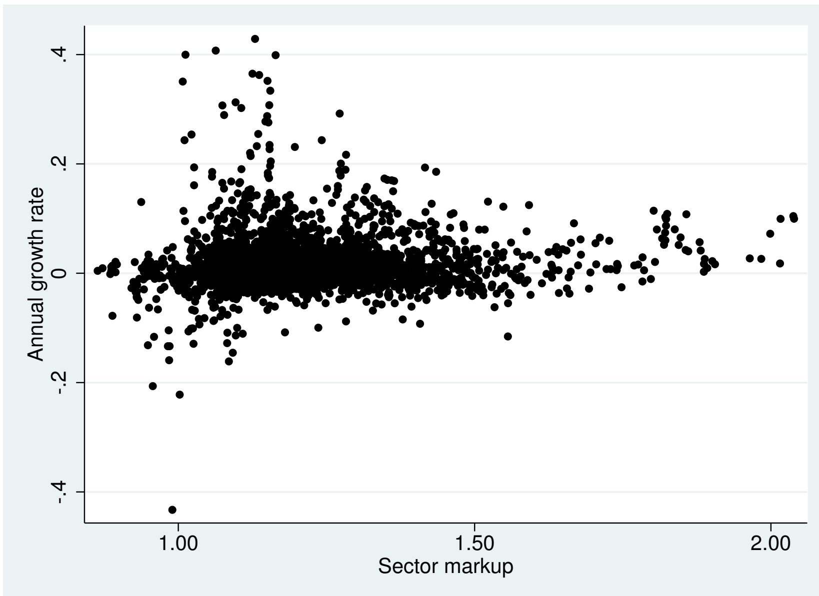
Our approach is similar to that of Bouis & Klein (2009), who studies the effect of competition intensity on labor productivity gains within a range of sectors using a panel of OECD countries. This section provides empirical evidence that the relationship between the level of markup and the rate of hourly productivity growth depends on each sector and that this relationship can be described as an inverted U-shaped curve. Moreover, the results demonstrate that the optimal sector markups increase with the growth rate of technical progress. To provide evidence of an inverted U-shaped relationship between competition and labor productivity, the markups are estimated according to the methodology developed by Roeger (1995) and detailed in appendix 1. The markups are estimated for each of the twenty-eight sectors in each of the eight countries for sixteen defined periods with an average duration of eight years, which provide 3584 estimated markups. Sixteen overlapping periods are considered for the estimation: Period 1 (1996-2003); Period 2 (1997-2004); Period 3 (1998-2005)... and Period 16 (2011-2018). The duration of each period was based on a trade-off between the accuracy of the markup estimations and the number of periods that provides more observations. Indeed, longer periods improve the accuracy of the markup estimations; however, they also reduce the number of observations. Thus, the compound annual growth rate of hourly labor productivity is computed for each of the 16 periods in each sector in each country. This computation is detailed in appendix 2. The rate of technical progress is computed from the Solow residual. This computation is detailed in appendix 3.

3.3 The relationship between markups and productivity growth

Is there an inverted U-shaped relationship between markups and hourly labor productivity growth rates?

The figure 1 below, represents the hourly labor productivity growth rate according to the level of markup for each sector in each country during each period.

Figure 1: Hourly labour productivity growth and mark-ups by sector



At first glance, the scatter plot of the relationship does not provide any obvious or robust result regarding this relationship. However, the different sectors involved in this graph are underpinned by very different rates of technical progress, and the relationship between markups and productivity growth is very sensitive to the rate of technical progress. Therefore, we provide a first econometric model based on a quadratic function to test the relationship between markups and productivity growth and the impact of technical progress on this relationship. We estimate the following equation:

$$CAGRprod_{ijp} = c + (\alpha_0 + \alpha_1\ \theta_{i(j)})\ markup_{ijp} + \beta\ markup^2_{ijp} + \gamma_n X_n + \lambda\ d_p + \delta\ d_j + \varepsilon_{ijp} \qquad (1)$$

This equation is estimated with the Ordinary Least Square estimator (OLS), where $i \in \{1, 2..., 28\}$ is the index of sector, $j \in \{1, 2..., 8\}$ is the index of country and $p \in \{1, 2..., 16\}$ is the index of period. $CAGRprod_{ijp}$ is the compound annual growth rate of production at current price of sector i in country j during period p. $markup_{ijp}$ is the estimated markup for sector i in country j during period p. $\theta_{i(j)}$ is the technical progress rate of sector i in country j. Note that j is in brackets, which means that we can use technical progress at the sector level, (the technical progress is the same for sector i in all countries) or the technical progress at the sector/country level (the technical progress is computed for each sector in each country.) X_n is a set of dummy variables, among which Intbub, service and industry. Intbub is a dummy variable that captures the impact of the internet bubble, which might have affected the information technology sectors during the first five periods in approximately the year 2000. During first five periods (1 to 5), $intbub = 1$ for the three sectors in the information technology category, which includes "computer, electronic and optical products", "Telecommunications" and "IT and other information services" ($intbub = 0$ otherwise). Industry and Service are dummy variables that take the value one respectively for industry and service sectors and the value 0 otherwise. The term d_p represents the period fixed effect, compounded from a set of dummy indicators, likewise, d_j represents the country fixed effects. Finally ε_{ijp} represents the error term.

An inverted U-shaped relationship between markups and productivity growth requires that the coefficient β be negative and that the term $(\alpha_0 + \alpha_1 \ \theta_{i(j)})$ is positive. In such case, the markup that maximizes productivity growth is given by:

$$markupmax = \frac{-(\alpha_0 + \alpha_1 \ \theta_{i(j)})}{2\beta} \tag{2}$$

If the coefficient α_1 is positive, an increase in the rate of technical progress increases the optimal markup. On the contrary, if it is negative, an increase in the rate of technical progress decreases the optimal markup. The results of the estimation of equation (1) are presented in the table below.

Table 1: Mark-up, technical progress and Hourly Labor Productivity Growth

Dependent variable: Hourly Productivity growth CAGRprod				
Specification	(1)	(2)	(3)	(4)
markup	0.067	0.129***	0.182***	0.131***
	(0.052)	(0.044)	(0.049)	(0.050)
markup^2	-0.027	-0.043***	-0.062***	-0.043***
	(0.019)	(0.016)	(0.019)	(0.019)
$\theta_i.markup$	2.264***	1.827***		
	(0.095)	(0.115)		
$\theta_{i(j)}.markup$				
. Austria			0.694***	0.683***
			(0.193)	(0.190)
. Belgium			1.203***	1.203***
			(0.198)	(0.189)
. Finland			2.101***	2.015***
			(0.276)	(0.258)
. France			2.121***	2.194***
			(0.205)	(0.192)
. Germany			2.205***	2.248***
			(0.233)	(0.246)
. Italy			1.721***	1.585***
			(0.184)	(0.200)
. Netherlands			1.457***	1.367***
			(0.197)	(0.187)
. Slovakia			2.872***	3.398***
			(0.484)	(0.502)
intbub	0.031***	0.037***	0.037***	0.037***
	(0.006)	(0.006)	(0.006)	(0.006)
service		-0.025**	-0.026**	-0.026**
		(0.010)	(0.010)	(0.010)
industry		-0.011	-0.012	-0.012
		(0.010)	(0.010)	(0.010)
country fixed effects	yes	yes	yes	yes
period fixed effects	yes	yes	yes	yes
constant	-0.021	-0.055*	-0.089**	-0.057**
	(0.036)	(0.033)	(0.036)	(0.036)
R^2	0.310	0.328	0.338	0.343
Observations	3547	3547	3547	3547

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

In specification (1), (2) and (3), technical progress at the sector level is used. In specification (4), technical progress at the sector/country level is used. In specifications (1) and (2), the interaction between technical progress and squared markup is global for all the countries. In specifications (3) and (4), the interaction is detailed by country. In specification (1), the dummies for service and industry are not used.

In all specifications, the coefficient α_0 is positive and the coefficient β is negative. They are significant in all specifications except specification (1). As expected, the coefficient α_1 is positive and significant in all specifications, even in specifications (3) and (4), where this coefficient is detailed by country. The sum $\alpha_0 + \alpha_1\theta_{i(j)}$ is positive and β is negative in all specifications, which means that the relationship between markups and productivity growth is an inverted U-shape; therefore, there is a value of markup that maximizes productivity growth, which we denote $markupmax$. Furthermore, since α_1 is positive, an increase in technical progress entails an increase in $markupmax$. The values of $markupmax$ can be estimated by the "delta method" using equation (2) and the result of the regression reported in table 1. Table 2 below provides the estimations of $markupmax$ as a function of the technical progress rate, for specifications (1) and (2), where the coefficient α_1 is the same for all the countries.

Table 2: mark-up that maximizes Hourly Labor Productivity Growth

estimations of the mark-up that maximizes Hourly Productivity growth mark-upmax		
Specification	(1)	(2)
θ_i		
-0.015	0.605	1.187***
	(0.540)	(0.089)
-0.010	0.814**	1.293***
	(0.395)	(0.066)
-0.005	1.023***	1.400***
	(0.254)	(0.066)
0.000	1.232***	1.506***
	(0.134)	(0.088)
+0.005	1.441***	1.612***
	(0.126)	(0.121)
+0.010	1.650***	1.718***
	(0.241)	(0.159)
+0.015	1.860***	1.825***
	(0.381)	(0.198)

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

The growth of $markupmax$ as a function of technical progress is given by:

$$\frac{\partial markupmax}{\partial \theta} = -\frac{\alpha_1}{2\beta} \tag{3}$$

An increase in technical progress by 1% entails an increase in $markupmax$ by 0.42 in specification (1) and by 0.21 in specification (2). For specifications (3) and (4), the growth depends on the countries. *intbub* is positive and significant in all specifications, which means that productivity growth has been boosted for information technologies during internet bubble. The coefficient of service is negative and significant in all specifications where it is used, which means that the growth of productivity is lower in the service sectors than in the industry or the primary sectors. The coefficient of industry is not significant, which means that the productivity growth of industry sectors is not significantly different from that of primary sectors. β_1 and the coefficients of *intbub*, *service* and *industry* are quite similar, whether each uses technical progress at the sector level or at the sector/country level. Indeed, technical progress depends more on the sectors than the countries.

3.4 Estimation of optimal sector markups

In the previous section, we showed how technical progress tends to increase the markups that maximizs hourly productivity growth. In this section, we estimate the value of the markup that maximizes productivity growth for all sectors in all countries. To do so, we use the following equation:

$$CAGRprod_{ijp} = c + \alpha_i \ d_i.markup_{ijp} + \beta \ markup_{ijp}^2 + \gamma \ intbub + \lambda \ d_p + \delta \ d_j + \varepsilon_{ijp} \tag{4}$$

d_{ij} is a dummy indicator of each sector in each country. d_i is a dummy indicator of sectors, regardless of the countries. d_p is a dummy indicator of periods and represents the period fixed effects, d_j represents the country fixed effects and ε_{ijp} is the error term.

The results of the estimation of equation (4) are presented in the table below.

Table 3: estimation of the Mark-up that maximizes Hourly Labor Productivity Growth

Dependent variable: Hourly Productivity growth CAGRprod	Coef	(Std.Err)	markupmax	(Std.Err)
mark-up				
Food products, beverage and tobacco	0.134**	(0.055)	1.275***	(0.082)
Textiles,wearing apparel, leather and related products	0.144***	(0.055)	1.375***	(0.078)
Wood and paper products, and printing	0.145***	(0.054)	1.379***	(0.074)
Coke and refined petroleum products	0.145***	(0.055)	1.379***	(0.104)
Chemical and pharmaceutical products	0.150***	(0.054)	1.427***	(0.076)
Rubber and plastic products, and other non-metallic mineral products	0.142***	(0.054)	1.353***	(0.073)
Basic metals and fabricated metal products, except machinery and equipment	0.134**	(0.054)	1.282***	(0.078)
Computer, electronic and optical products	0.190***	(0.053)	1.810***	(0.195)
Electrical equipment	0.146***	(0.054)	1.396***	(0.079)
Machinery and equipment n.e.c	0.148***	(0.054)	1.408***	(0.076)
Transport equipment	0.144***	(0.054)	1.376***	(0.075)
Furniture; other manufacturing; repair and installation of machinery and equipment	0.135**	(0.054)	1.287***	(0.081)
Electricity, gas,steam and air conditioning supply	0.134**	(0.054)	1.282***	(0.068)
Water supply; sewerage, waste management and remediation activities	0.115**	(0.054)	1.1001***	(0.111)
Construction	0.120**	(0.054)	1.142***	(0.109)
Wholesale and retail trade, repair of motor vehicles and motorcycles	0.130**	(0.054)	1.239***	(0.076)
Transportation and storage	0.128**	(0.054)	1.223***	(0.083)
Accommodation and food service activities	0.112**	(0.054)	1.066***	(0.126)
Publishing, audiovisual and broadcasting activities	0.128**	(0.054)	1.222***	(0.082)
Telecommunications	0.168***	(0.054)	1.601***	(0.111)
IT and other information services	0.127**	(0.054)	1.212***	(0.087)
Financial and insurance activities	0.132**	(0.054)	1.255***	(0.072)
Legal and accounting activities; consultancy; architecture and engineering	0.116**	(0.054)	1.101***	(0.117)
Advertising and market research and technical activities	0.116**	(0.055)	1.106 ***	(0.126)
Administrative and support service activities	0.118**	(0.054)	1.123***	(0.106)
Public administration and defence;social security; education	0.119**	(0.054)	1.138***	(0.109)
Arts, entertainment and recreation	0.118**	(0.054)	1.129 ***	(0.106)
Other service activities	0.112**	(0.054)	1.064***	(0.135)
mark-up^2	-0.052***	(0.020)		
intbub	0.018***	(0.006)		
country fixed effects	yes			
period fixed effects	yes			
constant	-0.062*	(0.037)		
R^2	0.375			
Observations	3547			

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

The first column, Coef, provides the estimation of the coefficients, the second column provides the standard errors, and the third column provides the estimation of *markupmax*, the markup that maximizes the productivity growth. The value of $markupmax_i$, the markup that maximizes sector i, is computed using the 'delta method' and the following equation:

$$markupmax_i = -\frac{\alpha_i}{2\beta}$$

and the last column provides the standard errors of the estimations of *markupmax* for each sector.

The results show that the coefficient of mark-up is positive and highly significant for all sectors. The coefficient of the squared markup is negative and significant. The coefficient of *intbub* is, as expected positive and significant. These results allow us to estimate the values of *markupmax* that are highly significant for all the sectors.

3.5 Comparison between the markups that maximize productivity growth and the sectors' technical progress rate

In this section, for each sector, we compare $markupmax_i$, the markup that maximizes productivity growth, and θ_i, the technical progress rate. The graph below, figure.2, represents the sectors' markupmax according to their rate of technical progress.

Figure 2: mark-up that maximizes productivity growth and technical progress

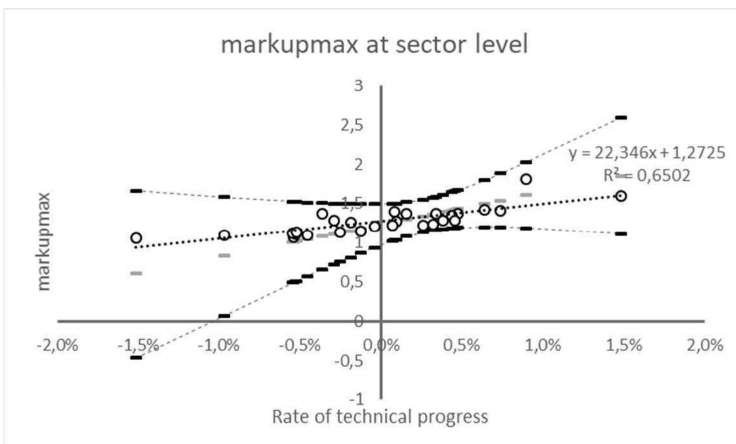


Figure 2 shows that the markup that maximizes productivity growth increases with technical progress. The hollow circles represent sector $markupmax_i$ as a function of technical progress. The gray dashes represent the medium markupmax according to the rate of technical progress. These values are obtained from equation (1). The upper and lower dashes represent the confidence interval at 95%.

The values of *markupmax* obtained with equation (4) are consistent with the results obtained with equation (1). This confirms the increase in *markupmax* with technical progress. An increase in technical progress by 1% corresponds in average to an increase of 0.22 in the markup that maximizes productivity growth. This result is consistent with the results obtained with equation (1).

3.6 Extension at sector/country level

The two previous sections estimated the markup that maximizes productivity growth at the sector level regardless of the country. This section estimates the optimal markup in each sector within each country. The econometric equation is similar to equation (4), but we use a dummy indicator for each sector in each country, rather than a dummy indicator for each sector regardless of the country. This leads to the following equation:

$$CAGRprod_{ijp} = c + \alpha_i \; d_{ij}.markup_{ijp} + \beta \; markup^2_{ijp} + \gamma \; intbub + \lambda \; d_p + \delta \; d_j + \varepsilon_{ijp} \tag{5}$$

This equation estimates *markupmax* for the 28 sectors in the 8 countries, producing 224 estimated values of *markupmax*, all of which are significant. Rather than presenting all of them, we compute the slope of the growth of *markupmax* as a function of the rate of technical progress for the 28 sectors in each country.

The slope can be estimated for each country by regressing the *markupmax* obtained with equation (5) on technical progress at the sector level or at the sector/country level.

$$markupmax_{ij} = c_j + slope_j \theta_{(i)j} + \varepsilon_{ijp} \tag{6}$$

Table 4 below provides both the results and, for comparison, the slopes computed from the results of equation (1) in specifications (3) and (4), using equation (3).

Table 4: Slope of mark-upmax by country

Slope of markupmax in function of the rate of technical progress				
Column	(1)	(2)	(3)	(4)
Austria	7.415***	6.695**	5.566**	8.023*
	(2.480)	(2.521)	(2.327)	(4.300)
Belgium	11.708 ***	11.673***	9.651***	14.119**
	(2.786)	(2.579)	(3.582)	(7.089)
Finland	14.868***	14.490***	16.850***	23.652**
	(4.151)	(3.702)	(5.853)	(11.475)
France	16.350***	16.614***	17.014***	25.750**
	(4.034)	(3.766)	(5.426)	(11.725)
Germany	16.430***	16.751***	17.682***	26.394**
	(4.779)	(5.039)	(5.707)	(12.191)
Italy	14.076***	13.545**	13.806***	18.607**
	(4.260)	(4.974)	(4.157)	(8.446)
Netherlands	13.096 ***	12.425***	11.685***	16.053**
	(2.555)	(2.257)	(4.089)	(7.874)
Slovakia	28.314*	31.459**	23.037***	39.884**
	(14.013)	(13.768)	(7.749)	(18.447)

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

Columns (1) and (2) present the slope of markupmax according to the technical progress computed from the results of equation (6). Column (1) uses technical progress at the sector level θ_i and column (2) technical progress at the sector/country level θ_{ij}. Columns (3) and (4) provide the slopes, computed with equation (3) using the results of equation (1) in specification (3) (column (3)) and specification (4) (column (4)).

All the slopes are positive and significant, which confirms that an increase in the rate of technical progress has a positive effect on the markup that maximizes productivity growth. All the results are consistent. The differences are included in the confidence interval. The first three columns provide similar results. The fourth column provides slightly higher results; however they are, on the whole, less significant.

4 Labour productivity losses due to unsuitable markups

4.1 Sectoral analysis

In the previous section, we calculated the optimal markup for each sector in each country. This means that when a markup 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 can be considered a productivity loss. To estimate the productivity losses for each sector during each time, it is necessary to compute, on the one hand, the difference, in each period and for each sector, between the observed markup and the optimal markup:

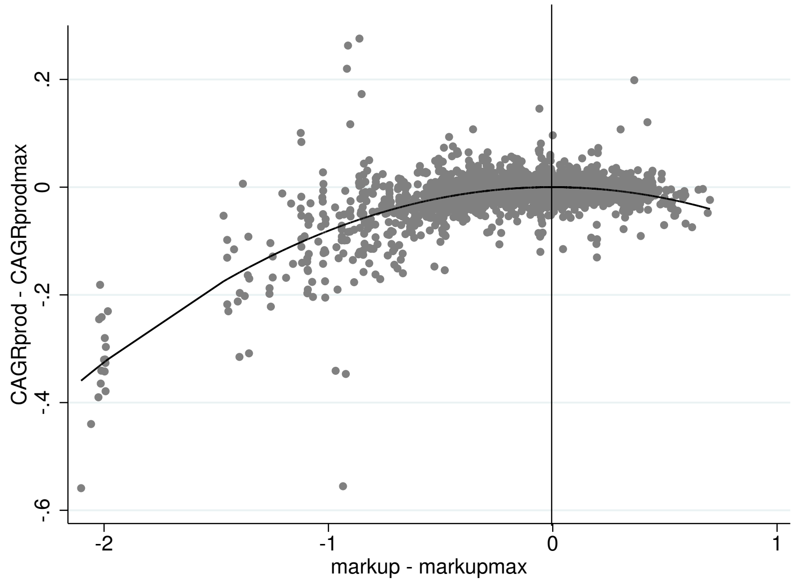
$$\Delta markup_{ijp} = markup_{ijp} - markupmax_{ij}$$

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 markups coincide with their optimal levels in each sector:

$$\Delta CAGRprod_{ijp} = CAGRprod_{ijp} - CAGRprodmax_{ij}$$

If $markupmax_i$ is the optimal markup, we can expect that the first difference $\Delta CAGRprod_{ijp}$ will increase when $\Delta markup_{ijp} < 0$ and decrease when $\Delta markup_{ijp} > 0$. Hence, an increase in the variation rate of markups leads to a decrease in the variation rate of labor productivity. Figure 3 below presents the variations in hourly labor productivity growth as a function of the markup over perfectly competitive prices.

Figure 3: Productivity losses due to unsuitable mark-ups



Each point represents a sector within a country during a specific period. The x-axis represents the difference between the actual markup and *markupmax*, the markup that maximizes productivity growth. The y-axis represents the difference between actual productivity growth and maximum productivity growth. A point located on the left side means that the markup is lower than *markupmax* and a point located on the right side means that the markup is higher. In fact, whether the markup is more or less than *markupmax*, we find that the further the markup of sectors moves away from its *markupmax*, the greater the loss in its productivity growth.

The black curve is the quadratic trend curve ($y = -0.08158x^2 - 0,00056x + 0.00003$). The maximum of this curve is very close to the point $(0, 0)$, which means that *markupmax* effectively maximizes hourly productivity growth.

4.2 Cross country analysis

The relationship between the level of competition captured by markups and the rate of labor productivity growth across 28 sectors of the 8 euro area countries over the period of 1995-2018 follows an inverted U-shaped form, which implies the existence of optimal sector-level markups that depend on the sector-specific rates of technical progress. Discrepancies between the observed and optimal markups are associated with measurable losses in the productivity rates of sectors in each country. Overall, the weighted average loss in annual productivity growth due to unsuitable sector-level markups amounts to -0.31% for the entire panel. Annual productivity rate losses by country, as shown in table 5 below, varies from -0.07% (France) to Finland (-1.39%) and Slovakia (-2.29%).

Table 5: losses of productivity growth due to unsuitable mark-ups

Country	Average annual losses	Weight on the sample
Austria	-0.68%	4.04%
Belgium	-0.23%	4.88%
Finland	-1.89%	2.41%
France	-0.07%	24.64%
Germany	-0.42%	34.81%
Italy	-0.17%	20.28%
Netherlands	-0.23%	8.13%
Slovakia	-2.25%	0.81%
All	-0.31%	100%

Cross-country variations in productivity losses would require a more in-depth analysis, based on the share of sectors in aggregate value added and their contributions to productivity growth. However, some preliminary observations could already help form hypothesis in support of Finland's greater losses due to unsuitable markups. Indeed, Finland has a relatively large share of digital sector in GDP, approximately 9% in 2016 and 2017, which appears to be in line with the share of the US' digital sector; this share is higher than both the euro area's and the European Union's average, which was limited to 6% in 2016 according to Anderton *et al.* (2021). As the digital sector provides the bulk of productivity gains in the service sector, it follows that suboptimal markups in these sectors could generate important losses in productivity. Moreover, it also appears that countries with higher average aggregate productivity growth tend to exhibit the greater losses due to unsuitable markups (Slovakia and Finland), partly because too low markups in the sectors that are the most intensive in technical progress hamper the productivity gains resulting from investment in innovation. At the sector level, it appears that the manufacturing industry tends to exhibit higher levels and growth rates of productivity than that the service sector Sorbe *et al.* (2018). The following figures show the distributions across all sectors in all countries of the sample over the period of 1996-2018: The figure 4 shows the manufacturing industry (black dots) among all sectors and figure 5 shows the service sector (black dots) among all sectors.

Figure 4: Productivity losses in manufacturing industries

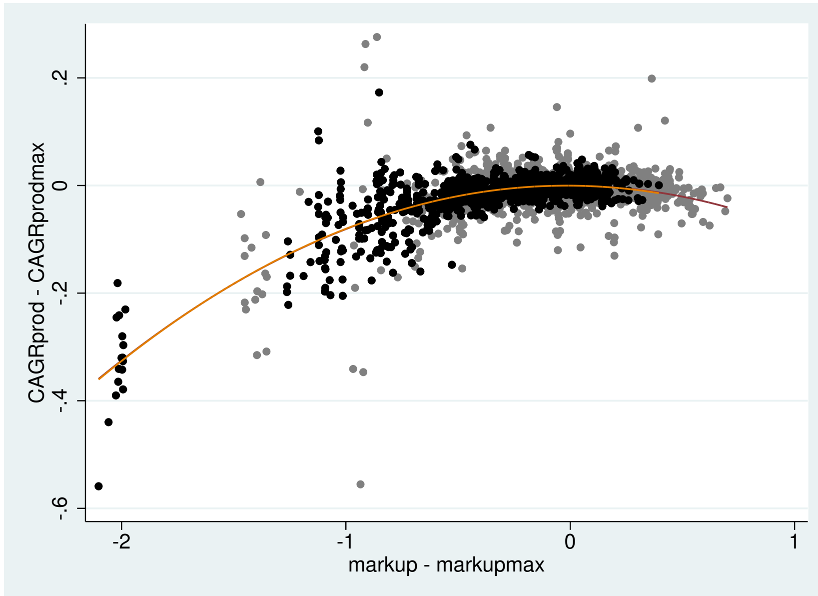
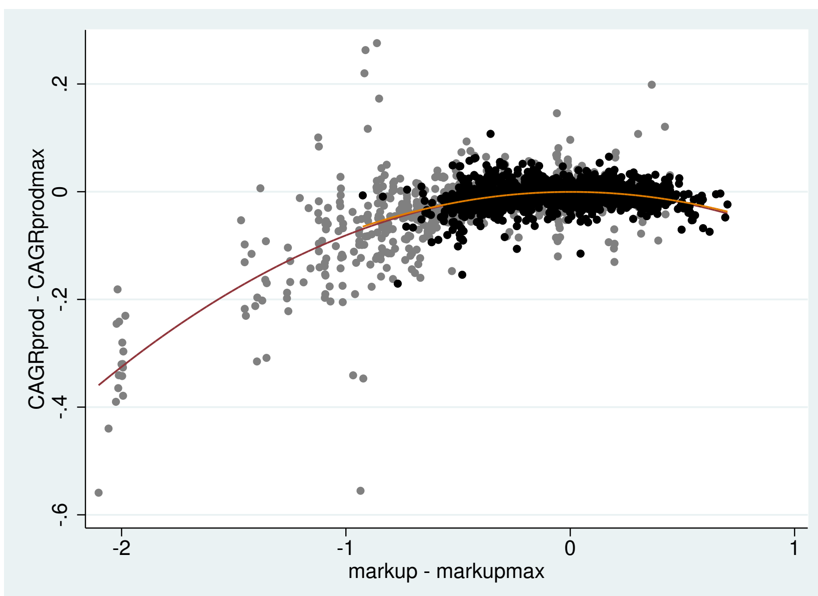


Figure 5: Productivity losses in service sector



These figures indicate that manufacturing industries tend to have suboptimal levels of markups more often than service sectors. It implies that the rates of productivity growth in the manufacturing industries are lower than the rates that would be observed if their levels of competition were set according to their rates of technical progress (which have been shown to be positively correlated to the optimal markups). As more manufacturing sectors than services sectors are located on the left side of the figure above, and as manufacturing sectors have overall higher productivity growth than service sectors, unsuitable markups in manufacturing industries might be largely responsible for to the aggregate productivity losses. However, given that digital services in general and telecommunications services in particular exhibit higher productivity gains (and have higher rates of technical progress) than most sectors of the production system, competition policies should also attempt to adjust the levels of competition to the optimal markups of these sectors. The differences between actual markup and optimal markup are associated with a decrease in the average growth rate of labor productivity, it implies that sectors with strong technical progress, should be allowed to adjust their competition intensity levels to their rates of technical progress. Otherwise, they could be prevented from achieving their full productivity gains. Digital sectors, which have high productivity growth rates (i.e., high technical progress), necessitate markups that are high enough to maximize their labor productivity growth.

5 Conclusions and policy implications

We have shown that the relationship between the levels of competition and the rates of productivity growth across 28 sectors of eight economies in the euro area over the period of 1995-2018 is in the form of an inverted U-shape. This implies that there is a unique and optimal level of competition for each sector in each country. This optimal level is defined by the price markup that maximizes the growth rate of hourly labor productivity in a sector. The significant and strong positive correlation between the optimal markup in each sector and its rate of technical progress implies that sectors with higher technical progress require higher markups to maximize their labor productivity growth. A persistence of nonoptimal markups in the production systems of the eight euro area countries is associated with a 0.31% loss in aggregate annual labor productivity growth over the period of 1995-2018. Based on these results, public policies should adjust price markups to their optimal levels to enable sectors with higher technical progress to maximize their rates of labor productivity growth. Our results indicate that the European public authorities, in assessing the level of sectors' competition intensities, should take into account the rates of technical progress. More specifically, in the digital sectors, and telecommunications services in particular, the rate of innovation is high, and the growth of labor productivity is driven by investment - or dynamic efficiency - rather than price competition - or static efficiency, as shown in Jeanjean (2015) and Houngbonon & Jeanjean (2016). Ciriani & Lebourges (2016) have demonstrated that within such high innovation sectors, higher prices do not necessarily indicate greater market power, and higher markups could reflect the uncertainty of expected returns on investment in technologies. Our research suggests that competition policies seeking to minimize market power through minimizing the price markups could shift the levels of competition beyond their optimal levels. As a result, such policies might inhibit the profit margins necessary to finance current and future investments in technologies. Reducing and maintaining price markups below their optimal levels in sectors of high innovation would hinder their contributions to the growth of aggregate labor productivity.

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Appendix

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

Starting from the neoclassical Cobb-Douglas production function:

$$Q_t = A_t \; {N_t}^{\alpha_{Nt}} \; {M_t}^{\alpha_{Mt}} \; {K_t}^{\alpha_{Kt}} \tag{7}$$

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:

$$SR_t = \Delta q_t - \alpha_{Nt}\Delta n_t - \alpha_{Kt}\Delta k_t - \alpha_{Mt}\Delta m_t \tag{8}$$

We can also calculate the dual residual based on prices:

$$SRP_t = \alpha_{Nt}\Delta w_t - \alpha_{Kt}\Delta r_t - \alpha_{Mt}\Delta z_t - \Delta p_t \tag{9}$$

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:

$$SR_t = \left(1 - \frac{1}{\mu_t}\right)(\Delta q_t - \Delta k_t) + \frac{1}{\mu_t}\theta_t \tag{10}$$

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

$$SRP_t = \left(1 - \frac{1}{\mu_t}\right)(\Delta p_t - \Delta r_t) - \frac{1}{\mu_t}\theta_t \tag{11}$$

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

$$y_t = \beta x_t + \varepsilon_t \tag{12}$$

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 12: $y_{i,p} = \beta_{i,p}x_{i,p} + \varepsilon_{i,p}$ 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:

$$CAGRprod_{ip} = \left(\frac{HPROD_{i,t_f}}{HPROD_{i,t_0}}\right)^{(t_f - t_0)} \tag{13}$$

■ Appendix 3: Calculation of technical progress:

Technical progress is given by equation (8) and equation (10).

$$\theta_{it} = \mu_{it} SR_{it} - (\mu_{it} - 1)(\Delta q_{it} - \Delta k_{it}) \tag{14}$$

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:

$$\theta g_i = \sum_{t=1979}^{2015} \theta g_{it}/37 \tag{15}$$

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