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A new unit labour cost changes decomposition

Four pillars of cost competitiveness recovery

Charles-Henri DiMaria and Chiara Peroni*

Abstract

This article presents a new decomposition of unit labour costs into compensation per worker and labour productivity, which, in turn, is decomposed into efficiency gains, technical progress and capital deepening. Data for Western European countries and the US show that the evolution of labour productivity components counteracts the deterioration in countries' cost competitiveness caused by increases in nominal wages. The policy implication is that efforts aimed at reducing nominal labour costs should be accompanied by policies fostering capital deepening. Further improvements in countries' cost competitiveness can be achieved by enhancing efficiency gains and technical progress, which has been mostly negative during the period under study.

KEYWORDS: unit labour cost, labour productivity, efficiency, technical change, capital deepening.

Competitiveness is high on the policy agenda. The recent crisis has highlighted structural weaknesses of developed economies and re-fuelled a heated debate on the causes and remedies to the high unemployment and deterioration in the economic performance of Western European countries. The budgetary tightening dictated by the public debt crisis means that limited resources are available to foster economic growth; furthermore, countries belonging to a monetary union can no longer use competitive devaluation for expanding demand. Thus, for members of the Euro zone, where monetary policy is committed to price stability, unit labour costs are crucial to attain increased competitiveness (Collignon, 1999). As devaluation is no longer possible and the EU strengthens fiscal discipline, it is proposed that economic recovery should be achieved through labour market and wage bargaining adjustments (Barkbu et al., 2012). The so-called internal devaluation proposal advocates a reduction in nominal wages as essential to exit the crisis. Others question the relevance of such policy as there is no conclusive empirical evidence showing that decreases in unit labour costs lead to the growth of export shares (Felipe and Kumar, 2011).

This short article aims to clarify the link between labour costs and countries' competitiveness. In particular, it examines the link between cost competitiveness (intended as a reduction in unit labour cost) and labour productivity and its determinants, and stresses that the latter are important sources of competitiveness. Unit labour costs (ULC hereafter) are defined as the ratio of total nominal cost per employee to real labour productivity. If in a given country total nominal costs per employee increase faster than labour productivity,

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then inflationary demand pressures may emerge and the country could lose competitiveness. Thus, ULC changes reflect the comparative evolution of total nominal costs per employee to labour productivity (e.g. Ark et al., 2005). In turn, following Kumar and Russell (2002), labour productivity changes can be decomposed into three elements: efficiency changes, technical changes and capital deepening. This allows us to highlight four components of ULC, which broadens policy perspective and enriches the analysis of ULC changes. Innovation, investment in tangible and intangible capital, labour quality and business environment come into play in a formalised manner through efficiency change, technological change and capital deepening.

This article is organised as follows. The first section presents the decomposition of ULC, and gives an economic interpretation of each of its components. Then, the following section presents real data on the evolution of each term of the decomposition for 15 European countries and the United States from 1995 to 2009. The last section concludes.

1 The decomposition of Unit Labour Costs

ULC is defined as total labour compensation (TLC) per unit of output (GDP).¹ Dividing each term by labour (L), ULC can be written as the ratio of compensation per employee to labour productivity:²

$$ULC_t = \frac{TLC_t/L_t}{GDP_t/L_t} \quad (1)$$

Changes in ULC from t to t+1 can be written as follows:

$$\frac{ULC_{t+1}}{ULC_t} = \frac{\frac{TLC_{t+1}/L_{t+1}}{GDP_{t+1}/L_{t+1}}}{\frac{TLC_t/L_t}{GDP_t/L_t}} \quad (2)$$

Taking logs and rearranging terms one has:

$$d \ln(ULC_{t+1}) = d \ln \frac{TLC_{t+1}}{L_{t+1}} - d \ln \frac{GDP_{t+1}}{L_{t+1}} \quad (3)$$

(Here d denotes change in the logarithm from t to t+1.) The equation above shows that, in order to recover cost competitiveness, a country could decrease labour cost and/or increase labour productivity. Kumar and Russell (2002), in a framework that allows for inefficiency in production, and assuming constant returns to scales technology, show that labour productivity changes can be decomposed into efficiency changes (EFF), technical changes (TECH) and capital deepening (CAP). ULC changes can be written as follows:

$$d \ln(ULC_{t+1}) = d \ln \frac{TLC_{t+1}}{L_{t+1}} - \ln(EFF)_{t+1} - \ln(TECH)_{t+1} - \ln(CAP)_{t+1} \quad (4)$$

¹Whether total labour compensation is expressed in real or nominal terms, the reasoning presented in this section remains the same.

²Ideally, a measure of ULC should be based on hours worked, especially for the purpose of international comparisons. In practice, this is not feasible due to the lack of essential data. Another data limitation concerns the composition of the workforce, which prevents us to take it into account into the computation of the TFP. This is relevant as the labor factor is not homogeneous and the most skilled workers tend to have greater productivity.

The equation above shows that an increase in 1% in efficiency (or any other components of labour productivity) lowers unit labour costs by about the same amount (*ceteris paribus*). Conversely, any percentage increase in nominal compensation per worker will increase ULC by the same amount. It should also be noted that a percent change in efficiency has the same effect than one percent change in technical progress and capital deepening on ULC. (Efficient countries, however, can only improve their ULC performance by technical change and capital deepening.)

Positive efficiency changes mean that countries moves towards best practices (the technological frontier), or maximum feasible production given inputs use. This could be achieved through improvements/changes in managerial practices, firms' decision structure and learning by doing. Such elements, under the control of the management, are among the determinants of productivity identified by Syverson (2011).³

Technical change measures technical progress, or expansions in feasible production. Technical progress reflects the ability of countries to innovate, as it results from successful research and development activities. It evolves with investments in intangible capital, which measures the amount of knowledge and organisational capital and firm-specific skills. (Corrado et al., 2009, highlight that intangibles are also a determinant of the evolution of efficiency.)

The first two components of labour productivity, efficiency and technical change, determine total factor productivity (TFP), which represents those productivity gains resulting from efficiency in combining inputs to production. (In other words, higher TFP means that one can produce more for any given combination of inputs.) As seen above, TFP changes reflect a complex mix of elements such as increase in knowledge from innovation, investment in intangible, organisational and managerial practises.

The last term, capital deepening, which summarises the contribution of the two inputs to production, capital and labour, has received various interpretations. Pilat (2004) explains that, when capital deepening increases, new capital is used, which introduces new technologies in the production process. The most interesting explanation of capital deepening is given by Frankel (1962). This author argues that firms accumulate capital in response to market conditions and economic opportunities. As a result, capital deepening increases reflect factors external to the firm that explain productivity changes, such as changes in regulatory frameworks or flexible inputs markets.

The Kumar and Russell framework has become popular in interpreting and depicting the evolution of labour productivity. Acemoglu and Guerrieri (2006) have developed a model where the engine of growth is capital deepening. Others have focused on innovation and technical progress as main determinants of growth (Romer, 1986, 1989). Empirically, it has been found that a substantial part of labour productivity growth cannot be explained by capital deepening (Fare et al., 1994).

The ULC decomposition of this section shows that increases in average compensation of workers worsen competitiveness. Conversely, countries cost competitiveness improves following improvements in efficiency and/or the occurrence of technical change and/or capital intensity increases.

The following section analyses the evolution of components of cost competitiveness reviewed in this section in real data, from 1995 to 2009. ULC is defined by total labour com-

³This list is clearly non-exhaustive, as other elements can affect efficiency. The adoption of ICT systems has also been linked to increased efficiency and productivity. On this, one can see, for example, Milana and Zeli (2002) and references therein. Others elements are organizational changes and emerging business models such as outsourcing and use of knowledge intensive business services (KIBS).

pensation (TLC) divided by labour. It is compiled by the OECD and is expressed in PPP. Output is measured by GDP and labour by number of persons employed. GDP and employment series are from the Eurostat Economy and Finance database.⁴ Estimates of capital stock are constructed using capital stock data from the EUKLEMS database and investment series from Eurostat.⁵

The components of labour productivity are computed using Data Envelopment Analysis (DEA) assuming constant returns to scale (Fare et al., 1994). The DEA method, based on the concept of production possibility sets, evaluates the performance of each economic units (countries/industries/firms) with reference to an efficient frontier, which identifies the best-practise technology using convex combinations of observed inputs and outputs. One of the main advantages of DEA is precisely that it computes different sources of TFP growth, distinguishing the effect of efficiency changes from the effect of “pure” technical progress. Another advantage is that measures of productivity are computed by using only the available data, while making minimal assumptions on the functional form of the technology (*sauf* returns to scale) or on market structure. The method, though computationally intensive, has mild data requirements and is robust to changes in the data. A brief overview of DEA, with some technical and computation details, is available in the appendix to this article.

2 Results

Table 1 shows that countries have experienced competitiveness losses from 1996 to 2009. Notably, in the aftermath of the 2007-2009 recession ULC decreased in all countries, with the exception of Luxembourg and United Kingdom.

Greece, United Kingdom and Portugal have experience the largest increase in ULC moving, respectively, from a value of 100 in 1995 to 161, 148 and 143 in 2010. (Spain’s ULC growth is also high, but data is missing for the last year.) Countries with the lowest ULC are Germany (104 in 2010, assuming a value of 100 in 1995), Austria (111) and Sweden (120). The case of Germany is interesting in the light of a study of Soskice and Iversen (2001). According to these authors, in a group of countries comprising the Netherlands, Belgium, Austria and France, large companies increasingly relate their wage increases to unit labor cost developments in Germany. The correlation of the ULC evolution in those countries to the one of Germany ranges from 0.55 for France to 0.69 for Austria.

Interestingly, the countries hit by the debt crisis (Spain, Greece, Ireland and Portugal) are among those that experienced the largest growth in ULC, which seems to support the “internal devaluation” view. Indeed, the highest deterioration in cost competitiveness occurred in Greece (3.5% average per year) followed by the UK, Spain (2.7%), Portugal (2.6%) and Ireland (2.5%). Italy’s ULC increased on average by 2.1% and, in contrast to other countries, failed to decrease during the crisis. The rise in unit labor costs in Greece, relative to the other eurozone countries, has been related to the inherent inability of the country’s trade union movement to accept real wage increases for private-sector workers in line with productivity developments (Katsimi and Moutos, 2010).

⁴The series have been converted using the PPP, which ensures comparability of aggregates across countries. PPP allow researchers to express economic variables ‘as if’ they were recorded in a single common currency. This takes into account not only nominal exchange rates but also the different price levels (purchasing powers) across countries, and ensures that, for example, variables such as GDP reflect the actual size of an economy.

⁵Details on the method used to compute the capital stock are available in Dubrocard et al. (2010).

What are the main determinants of ULC increases? Table 2 shows that the largest contributor to the deterioration of cost competitiveness is the increase in labour compensation. This is the case for all countries. One can also see that, exception made of Spain, Greece and Italy, the growth rate of labour compensation is higher than ULC changes. This implies that the evolution of labour productivity has compensated the effects of increases in labour compensation, lowering the latter's impact on ULC. In problematic countries, however, this has not happened and a lack in productivity improvements has resulted in an even bigger deterioration in competitiveness.

Table 3 summarises the evolution of labour productivity in the countries analysed. One can see that labour productivity performance was weak in all countries. Its average rate of growth was barely higher than 1% in 5 European countries (Austria, Finland, Germany, Ireland and Sweden). Overall, labour productivity deteriorated in the years post-2000 and became more volatile, with the possible exception of Germany. Labour productivity declined in many countries during the recessions of 2001-2003, but this decline was more pronounced and generalised in 2008 and 2009, with all countries recording negative rates of labour productivity growth in both years.⁶

Labour productivity declined in Italy, Spain and Greece. Tables 4-6 show the evolution of the components of labour productivity, respectively efficiency changes, technical progress, and capital deepening. (Positive figures for the logarithm of efficiency change indicate that efficiency gains have occurred.)

On average, most countries have realised efficiency gains. Efficiency has decreased only in Belgium, Spain, Italy and Portugal. After realising some efficiency gains from 1995 to 1998, the US was on the frontier for the remaining of the period. The UK was on the frontier since 2003. Also Ireland made, on average, an efficient use of inputs.⁷ Conversely, the lack of technical progress or even technical regress, have worsened the cost competitiveness performance of nearly all countries, by not reducing ULC. Only exceptions were Austria and Belgium, whereas Luxembourg's technical progress was absent (but, at least, not negative).

Whereas technical regress can be found in many studies at firm level (e.g. Sena, 2006), industry level (e.g. Tortosa-Ausina et al., 2012) and country level (e.g. Chen and Yu, 2012), only few authors have attempted to provide a plausible explanation of this result. For Lee and Johnson (2012), technical regress is often attributed to production issues when in fact it may result from lack of demand. Bontemps et al. (2012) emphasizes the negative effect of new regulations that generate negative technical progress. Last, for Sena (2006) it is a consequence of sharp recessions. Based on Caballero and Hammour (1994, 1996), this author argues that during recessions old techniques are substituted by new techniques. If the process of destruction of old techniques is faster than the creation of new techniques, firms/industries/countries are experiencing technical regress. The last term, capital deepening, has improved on average for all countries and has contributed to increase the cost competitiveness (decreases in ULC).

⁶For detailed patterns of labour productivity and its relation with technical progress and efficiency changes, one can see Peroni (2012).

⁷A zero log of efficiency means that a country is on the frontier, that is, it is making an efficient use of inputs to production. This is a positive feature of the data for a country, but it also indicates that the country in question can achieve further improvements in its economic performance only by realising substantial technical gains.

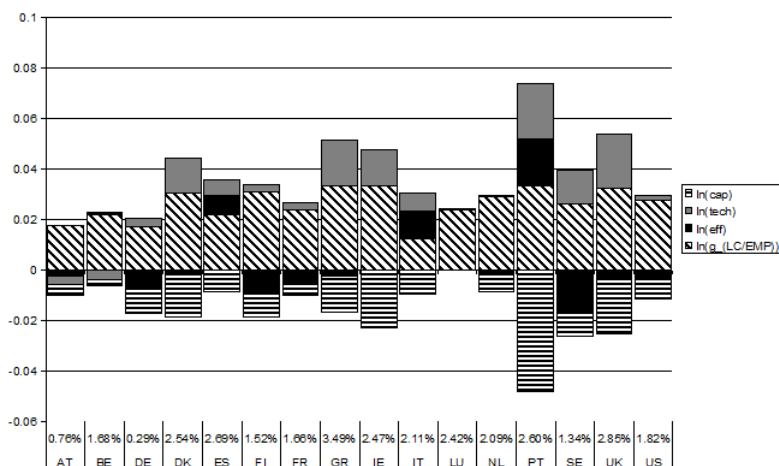


Figure 1: Decomposition of average ULC changes

3 Conclusions

Results presented in this study support the idea that policy targeted to restrain labour costs should be mitigated by efforts to improve countries economic efficiency and technological changes. Indeed, an approach based solely on the compression of labour costs has several drawbacks; lower nominal wage growth is obviously less attractive than higher productivity growth (Blanchard, 2007) and has adverse social consequences. Such drawbacks make the compression of nominal wages an unlikely and possibly unsustainable long term strategy to foster economic growth. This strategy also assumes the absence of nominal wage rigidities, which is not supported by the data (Arpia and Pichelmann, 2007, founded significant wage rigidity in the Euro Area). An alternative policy could be to lower employers' social contribution (as suggested in Siebert, 1999), which is unlikely, unless the aim is to reduce unemployment (Marx, 2001). However, the decomposition of unit labour costs presented in this document suggests that other options, such as structural reforms to foster capital deepening, new industrial organization to improve efficiency and research and development policies, could be successful in fostering countries cost competitiveness. The burden of improving unit labour cost should not fall only on labour market adjustment but also on structural reforms and the design of new production systems. The decomposition proposed in this article emphasizes the important role of intangible, supporting the finding of Corrado et al. (2009). Further research should aim to find conclusive empirical evidence that reducing unit labour cost strengthen competitiveness of countries. It should also investigate what mix of intangible assets explains efficiency gains and technical progress, and what is the optimal policy mix to foster capital deepening. A possible extension of this work is the use of industry level data to examine pattern of productivity and cost competitiveness across countries. Current issues of data availability prevented this exercise, and this is left for future work.

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Table 1: Growth rates of ULC (%) 1995-2009

Country	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	mean
AT	-0.5%	-0.2%	0.0%	-0.1%	0.8%	0.2%	1.3%	-0.7%	0.6%	1.0%	0.7%	3.3%	4.6%	-0.6%	0.7%
BE	0.2%	1.1%	1.4%	0.4%	4.2%	2.3%	1.0%	-0.6%	1.4%	1.8%	2.1%	4.3%	4.3%	-0.5%	1.7%
DE	-1.0%	0.3%	0.7%	0.5%	0.3%	0.5%	0.9%	-0.4%	-0.9%	-2.4%	-1.0%	2.2%	5.8%	-1.5%	0.3%
DK	1.0%	3.4%	1.9%	1.0%	4.1%	3.5%	2.1%	0.3%	1.9%	2.1%	4.4%	6.2%	4.7%	-1.1%	2.5%
ES	1.8%	1.8%	1.7%	2.7%	3.1%	2.8%	2.8%	2.3%	3.1%	3.1%	4.0%	4.7%	1.0%		2.7%
FI	-1.1%	1.3%	0.7%	0.6%	3.6%	0.8%	0.8%	-0.1%	2.2%	0.3%	0.5%	5.8%	7.3%	-1.5%	1.5%
FR	0.2%	-0.2%	0.8%	1.6%	2.2%	2.9%	2.0%	1.0%	1.8%	1.8%	1.5%	3.0%	3.1%		1.7%
GR	9.2%	4.7%	2.9%	1.4%	-0.7%	9.4%	1.7%	1.9%	3.5%	1.6%	3.4%	5.8%	5.4%	-1.6%	3.5%
IE	-0.1%	5.4%	1.1%	2.7%	5.9%	0.8%	3.7%	3.9%	5.2%	3.8%	3.9%	5.0%	-1.3%	-5.6%	2.5%
IT	2.7%	-2.1%	1.5%	0.3%	3.2%	3.4%	4.0%	1.7%	3.1%	1.7%	2.2%	3.9%	3.8%	0.0%	2.1%
LU	-0.1%	-1.0%	0.7%	2.5%	6.3%	2.2%	1.4%	1.2%	2.1%	1.2%	1.6%	6.0%	8.2%	1.7%	2.4%
NL	1.0%	2.5%	1.8%	3.2%	4.5%	4.5%	2.4%	0.4%	-0.3%	0.7%	1.6%	2.6%	5.1%	-0.8%	2.1%
PT	3.9%	3.3%	2.3%	4.3%	3.8%	3.2%	3.8%	1.0%	3.5%	0.9%	1.2%	3.4%	3.2%	-1.4%	2.6%
SE	0.8%	0.1%	-1.2%	4.9%	5.0%	0.5%	0.5%	-1.0%	0.4%	-0.7%	4.1%	2.7%	4.6%	-1.9%	1.3%
UK	2.4%	3.9%	2.4%	2.7%	3.3%	2.1%	2.9%	1.7%	2.5%	2.5%	2.9%	2.3%	6.0%	2.2%	2.9%
US	1.5%	2.8%	1.4%	3.6%	2.1%	0.3%	2.0%	1.4%	2.3%	3.0%	2.8%	2.8%	0.3%	-1.0%	1.8%

Note: data are yearly changes, so that figures for 1996 reflect changes of variable from 1996 to 1997. Data is missing for Spain and France in 2009. (Sources: author's calculations form Eurostat, OECD, Statac data.)

Table 2: Growth rates of labour compensation (%) 1995-2009

Country	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	mean
AT	2.3%	3.1%	2.9%	4.2%	-2.4%	4.0%	2.1%	2.2%	-0.6%	3.5%	0.9%	0.1%	-0.3%	2.0%	1.7%
BE	3.8%	-0.2%	4.9%	5.5%	2.7%	5.7%	-0.5%	-0.5%	0.3%	2.2%	2.5%	0.7%	0.0%	3.1%	2.2%
DE	1.7%	1.2%	3.5%	2.8%	1.2%	2.2%	3.3%	2.6%	2.2%	1.3%	1.0%	-0.1%	-1.3%	2.8%	1.7%
DK	3.5%	4.4%	3.8%	4.8%	1.8%	5.5%	0.1%	4.6%	0.0%	3.5%	3.9%	1.4%	0.6%	4.8%	3.1%
ES	2.5%	1.7%	1.1%	2.6%	1.3%	3.6%	-0.6%	1.0%	0.8%	4.3%	5.1%	2.8%	2.5%		2.2%
FI	2.9%	3.7%	3.2%	4.7%	1.3%	2.2%	1.2%	7.0%	2.4%	2.8%	4.2%	2.1%	0.6%	4.8%	3.1%
FR	3.7%	2.1%	3.6%	4.9%	3.2%	4.4%	-1.5%	3.0%	3.6%	2.5%	3.0%	-1.3%	-0.1%		2.4%
GR	9.9%	0.1%	4.2%	5.8%	2.9%	11.9%	1.3%	2.7%	1.3%	2.6%	2.7%	4.7%	0.0%	-3.5%	3.3%
IE	2.4%	1.4%	0.1%	3.9%	2.8%	3.5%	4.2%	5.6%	4.1%	4.5%	7.6%	-0.5%	2.4%	4.8%	3.3%
IT	3.9%	-0.8%	1.7%	1.7%	2.7%	-2.7%	0.8%	0.4%	2.8%	2.8%	4.0%	1.6%	-1.4%	0.0%	1.3%
LU	2.1%	1.8%	5.7%	5.5%	1.0%	4.1%	-0.4%	5.2%	0.2%	3.8%	2.1%	-0.1%	-0.5%	3.1%	2.4%
NL	2.6%	4.1%	4.9%	6.5%	1.4%	4.2%	-0.2%	5.3%	1.6%	2.6%	3.8%	-0.1%	-0.7%	4.5%	2.9%
PT	4.4%	2.3%	5.5%	5.8%	1.6%	2.6%	3.0%	1.0%	8.0%	2.3%	3.4%	0.3%	3.1%	3.4%	3.3%
SE	4.8%	1.7%	3.2%	8.7%	0.3%	2.5%	2.8%	6.2%	-0.8%	2.2%	6.8%	-2.3%	-2.9%	3.4%	2.6%
UK	5.5%	4.7%	4.4%	8.1%	4.9%	2.9%	1.9%	4.7%	1.9%	3.0%	1.5%	-2.0%	-0.5%	4.0%	3.2%
US	4.3%	5.6%	5.4%	5.4%	1.6%	2.0%	2.9%	3.5%	2.5%	0.9%	3.1%	-1.4%	-2.1%	4.7%	2.8%

(Sources: author's calculations form Eurostat, OECD, Statac data.)

Table 3: Labour productivity growth (2000-2009): yearly changes (%)

Country	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	mean
AT	3.4%	2.8%	3.4%	2.9%	4.4%	-3.1%	3.9%	0.8%	3.0%	-1.2%	2.5%	0.1%	-3.1%	-4.8%	1.1%
BE	2.1%	3.7%	-1.3%	3.6%	5.2%	-1.4%	3.5%	-1.5%	0.1%	-1.1%	0.5%	0.4%	-3.6%	-4.2%	0.6%
DE	3.2%	2.8%	0.8%	2.9%	2.3%	0.9%	1.7%	2.4%	3.0%	3.2%	3.7%	2.0%	-2.3%	-6.9%	1.6%
DK	3.2%	2.6%	1.0%	1.9%	3.9%	-2.4%	2.1%	-2.0%	4.4%	-1.9%	1.5%	-0.4%	-4.7%	-4.0%	0.7%
ES	0.5%	0.7%	0.0%	-0.6%	-0.1%	-1.8%	0.8%	-3.3%	-1.3%	-2.3%	1.1%	1.1%	-1.9%	1.5%	-0.2%
FI	2.7%	4.0%	2.4%	2.5%	4.2%	-2.2%	1.3%	0.5%	7.3%	0.2%	2.5%	3.7%	-3.6%	-6.4%	1.6%
FR	2.0%	3.6%	2.3%	2.9%	3.4%	1.0%	1.5%	-3.5%	2.0%	1.8%	0.7%	1.5%	-4.3%	-3.1%	1.0%
GR	-1.7%	0.6%	-4.6%	1.4%	4.5%	3.6%	2.5%	-0.4%	0.7%	-2.2%	1.0%	-0.7%	-1.1%	-5.3%	-0.3%
IE	7.9%	2.5%	-3.9%	-1.0%	1.2%	-3.0%	2.7%	0.5%	1.7%	-1.1%	0.6%	3.8%	-5.3%	3.7%	1.3%
IT	-1.0%	1.3%	1.3%	0.3%	1.4%	-0.5%	-6.0%	-3.2%	-1.3%	-0.3%	1.1%	1.8%	-2.3%	-5.1%	-0.9%
LU	0.1%	2.2%	2.9%	5.1%	3.0%	-5.2%	2.0%	-1.8%	4.1%	-1.9%	2.6%	0.6%	-6.0%	-8.4%	0.0%
NL	2.9%	1.6%	1.6%	3.1%	3.4%	-3.1%	-0.3%	-2.6%	5.0%	1.9%	2.0%	2.2%	-2.7%	-5.7%	0.9%
PT	1.2%	0.5%	-1.0%	3.3%	1.5%	-2.2%	-0.6%	-0.8%	0.0%	4.6%	1.4%	2.3%	-3.1%	-0.1%	0.8%
SE	4.8%	4.1%	1.6%	4.5%	3.9%	-4.5%	2.0%	2.4%	7.4%	-1.2%	2.9%	2.8%	-4.9%	-7.2%	1.5%
UK	2.8%	3.1%	0.8%	2.0%	5.5%	1.6%	0.8%	-1.0%	3.0%	-0.5%	0.5%	-1.4%	-4.2%	-6.3%	0.5%
US	3.3%	2.8%	2.8%	4.4%	1.7%	-0.5%	1.7%	0.9%	2.1%	0.3%	-2.1%	0.3%	-4.1%	-2.4%	1.1%

(Sources: author's calculations form Eurostat, Statac data.)

A APPENDIX: THE DEA METHOD TO MEASURE EFFICIENCY, TECHNICAL GAINS, AND PRODUCTIVITY

Table 4: Logs of efficiency 1995-2009

Country	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	mean
AT	-0.001	0.038	-0.015	0.019	-0.018	0.017	0.001	0.004	-0.010	0.036	0.002	0.014	-0.015	-0.039	0.002
BE	0.010	-0.005	-0.007	0.026	0.000	0.015	-0.016	-0.017	-0.010	0.018	0.002	0.008	-0.010	-0.030	-0.001
DE	0.000	0.025	-0.008	0.006	0.020	-0.002	0.001	0.003	0.025	0.051	0.017	0.019	-0.041	-0.014	0.007
DK	-0.014	0.033	0.007	0.016	0.005	-0.005	-0.012	0.020	0.004	0.010	-0.005	-0.010	-0.015	-0.005	0.002
ES	-0.018	0.011	-0.045	-0.016	0.000	-0.011	-0.028	-0.024	-0.012	0.003	-0.003	0.010	0.034	-0.036	-0.008
FI	0.016	0.037	-0.014	0.024	0.005	0.002	0.000	0.027	0.010	0.033	0.033	0.007	-0.052	0.005	0.010
FR	0.009	0.034	-0.013	0.015	0.016	-0.002	-0.036	-0.003	0.011	0.024	0.010	-0.001	-0.004	-0.031	0.005
GR	-0.010	0.016	-0.004	-0.001	0.046	-0.003	0.014	0.010	-0.007	0.012	0.005	0.011	0.005	-0.062	0.002
IE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.008	-0.005	0.009	-0.039	0.012	0.030	0.000
IT	-0.014	0.023	-0.036	-0.003	0.007	-0.048	-0.028	-0.013	-0.006	0.007	0.005	-0.001	-0.021	-0.023	-0.011
LU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NL	-0.008	0.027	-0.011	0.014	-0.019	-0.014	-0.022	0.012	0.011	0.036	0.019	0.016	-0.025	-0.012	0.002
PT	-0.065	-0.030	-0.048	-0.040	-0.017	-0.041	-0.044	-0.020	-0.010	-0.001	0.013	0.009	0.028	0.011	-0.018
SE	0.014	0.045	0.030	0.025	0.000	0.008	0.028	0.052	0.013	0.022	0.014	-0.014	-0.024	0.019	0.017
UK	-0.009	0.018	-0.001	0.009	0.028	0.002	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
US	0.002	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003

(Sources: author's calculations form Eurostat, Statac data.)

Table 5: Logs of technical progress 1995-2009

Country	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	mean
AT	0.022	-0.011	0.037	0.015	-0.015	0.011	0.002	0.020	-0.002	-0.014	0.001	-0.042	-0.035	0.062	0.004
BE	0.022	-0.008	0.037	0.016	-0.016	0.011	0.002	0.020	-0.001	-0.015	0.000	-0.042	-0.034	0.061	0.004
DE	0.022	-0.022	0.019	0.001	-0.026	-0.003	-0.002	0.012	-0.004	-0.018	0.000	-0.041	-0.030	0.049	-0.003
DK	0.007	-0.033	-0.001	0.001	-0.032	0.000	-0.012	-0.008	-0.017	-0.014	-0.014	-0.035	-0.048	0.019	-0.013
ES	0.022	-0.014	0.036	0.010	-0.022	0.000	-0.004	0.002	-0.013	-0.017	-0.011	-0.037	-0.031	0.059	-0.006
FI	0.022	-0.014	0.035	0.009	-0.023	-0.004	-0.006	0.005	-0.011	-0.017	-0.010	-0.034	-0.035	0.040	-0.003
FR	0.022	-0.014	0.035	0.011	-0.012	0.008	0.004	0.011	-0.005	-0.019	0.000	-0.041	-0.030	0.055	-0.002
GR	-0.001	-0.031	-0.016	-0.008	-0.041	-0.001	-0.018	-0.018	-0.019	-0.012	-0.015	-0.036	-0.054	0.011	-0.018
IE	0.011	-0.035	-0.014	-0.008	-0.042	-0.010	-0.024	-0.015	-0.019	-0.014	-0.014	-0.035	-0.038	0.058	-0.014
IT	0.022	-0.019	0.027	0.005	-0.022	-0.003	-0.008	-0.004	-0.016	-0.015	-0.013	-0.034	-0.043	0.022	-0.007
LU	0.021	0.028	0.047	0.031	-0.048	0.016	-0.019	0.035	-0.015	0.023	0.007	-0.058	-0.087	0.013	0.000
NL	0.022	-0.014	0.036	0.013	-0.011	0.001	-0.004	0.008	-0.006	-0.019	-0.001	-0.041	-0.033	0.038	-0.001
PT	-0.001	-0.031	-0.016	-0.016	-0.046	-0.022	-0.019	-0.007	-0.017	-0.014	-0.019	-0.035	-0.065	-0.003	-0.022
SE	0.022	-0.030	0.003	0.001	-0.033	0.002	-0.020	-0.015	-0.020	-0.013	-0.015	-0.035	-0.050	0.015	-0.013
UK	-0.001	-0.031	-0.016	-0.016	-0.046	-0.022	-0.019	-0.005	-0.016	-0.011	-0.018	-0.036	-0.065	-0.001	-0.022
US	0.022	-0.019	0.027	0.007	-0.018	0.003	0.002	0.012	-0.005	-0.019	-0.007	-0.037	-0.035	0.038	-0.002

(Sources: author's calculations form Eurostat, Statac data.)

Table 6: Logs of capital deepening 1995-2009

Country	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	mean
AT	0.007	0.007	0.007	0.009	0.001	0.009	0.005	0.005	-0.001	0.003	-0.001	-0.004	0.001	0.003	0.004
BE	0.004	0.001	0.006	0.009	0.002	0.008	0.000	-0.002	0.000	0.001	0.002	-0.003	0.001	0.005	0.002
DE	0.005	0.006	0.017	0.015	0.015	0.022	0.025	0.016	0.010	0.004	0.002	-0.002	-0.001	0.007	0.010
DK	0.032	0.010	0.013	0.022	0.003	0.025	0.004	0.030	-0.006	0.019	0.015	-0.003	0.022	0.045	0.017
ES	0.003	0.002	0.002	0.005	0.004	0.019	-0.002	0.009	0.002	0.025	0.024	0.008	0.012	0.009	0.009
FI	0.001	0.001	0.004	0.007	-0.004	0.015	0.010	0.038	0.004	0.008	0.013	-0.010	0.021	0.019	0.009
FR	0.005	0.003	0.007	0.007	0.007	0.009	-0.003	0.012	0.013	0.003	0.005	-0.001	0.003	0.006	0.005
GR	0.017	-0.031	0.034	0.053	0.030	0.029	0.000	0.015	0.003	0.010	0.004	0.014	-0.005	0.031	0.014
IE	0.014	-0.005	0.004	0.020	0.011	0.036	0.029	0.032	0.016	0.025	0.042	0.018	0.062	0.016	0.023
IT	0.005	0.008	0.011	0.012	0.010	-0.011	0.004	0.004	0.019	0.019	0.027	0.012	0.011	0.001	0.009
LU	0.001	0.001	0.003	-0.001	-0.005	0.003	0.002	0.005	-0.003	0.003	-0.001	-0.004	-0.001	0.001	0.000
NL	0.002	0.003	0.005	0.007	-0.002	0.010	-0.001	0.028	0.013	0.003	0.003	-0.002	-0.001	0.026	0.007
PT	0.072	0.051	0.096	0.071	0.041	0.057	0.055	0.028	0.072	0.029	0.028	-0.006	0.036	0.041	0.048
SE	0.004	0.001	0.011	0.012	-0.014	0.010	0.016	0.035	-0.005	0.019	0.029	-0.001	-0.001	0.019	0.010
UK	0.041	0.022	0.036	0.061	0.035	0.028	0.000	0.035	0.010	0.016	0.004	-0.006	0.000	0.019	0.021
US	0.004	0.007	0.016	0.011	0.013	0.014	0.007	0.009	0.008	-0.002	0.009	-0.005	0.010	0.018	0.009

(Sources: author's calculations form Eurostat, Statac data.)

A Appendix: the DEA method to measure efficiency, technical gains, and productivity

The calculations of TFP components carried out in this article uses a framework originally developed by Farrell (1957) for measuring the *productive efficiency* of economic units. In this framework, production sets and distance functions generalise the idea of production function. Production sets define technology in terms of feasible input/output sets; distance functions

measure operating efficiency by comparing observed output to the boundary of the production set (the frontier). Distance functions offer a mean of comparing different units in terms of their position to the frontier, and to study the evolution of the units' performance when the structure of technology changes.

Assume that each economic unit — or Decision Making Unit (DMU) — produces a single output, denoted by y , using a vector of input $\mathbf{x} \in R_+^N$.⁸ Formally, the **production possibility set** in period t is as follows:

$$S_t = \{(\mathbf{x}_t, y_t) : \mathbf{x}_t \text{ can produce } y_t\}; \quad (5)$$

Here, The set S represents all feasible input/output vectors (\mathbf{x}, y) such that using \mathbf{x} one can produce y . The boundary of S , the *frontier*, gives the maximum output obtainable from a given amount of inputs use. DMUs operating on the frontier are said to be efficient because they make full use of the inputs. The **output distance function** describes all operating DMUs in terms of their *relative* position to the frontier:

$$D^t(\mathbf{x}_t, y_t) = \inf\{\theta : (x_t, \frac{y_t}{\theta}) \in S_t, \theta \geq 0\}; \quad (6)$$

Here, D gives the smallest (*infimum*) of the set of real numbers θ , where θ is such that the input/output combination (\mathbf{x}_t, y_t) belongs to the production possibility set S_t .⁹ $D^t(\mathbf{x}_t, y_t)$ measures the reciprocal of the required expansion in output given inputs \mathbf{x}_t to attain the frontier defined by S_t . D takes the value of 1 for those DMUs on the frontier and less than 1 for those DMUs below the frontier. Larger values of D are associated to units closer to the frontier.

The DEA method (Charnes et al., 1978) provides a way of computing distance functions. DEA selects the most efficient unit for each observed combination of input (that is, the unit which produces the highest amount of output), and constructs the frontier by joining the set of points represented by those efficient units. This is done by solving the following linear programming problem (LP):

$$\begin{aligned} & \max_{\lambda, \Phi} \quad \lambda_0 \\ & \text{s.t.} \quad \sum_{j=1}^J x_{ij} \phi_j \leq x_{i0}, \quad \text{for every } i \\ & \quad \quad - \sum_{j=1}^J y_j \phi_j + \lambda_0 y_0 \leq 0 \\ & \quad \quad \Phi, \lambda \geq 0 \end{aligned} \quad (7)$$

Here, the subscripts i and j index, respectively, inputs and DMUs; Φ is a vector ($J \times 1$) of coefficients for the DMUs; λ is a score to be maximized. (The subscript 0 indicates that the problem is solved with respect to a reference DMUs.) Intuitively, the LP problem above seeks the biggest possible expansion of the output of DMU₀, while remaining within the feasibility set. The solution gives a score for each DMU, λ_0^* ; the efficiency measure for DMU₀ is equal to the reciprocal of such score: $E_0 = 1/\lambda_0^*$. The DMUs with a score equal to 1 will define the efficient frontier.¹⁰

⁸Economic units, object of the efficiency analysis, may indicate firms, industries, regions, countries.

⁹The term *infimum* denotes the lowest bound of the set θ .

¹⁰The formulation of problem 7, also referred to as the envelopment form, represents the dual of a non-linear fractional problem. Charnes et al. (1978) shows how the original problem, which minimises a ratio of input on output, can be transformed into a linear score problem. This clarifies the link between the linear program and

Clearly this method avoids the use of a tightly specified production function for which parameters should be estimated, but it is computationally intensive. Moreover, this approach does not require assumptions on the market structure (ie perfect competition), and permits different specifications of returns to scale technologies. Distance functions can also be used to construct productivity indices, as outline in the remaining of this appendix.

Caves et al. (1982) first proposed the use of the Malmquist index to measure productivity changes. Given two time period t and $t + 1$, the Malmquist index of productivity is defined as follows:

$$M^{t,t+1} = \left[\left(\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \right) \left(\frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} \right) \right]^{\frac{1}{2}}; \quad (8)$$

The index is given by the ratio of distance functions obtained by comparing output to inputs in time t and time $t + 1$ using a given reference technology. (Here, the geometric averages of indices obtained using both S^t and S^{t+1} production sets avoids the arbitrary choice of a reference technology.) In other words, equation 8 considers how much a unit could produce using the inputs available in $t + 1$, if it used the technology at time t , and how much a unit could produce using the inputs available in t , if it used the technology available in $t + 1$.¹¹ Fare et al. (1994) showed that equation 8 can be decomposed into efficiency gains and technical progress, as follows:

$$M^{t,t+1} = \underbrace{\frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)}}_{\text{efficiency gains}} \underbrace{\left[\left(\frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \right) \left(\frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)} \right) \right]^{\frac{1}{2}}}_{\text{technical progress}}; \quad (9)$$

Here, the first term — a ratio of distances to the frontiers in period t and $t + 1$ — represents the pure change in efficiency. The second term, which measures the shifts in the frontier, provides a measure of technical change.¹² This is achieved by comparing, for the same level of inputs (in t or $t + 1$), the distance functions obtained under the technology in t and $t + 1$. (Once again, we have a geometric mean of ratios obtained under the technology in t and $t + 1$.)

the measurement of productive efficiency. The score formulation reduces the dimensionality of the problem as the number of constraints is equal to I (number of inputs) rather than J (number of DMU). The optimisation problem presented here is an output-oriented version, but it is also possible to formulate the problem as an input-oriented one. In the latter case, we seek the biggest possible reduction in inputs' use, while keeping output levels constant.

¹¹One can see that practical implementation requires the solution of 4 LP problems.

¹²In this framework, technical change means an expansion of the production possibility set.