Focus

I. The knowledge drivers of total factor productivity

Over the past 15-20 years, the euro area's productivity record has been hampered by a significant deceleration in the growth of total factor productivity (TFP). In the long run, TFP is the main driver of income per capita. The decelerating trend is all the more worrying given that the euro area is facing a number of serious medium- to long-term growth challenges, including population ageing and the negative effect of the crisis on potential output. Tackling the deceleration in TFP growth requires a good understanding of its main causes. This focus section offers new empirical insights into the key knowledge determinants of TFP. It shows that a significant part of the deceleration of trend TFP in euro-area Member States can be explained by changes in the skill composition of the labour force as well as by trends in domestic and foreign knowledge capital stocks. In particular, most Member States show a declining contribution from skill improvements to TFP. In many euro-area Member States, the contribution of knowledge capital to TFP has been depressed by adverse trends in domestic knowledge investment. Finally, the analysis also shows the importance of cross-border knowledge spillovers. Slower accumulation of knowledge capital at the world level, reflecting in particular a slowdown in US R&D efforts, has weighed on TFP growth in the euro area.

This focus section looks into the deceleration of total factor productivity (TFP) in the euro area since the mid-1990s and the role it has played in influencing overall euro-area potential growth rates over this period. The sharp reversal in euro-area TFP fortunes over the last 15-20 years is in marked contrast to equivalent US trends. It is particularly worrying given the crucial role of TFP in driving sustainable per capita income trends, but also in the light of the likely impact of the financial crisis on potential output and of the economic 'headwinds' emanating from an ageing population structure.

Tackling the deceleration in TFP growth is at the top of the agenda for policy makers in the euro area. This does, however, require a deeper understanding of its main causes. This focus section offers new empirical insights into the key knowledge determinants of TFP. Its main aim is to assess the extent to which overall trends in TFP can be explained by factors such as the skill composition of the labour force and trends in domestic and foreign knowledge capital stocks.

I.1. Recent developments in potential growth

Any meaningful analysis of cyclical developments, of medium-term growth prospects or of the stance of fiscal and monetary policies is predicated on either an implicit or an explicit assumption concerning the rate of potential output growth. Such pervasive usage in the policy arena reflects the fact that potential output constitutes the best composite indicator of the aggregate supply-side capacity of an economy and of its scope for sustainable, non-inflationary growth.

In the production function (PF) framework used in this section, potential output is estimated by combining the inputs of labour, capital and TFP. ([1]) Whilst the primary focus is on deepening our understanding of TFP trends, it is important to place these trends in the wider perspective provided by overall potential growth rate developments. The remainder of this introductory section draws on Graph I.1 to identify some important stylised facts regarding overall potential growth and its underlying determinants over the last few decades. It first looks at trends in the pre-crisis period and then discusses the impact (so far) of the crisis on potential.

Pre-crisis trends in potential growth

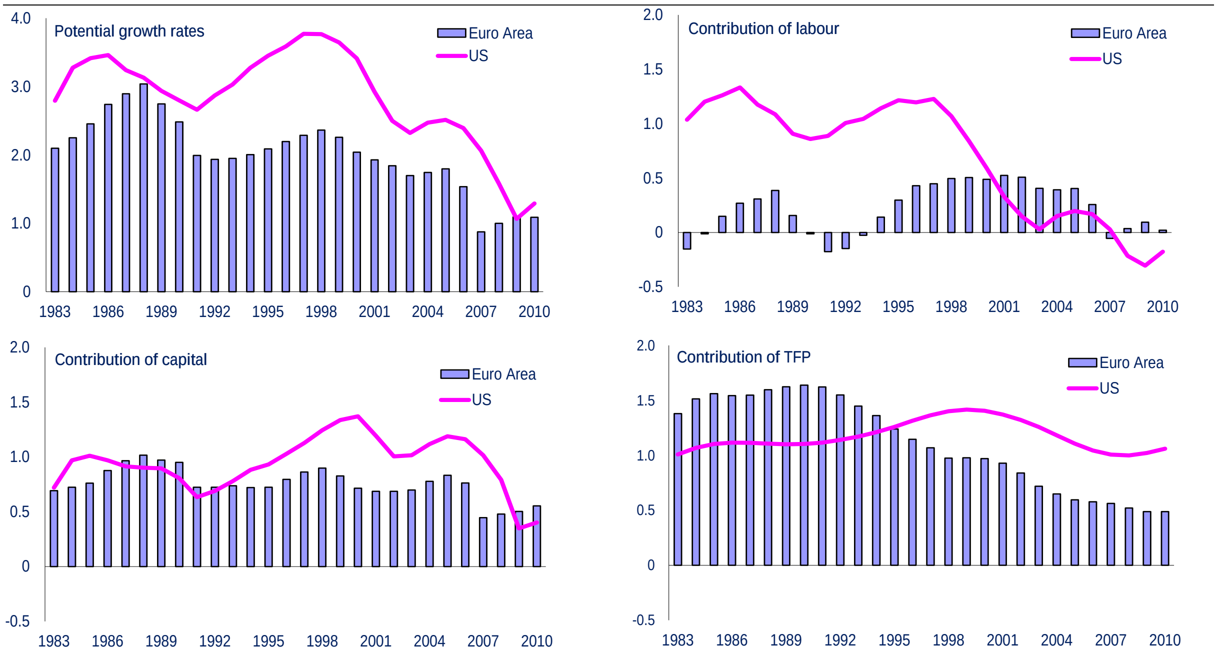
When we examine potential growth rate developments in the euro area and the US in the decades leading up to the crisis, a number of key facts emerge:

- Firstly, the US has clearly had higher potential growth over the period considered (1983-2007), with rates of growth of 3 % compared with 2¼ % in the euro area and this growth rate differential expanding to a full percentage point over the period 1995-2007. ([2])
- Secondly, there have been dramatic shifts in the contributions to growth from labour, capital and TFP in both regions over the period

([1]) See Solow, R.M. (1957), 'Technical change and the aggregate production function', *Review of Economics and Statistics*, Vol. 39, No 3, pp. 312-320.

([2]) Growth rates refer to aggregate potential. When population dynamics are taken into account, GDP per capita income trends in the US and the euro area have been broadly comparable in recent decades.

Graph I.1: **Comparison of euro-area and US potential growth rates and determinants (annual growth rates in %, 1983-2010)**



Source: Commission services.

1983-2010. Whilst the US outperformance over the first half of the period was driven by more favourable labour input trends, over the second part it was labour productivity developments that were the key driver, with US investment spending (relative to labour input growth) and TFP trends easily outperforming those of the euro area. ([3])

- Regarding labour market developments, the US outperformance for 1983-1994 was striking, with a contribution to overall potential growth of 1.1 % pp compared with 0.2 % pp for the euro area. This US performance was driven by much stronger demographic developments (also owing to higher inward migration), by lower rates of structural unemployment and by substantially higher labour force participation rates. Differences with the US in the contribution of labour have, however, been significantly reduced since the mid-1990s, with a number of euro-area Member States pursuing significant labour market reforms that have resulted in both reduced rates of structural unemployment, especially in the post-2000 period, and a large increase (i.e. of the order of 6 % pp) in participation rates to levels close to those of the US.
- Regarding labour productivity trends, whilst US/euro-area growth differentials were generally small for the period 1983-2007 as a whole, this relatively reassuring picture evaporates when one looks at the development of productivity over the second half of this period, i.e. 1995-2007. Since the mid-1990s, the US has experienced substantially higher contributions to growth from both total investment spending and TFP. As shown in Graph I.1, the deterioration in the euro area's productivity performance was not due to the contribution from capital accumulation, which remained remarkably stable over the period as a whole. The deterioration reflected a sharp downward movement in TFP growth rates, from a situation where the euro area was outperforming the US by close to half a percentage point, on an annual average basis, to the exact opposite situation where the euro area was experiencing TFP growth rates that were half a percentage point lower.

Impact of the financial crisis

A review of the literature on past financial crises, including the experiences of countries such as Finland, Sweden and Japan in the early 1990s, points to a number of important influences on the development of the different components of

([3]) Van Ark, B., M. O'Mahony and M. Timmer (2008), 'The productivity gap between Europe and the US: Trends and causes', *Journal of Economic Perspectives*, Vol. 22, No 1, pp. 25-44.

Box I.1: **Knowledge as a source of growth**

Standard growth models emphasise the role of physical capital and total factor productivity (TFP) as sources of growth. In fact TFP has always been regarded as the fundamental driver of growth and essentially the only determinant of long term per capita GDP growth (see, for example Solow (1957). Unfortunately, TFP was a black box and its determinants not further specified. This picture has changed with contributions from Romer (1986 and 1990), Lucas (1998), Aghion (2006), Jones (1995a and 1995b) and others who have introduced new growth enhancing factors, in particular knowledge creation, into growth models.

There are various ways in which one can look at knowledge creation. Broadly one can distinguish models which emphasise human capital formation or skill upgrading in the form of time spent on education and training (e.g. Lucas), whilst other models directly focus on R&D investment. The former approach models knowledge as a human capital formation problem at the household level whilst the latter approach emphasises knowledge investment decisions at the firm level. Both approaches are complementary and only focus on different aspects of knowledge creation. This explains the focus of the empirical analysis presented in this section on both skills and R&D.

By linking TFP to knowledge investment, these models opened the way to also empirically assessing knowledge as a source of growth. However, alternative models make radically different predictions about the impact of knowledge inputs on growth. In particular early generations of endogenous growth models (e.g. Romer) predicted a link between a (permanent) change in the level of knowledge inputs and the (long-run) growth rate of productivity, whilst later vintages of growth models (the so called semi-endogenous growth models) pioneered by Jones, for example, predict that changes in the level of knowledge will only lead to temporary (albeit rather persistent) growth effects, with the economy eventually settling down at a permanently higher level of productivity.

Consequently, the endogenous and semi-endogenous views on the impact of knowledge inputs have obviously drastically different growth implications. Whilst the endogenous view is optimistic concerning the impact of knowledge on generating growth, the semi-endogenous view arrives at the conclusion that only rising knowledge efforts can sustain past growth rates of productivity. Potentially the semi-endogenous growth view could explain why productivity in the EU has a tendency to decline despite either constant R&D shares or increasing efforts to lift the level of education. This view is also consistent with the observation that fairly constant growth in productivity over more than a century in the US is associated with ever increasing shares of knowledge inputs (see Jones (2002)).

Eventually the decision as to which model is correct is an empirical matter and one has to look at the crucial parameters which determine the growth dynamics. In fact, the crucial parameters that have been identified by growth economists are values for the output elasticity of physical capital (in models focussing on education) and parameters determining the elasticity of R&D in the creation of knowledge. Consider for example the effects of skill upgrading in an otherwise standard neoclassical production function :

(1) $$Y_t = K_t^{\alpha}(L_t H_t)^{\beta} A_t^{\theta} \quad with \;\; \alpha \leq 1, \beta > 0, \theta > 0$$

where *Y*, *K*, *L* and *A* denote GDP, capital, physical labour and TFP respectively and where *H* is a human capital or skill index. Assume the skill index is increased by x%. This leads to a direct increase of *Y* by $\beta * x\%$ but it will also have sustained second round effects, since it increases the marginal product of capital (MPK), which leads to higher physical capital. Notice, however, that this can only set in motion a sustained increase in the growth of GDP if the increase of capital does not lead to a decline in MPK i.e. only in the borderline case $\alpha = 1$. For all other parameter values, growth will eventually level off and the long run output multiplier is given by:

(2) $$\frac{dy}{dh} = \frac{\beta}{1-\alpha}$$

where *dy* and *dh* are % changes in *Y* and *H* respectively. Empirical estimates for the output elasticity of capital (α) (from growth regressions) clearly support the view that α is well below one, supporting the more pessimistic view.

Similar considerations apply to models that stress R&D as a source of growth and consider TFP as being proportional to a knowledge capital stock which is produced with R&D inputs/labour (*LA*) via the following knowledge production function:

(3) $$\Delta A_t = A_{t-1}^{\phi} LA_t^{\rho} \quad \text{with} \;\; \phi \leq 1, \rho > 0$$

(Continued on the next page)

Box (continued)

For this model too, it can be shown that only if $\phi = 1$, will a level shift in R&D inputs lead to a sustained increase in the growth rate of knowledge/TFP, while for all other parameter values a permanent increase in the level of R&D will only increase the level of TFP, with :

(4) $$\frac{da}{dla} = \frac{\rho}{1-\phi}$$

Also in the case of knowledge production functions, the empirical evidence points in the direction of $\phi < 1$ (Bottazzi & Peri 2003, Jones 1995a & 1995b), i.e. decreasing returns from new knowledge with respect to existing knowledge.

The empirical analysis from which the results in this focus section are derived follows the semi endogenous paradigm, i.e. the standard specification of capital in the production function is retained by imposing an output elasticity of capital which is close to one minus the wage share. A knowledge accumulation equation is estimated which imposes the constraint that level shifts in R&D inputs only lead to long run level shifts of output. In addition, a distinction is made between domestic knowledge A^D and foreign knowledge spillovers A^F. For each country, foreign knowledge is a positive function of the knowledge stock in the rest of the OECD area. Finally, the model allows for exogenous shocks to TFP (U).

(1') $$Y_t = K_t^{\alpha} (L_t H_t)^{\beta} A_t^{D,\theta d} A_t^{F,\theta f} U_t$$

The skill index H is defined as a function of the skill composition between low, medium and high skilled workers L_L, L_M and L_H respectively.

(5) $$H_t = \frac{\left(L_{L,t}^{\gamma L} L_{M,t}^{\gamma M} L_{H,t}^{\gamma H}\right)}{L_t} \quad \text{with } L = L_L + L_M + L_H$$

In the index, skills are ranked by their respective output elasticities ($\gamma L < \lambda M < \gamma H$) and these output elasticities are measured using information about average skill wage differentials.

Thus the measure of (trend) TFP is given by :

(6) $$\log(TFP_t) = \gamma_L \log\left(\frac{L_{L,t}}{L_t}\right) + \gamma_M \log\left(\frac{L_{M,t}}{L_t}\right) + \gamma_H \log\left(\frac{L_{M,t}}{L_t}\right) + \theta_d \log(A_t^D) + \theta_f \log(A_t^F) + u_t$$

This equation forms the basis of the TFP growth accounting exercise.

<u>References:</u>

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Cincera, M. and B. van Pottelsberghe de la Potterie (2001), "International R&D spillovers: a survey", *Brussels Economic Review*, Vol. 169, pp. 3-31.

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Lucas, R. (1988), "On the mechanics of economic development", *Journal of Monetary Economics*, Vol. 22, pp 3-42.

Planas.C., W.Roeger and A. Rossi (2011) "Explaining TFP" (DG ECFIN Economic Papers series, forthcoming)

Romer, P. (1986), "Increasing returns and long-run growth", *Journal of Political Economy*, Vol. 94, No. 5, pp 1002-1037.

Romer, P. (1990), "Endogenous technological change", *Journal of Political Economy*, Vol. 98, No.5, pp S71-S102.

Van Ark, B., J. Hao, C. Corrado C. Hulten (2009), "Measuring intangible capital and its contribution to economic growth in Europe", *EIB papers*, Vol.14, No. 1, pp 62-93.

potential growth in the post-crisis period. ([4]) With respect to labour, available research suggests that the length of the downturn in the aftermath of the crisis is pivotal in determining the extent of damage to an economy's underlying labour potential. A crisis can also reduce potential output in the short term through its adverse effects on investment. Given the unprecedented financial market problems, it is expected that the price and volume of capital will be affected but there is also a distinct risk of having an impaired capital allocation system. Deficiencies in the allocation function may result not only in a more anaemic investment trend in the recovery phase but also in a less than optimal reallocation of capital resources to aid the crucial restructuring of economies. With respect to TFP, economic theory and pre-crisis empirical evidence do not give a clear answer as to what the expected impact of the crisis on long-run TFP might be. Besides a number of mechanisms that tend to dampen TFP in the immediate aftermath of a crisis, including pro-cyclical R&D spending and higher risk premiums for venture capital financing, there are also arguments that downturns can have a positive TFP impact via a process of constructive restructuring and cleansing in the economy. ([5])

A look at the post-crisis evidence to date tentatively suggests that the severe economic shock has led to a significant downward revision in euro-area and US potential growth over the short run, with both euro-area and US rates falling by three quarters of a percentage point in 2010 compared to 2007. In terms of the components of growth, the results are broadly in line with the expected effects for labour, capital and TFP:

- Regarding labour, the crisis has produced substantial, short-run reductions in the growth contribution from labour in both the euro area and the US. The US has been relatively more affected on this front, with structural unemployment rising significantly compared with the pre-crisis period, compounded by a sharp fall in participation rates. ([6])
- As to capital, in keeping with the conclusions of the literature and the experiences of countries such as Finland, Sweden and Japan, the contribution of capital to growth in both the US and the euro area has been markedly reduced over the short run, with again the US being relatively more affected.
- For TFP, the results need to be assessed against the *a priori* assumption that the final long-run outcome is dependent on a range of offsetting positive and negative factors. In the short run, this balancing act would be expected to produce a negative overall impact, with one-off downward level shifts in TFP in a few crisis-related industries being a possible explanation. This is what appears to have happened so far, with both US and euro-area TFP growth rates declining compared with the pre-crisis period. It is hoped that these losses will be gradually recouped over the medium to long term, as gains from restructuring efforts start to emerge.

In overall terms, the results for the period since the start of the crisis look to be broadly consistent with the mainstream predictions from the literature and from an analysis of a number of relevant individual country experiences. The crisis has resulted in a sharp, short-run downturn in potential growth rates. In addition, although the growth rate effects of the crisis are likely to be transitory, the initial fall in growth combined with a relatively slow return to pre-crisis rates over subsequent years is expected to produce a substantial loss in the euro area's level of potential output. Such losses in levels will have significant implications in terms of the living standards and fiscal capacity of the most affected euro-area economies.

Looking further ahead, concerns regarding potential output relate not only to unfavourable pre-crisis trends and to the negative impact of the crisis but also to the fact that, in the coming years, labour market developments will increasingly be dominated by the impact of ageing populations and its negative effect on labour supply. As capital accumulation is essentially driven over the long run by the emerging labour and TFP trends, it is clear that the euro area's future growth prospects, especially its per capita income trends, will be largely determined by what happens to TFP. ([7]) It is therefore critical to better understand the fundamental drivers of TFP. The next section goes on to look more deeply into the TFP concept

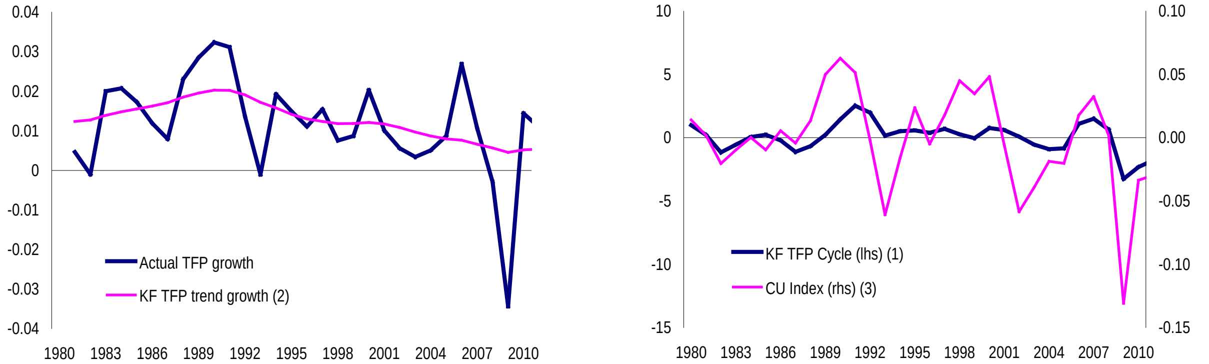
([4]) See, for example, Cerra, V. and S. Saxena (2008), 'Growth dynamics: the myth of economic recovery', *American Economic Review*, Vol. 98, No 1, pp. 439-57; Haugh D., P. Ollivaud and D. Turner (2009), 'The macroeconomic consequences of banking crises in OECD countries', *OECD Economic Department Working Paper*, No 683.

([5]) See, for example, Caballero, R.J. and M.L. Hammour (1994), 'The cleansing effect of recessions', *American Economic Review*, Vol. 84, No 5, pp. 1350-68.

([6]) See European Commission (2011), 'European economic forecast — Autumn 2011', *European Economy*, No 6.

([7]) See Easterly, W. and R. Levine (2001), 'It's not factor accumulation: Stylized facts and growth models', *World Bank Economic Review*, Vol. 15, No 2, pp. 177-219.

Graph I.2: **Official TFP estimates for Germany (annual growth in %, 1980-2010) (1)**



(1) TFP estimates calculated using the EPC's commonly agreed methodology for potential growth. (2) KF = Kalman filter (3) CU = Capital utilisation in level terms, normalised
Source: Commission services.

and, in particular, its key knowledge determinants, including the skill composition of the labour force, the scale and efficiency of domestic research efforts and the importance of spillovers from the technological frontier. ([8])

I.2. A deeper analysis of TFP and of its fundamental drivers

Estimating TFP is not straightforward since it is not a directly observable variable. There are two broad approaches to calculating trend TFP: an indirect approach, which focuses on isolating the cyclical component of actual TFP, and a direct approach, which focuses on isolating observable knowledge determinants of TFP. ([9])

Following an analysis by the EU's Economic Policy Committee (EPC) of the advantages and disadvantages of both approaches, it was agreed that the indirect approach was the better method for official EU policy surveillance purposes. This conclusion reflected the significant limitations with structural models in that it is difficult to be sure that all of the key drivers are taken into account, and structural breaks are common. Focusing on isolating the cyclical component of the TFP series ensures that the signals from the most recent data indicators can be taken on board and that turning points can be more quickly established. Whilst the indirect approach has many advantages, its key drawback is that it gives no explanation of the structural determinants that are driving trend TFP developments. Consequently, it is essential to supplement the official method with a more structural analysis of the determinants of TFP. This is what is done hereafter, with the first half of the section giving the official trend TFP estimates and the second half then providing an overview of the supplementary structural analysis, focusing on the role of the knowledge capital stock and the skill composition of the labour force. Whilst this supplementary analysis has been carried out for 11 EU countries, the US and Japan, the objective of this section is to illustrate the usefulness of this approach, with Germany (a good proxy for the euro area as a whole) and the US being discussed in some detail.

Official trend TFP estimates

The trend TFP calculations are a fundamental component of the commonly agreed methodology for estimating total potential growth rates for EU Member States. Trend TFP is estimated using a bivariate Kalman Filter model for 18 of the 27 Member States, with a simple HP filter being used for the remaining 9 Member States where short sample lengths preclude the use of the Kalman Filter. Both filtering approaches aim to isolate the cyclical component of actual TFP. In the case of the Kalman Filter, it does this by exploiting the link between the TFP cycle and the degree of capacity utilisation (CU). Survey data in manufacturing, services and construction are used to derive a CU index (see Graph I.2). ([10])

As shown in Graph I.3, German TFP growth rates have fallen by roughly 1 pp from around 1½% in the mid-1990s to ½% in 2010, a pattern almost identical to that for the euro area as a whole. The

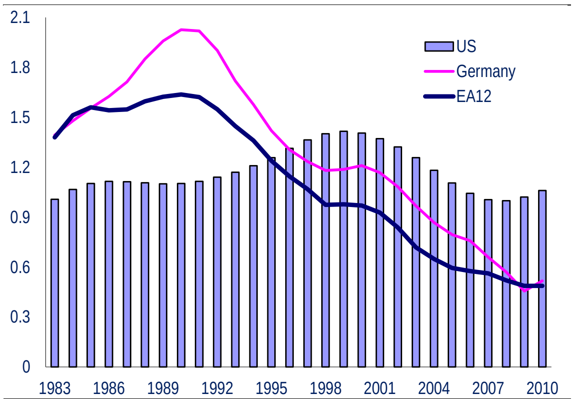
([8]) See Griliches, Z. (1979), 'Issues in assessing the contribution of research and development to productivity growth', *Bell Journal of Economics*, Vol. 10, No 1, pp. 12-116.

([9]) For examples of the latter see, for example, the work of Jones (1995b and 2002) cited in Box I.1.

([10]) The data come from the EU harmonised business and consumer surveys.

graph also shows that Germany and the euro area experienced a much greater decline in TFP growth rates compared with the US over the same period. ([11])

Graph I.3: **TFP growth rates for the euro area, the US and Germany (in %, 1983-2010)**



Source: Commission services.

Knowledge determinants of TFP

In order to isolate those factors which can explain this relatively poor German and euro-area performance, the cyclically focused analysis is supplemented with a more structural approach. The structural analysis has so far been carried out for 13 countries, but this focus section concentrates in particular on the specific cases of Germany and the US.

The structural analysis focuses on two main drivers of TFP: changes in human skills and in the quantity and efficiency of domestic and foreign knowledge investments. For the latter, an important result discussed further below is the marked slowdown in international innovation efforts, leading to lower international spillover effects for all countries via cross-border technology and scientific knowledge diffusion. In many countries this is aggravated by a low capacity to absorb new foreign technologies (e.g. because of insufficient investment when these new technologies are embedded in equipment). It is important to stress upfront that the structural approach produces results which are broadly consistent with the official (i.e. EPC-endorsed), cyclically focused estimates based on the Kalman Filter method in the sense that it can explain a large part of the changes in 'official' TFP trends. This confirmation provides greater confidence in the accuracy of the official estimates.

It is important to stress that whilst knowledge investments are a key driver of TFP, they are not the only driver, with the more efficient utilisation of factor inputs in production processes (i.e. static efficiency gains) also contributing. An economy's ability to exploit novel technologies and to adapt to a rapidly changing technological environment is essential to its prospects for improving standards of living. In assessing the impact of both of these TFP drivers (i.e. knowledge production and factor efficiency), the time dimension needs to be taken into account. For example, while over the short to medium term, factor efficiency considerations could be an important driver of TFP changes, over the longer run it is knowledge investments which are the key determinant. Awareness of this time dimension underlines the fact that TFP is not just about knowledge production – in fact the other determinants such as levels of competition, scale economies and organisational / managerial best practices can periodically be as important.

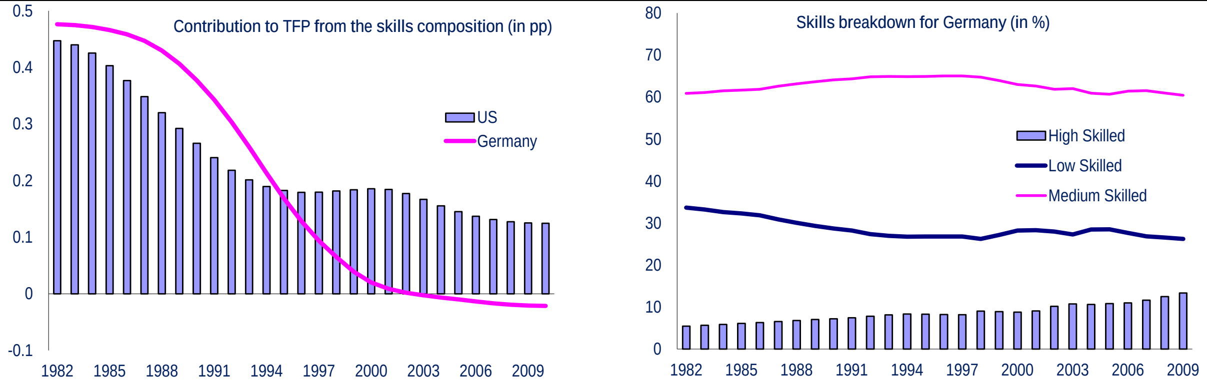
Contribution of skills to TFP trends. The current version of the official production function methodology uses a standard quantity measure of labour input (i.e. employment levels adjusted for hours worked) to calculate the contribution of labour to growth. The current approach should allow for differences in the productivity/'quality' of different workers but to construct such labour 'quality' measures, datasets for the breakdown of total employment and labour compensation by high-, medium- and low-skill groupings are needed. ([12]) Eurostat unfortunately does not currently produce validated data series for these skill breakdowns. Consequently, official TFP measures overstate 'true' TFP by including these skill composition effects.

In order to correct for this, observed TFP must be decomposed into a skill component and a residual TFP component. This is done by using an unofficial (i.e. not validated by Eurostat) skills-based breakdown of employment and labour compensation from EU KLEMS, with the weights used in the aggregation of the different skill groups reflecting the average share of each skill

([11]) Unlike the TFP estimates for Germany and the euro area, which are produced using the official Kalman Filter approach, the TFP estimates for the US are produced using a simple, univariate HP filter. The basic problem with such univariate techniques is that they tend to produce imprecise estimates at the end of the sample period (and especially close to turning points/'boom-bust' episodes). Consequently, preliminary HP trend TFP estimates are frequently and sizeably revised over time.

([12]) See for instance: Denison, E.F. (1967), 'Why growth rates differ: Postwar experience in nine Western countries', The Brookings Institution and Jorgenson, D.W. (1995), 'Productivity', MIT Press.

Graph I.4: **Contribution to TFP from the skills composition of the workforce and skills breakdown in Germany (1982-2010)**



Source: Commission services.

group in total labour compensation (see also Box I.1). (13) With this approach, a skills-based indicator of changes in the 'quality'/productivity of the workforce over time can be constructed. The results for this index for Germany and the US are shown in Graph I.4, including a skills breakdown of the German workforce. As can be seen from the skills breakdown, until the late 1990s there was an upward movement in the shares of medium- and high-skilled workers, with a reduction in the share of the low skilled. Since then, Germany has experienced an increase in the share of the low skilled and a reduction in medium skilled, with only the high skilled share continuing to increase. Part of the latter trend may be explained by the temporary effect of labour market reforms focused on low-skilled workers. But it also reflects a more persistent structural change as evidenced by the fact that it started before the major labour market reforms were put in place. It is also observable in a broad number of other euro-area Member States.

Contribution of innovation capital to TFP trends. In addition to skills, domestic and foreign innovation patterns are also playing a significant role in the German TFP story. To look at this question, the official TFP model adjusted for skills described earlier has been augmented so as to include intangible investment variables such as innovation capital, in order to try to directly explain the skills-adjusted actual TFP series. The specification for both the skills-adjusted official model and the knowledge-augmented variant are discussed in Box I.1. The augmented model is estimated as an unobserved components model where overall trend TFP (as derived from the skills-adjusted official model) is decomposed into an observable component, driven by domestic and foreign knowledge investments, and an unobserved trend component, which is essentially driven by everything else affecting trend TFP. The key coefficients are those which measure the strength of the relationship between domestic knowledge investments and domestic TFP and the extent of technology spillovers from abroad, linked to worldwide knowledge investments. (14)

In estimating this model, a fundamental question to ask at the outset is which indicator of innovation capital to use, with the choice being between using total intangible investments or just a proportion of the total, namely scientific R&D investments. (15) This is not a simple choice since the literature informs us that non-scientific intangible investments may be particularly important for explaining TFP trends in market services. However, given the ongoing conceptual

(13) EU KLEMS stands for EU-level analysis of capital (K), labour (L), energy (E), materials (M) and service (S) inputs. EU KLEMS provides a system of analysis at industry level which encompasses internationally harmonised, national accounts-based statistics and indicators, as well as an analytical framework for interpreting this information based on input-output analysis and growth accounting.

(14) See for instance:
Coe, D. and E. Helpman (1995), 'International R&D spillovers', *European Economic Review*, Vol. 39, No 5, pp. 859-887.
Griffith, R., S. Redding and J. van Reenen (2004), 'Mapping the two faces of R&D: productivity growth in a panel of OECD industries', *Review of Economics and Statistics*, Vol. 86, No 4, pp. 883-895.
Guellac, D. and B. van Pottelsberghe de la Potterie (2004), 'From R&D to productivity growth: do the institutional settings and the source of funds of R&D matter?', *Oxford Bulletin of Economics and Statistics*, Vol. 66, No 3, pp. 353-378.

(15) According to Corrado et al., intangible investments should be broken down into five key areas: (1) scientific R&D; (2) non-scientific R&D (measured by resources devoted to innovation and to new product/process R&D which does not draw on a scientific knowledge base); (3) computerised information systems (essentially investments in computer software); (4) firm-specific resources (including human capital investments — such as training — and organisational/restructuring skills); and (5) brand equity. See Corrado et al. (2006).

and data availability problems with non-scientific investments, the analysis presented here focuses only on scientific R&D, which for many of the countries analysed amounts to roughly 50 % of total intangible investments. ([16])

Another choice to make is between R&D expenditures or R&D volumes, as proxied by the amount of human resources devoted to science and technology (S&T). Since cross-country comparisons of the R&D expenditure data can sometimes suffer not only from exchange rate issues but also from wage inflation pressures in the research sector, it was decided to opt for the volume of human resources devoted to research. Further choices had to be made between the widest definition of the amount of human resources in S&T (which would include all people with both a tertiary level education and an S&T occupation) and the narrowest definition, namely researchers. It was decided to opt for the narrowest definition on the grounds that, of all the human resources devoted to S&T in an economy, the researchers sub-grouping is central to a country's R&D effort. Like in Germany, it is not surprising that this sub-grouping often makes up little more than 1 % of total employment since, to be included in this group, the OECD's Frascati manual states that the researcher must be 'engaged in the conception or creation of new knowledge, products, processes, methods and systems and also in the management of the projects concerned'.

Using the data for R&D researchers, a stock measure of the physical innovation inputs in the different countries was constructed, with a world total being created by aggregating the results for each of the countries. ([17]) The numbers of researchers are cumulated in order to construct the domestic and foreign stocks of knowledge, using the perpetual inventory method and an assumption of a 10 % depreciation rate. The foreign knowledge stock series for each country is the world total excluding the country itself.

Using the calculations for domestic and world innovation capital stocks, Germany's innovation performance can be directly compared to that of the US. Regarding trends with respect to foreign R&D capital stocks, developments in Germany are broadly comparable to those of the US, with both countries being faced with an apparent slowdown in the growth rate of the global stock of knowledge. However, since the US has a dominating share of the global total, the relatively dramatic slowdown in the growth rate of domestic researchers in the US has implications for all of the other countries in the sample, due to cross-border knowledge spillovers. This slowdown in the growth rate of the domestic knowledge capital stock in the US may be partly linked to the US entry restrictions put in place following the 9/11 tragedy, with knock-on effects in terms of the numbers of foreign students taking up advanced-level studies in US universities. This may have reduced the supply of qualified personnel for US private and public research labs.

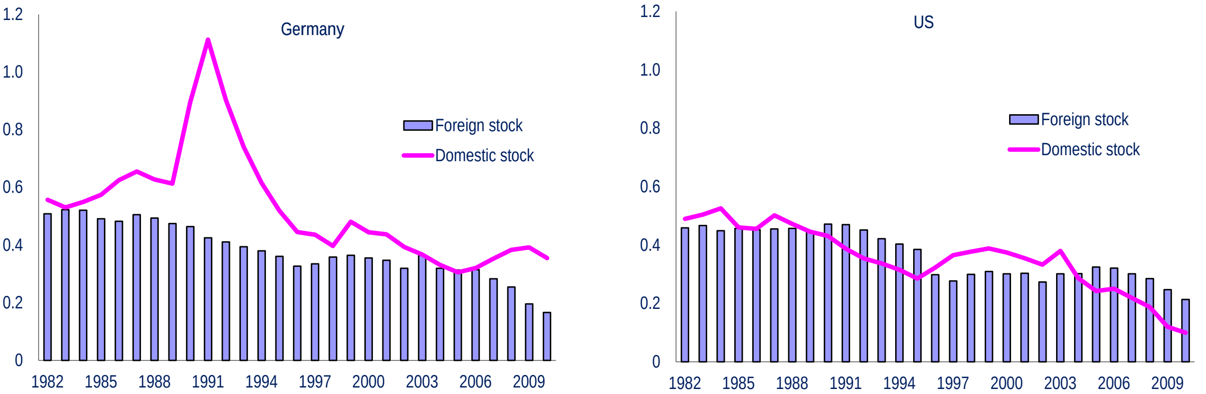
Turning to domestically driven innovation, the evidence for Germany is relatively positive, with annual growth rates of German knowledge investments being broadly comparable to those of the US over the last 30 years (apart from an unusual pattern around German unification). There was a slight acceleration in US knowledge investments in the post-1995 period which was not really replicated in Germany, with most of the differences over this period due to the US's higher investments in a few critical ICT-producing manufacturing industries. The acceleration proved temporary, however, with growth rates of domestic R&D capital stocks slowing rapidly in the US from around 2004 onwards.

In addition to the quantities of innovation capital, the estimates of elasticities/rates of return on those knowledge investments suggest that there are only small efficiency differences between Germany and the US, with foreign R&D elasticity almost identical in both countries and with domestic R&D elasticity in Germany being somewhat higher (see Table I.1). Similar domestic knowledge elasticities to those of Germany have been obtained for the Netherlands and Ireland. For Finland, the elasticity lies between those of Germany and the US. Belgium and France have elasticities which are close to those of the US. The output elasticities for Italy, Portugal and Spain are slightly lower than in the US. Finland has the highest output elasticity for knowledge spillovers, followed by Germany, the Netherlands and Belgium. The remaining countries in the sample have somewhat smaller coefficients. Interestingly, the knowledge spillover parameters are not (inversely) linked to the size of the economy, but may rather reflect the degree of international integration in the production of high-tech products.

([16]) See references in the box such as Griliches (1992); Cincera and Van Pottelsberghe (2001); van Ark et al. (2009).

([17]) Due to data limitations, the world total is in reality only an 'OECD' world total and clearly further work in this area will be needed to construct a truly global measure of world R&D efforts.

Graph I.5: **Contribution from domestic and world innovation capital stocks to TFP growth for Germany and the US (in pp, 1982-2010)**



Source: Commission services.

Table I.1: **Coefficients for domestic and foreign R&D capital**

	Domestic R&D Elasticity	Foreign R&D Elasticity
Germany	0.15	0.12
US	0.11	0.11

Source: Commission services.

There is a strong link between these estimated elasticities and rates of return on knowledge investments in terms of output. A rough rule of thumb suggests that a 0.1 elasticity would equate to a rate of return of 55 %, assuming an R&D expenditure intensity of 2 % and a depreciation rate of 10 %. ([18]) Using this rule, the implied rates of return on domestic German and US knowledge investments are reasonably similar, with rates in both countries estimated to lie between 60 % and 90 %. These rates are in keeping with the estimated rates of return in the literature, as shown in Table I.2.

When the knowledge stock growth rates and the estimated elasticities shown in Table I.1 are combined, the percentage point contribution from domestic and world innovation capital stocks to TFP growth can be calculated for the last 30 years (Graph I.5). The graph shows, for example for Germany, that there has been a sharp decline in the contribution from world innovation capital to German TFP growth. Since the US has such a large weighting in the world total, this German trend is clearly heavily influenced by US domestic developments. This is of course partly explained by the large decline in the contribution of US domestic innovation capital to US TFP growth. This rather alarming US trend with respect to domestic knowledge investments is not replicated in Germany, where domestic R&D investments have continued to contribute, on an annual average basis, around 0.4 pp to total TFP, compared with 0.1 pp in the US.

Table I.2: **Estimated rates of return to private R&D (in %)**

Author (year)	Private return	Social return (private return + knowledge spillovers)
Sveikauskas (1981)	7-25	50
Bernstein-Nadiri (1988)	10-27	11-111
Bernstein-Nadiri (1991)	15-28	20-110
Nadiri (1993)	20-30	50
Mansfield (1977)	25	56
Goto-Suzuki (1989)	26	80
Terleckyj (1974)	29	48-78
Scherer (1982,1984)	29-43	64-147

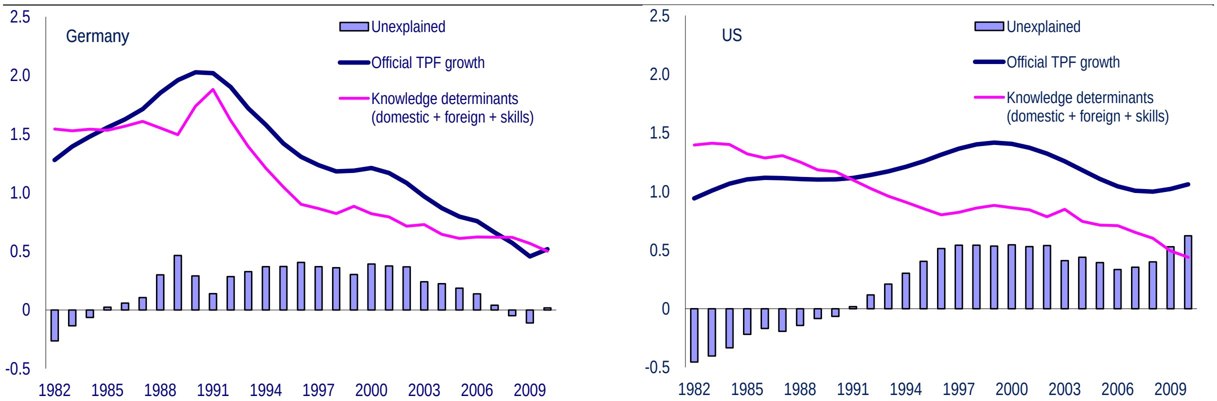
Source: Fraumeni, B.M. and S. Okubo (2005), 'R&D in the National Income and Product Accounts: A first look at its effect on GDP', in Corrado, C., J. Haltiwanger and D. Sichel (eds.), 'Measuring capital in the new economy', Studies in Income and Wealth, Vol. 65, NBER.

On the basis of the analysis so far, Table I.3 and Graph I.6 bring together the results from the skills analysis and from the domestic and knowledge capital stocks to show that this structural TFP approach can effectively supplement the official TFP analysis (which focuses on isolating the cyclical component of TFP).

Table I.3 shows part of the normal output from the official production function approach and then it adds an additional section which shows a decomposition of the official TFP series into the contribution from skills, from domestic R&D capital and from spillovers from the foreign R&D capital stock. If one subtracts these three columns

([18]) The output elasticity is the percentage change in GDP divided by the percentage change in knowledge capital, while the rate of return is the absolute change in output relative to the absolute change in knowledge (the derivative of output with respect to knowledge). Therefore the elasticity must be divided by the knowledge-to-TFP ratio to arrive at the rate of return. Since knowledge is a stock it can be expressed as the R&D flow divided by the depreciation rate.

Graph I.6: **Comparison of official TFP trends with those based on knowledge determinants, Germany and the US (in %, 1982-2010)**



Source: Commission services.

from the official total trend TFP, one is left with the unobserved trend component — in other words, that part of the trend which the structural model cannot explain. For example, if one looks at the decline in German TFP growth of around 1 pp between 1995 and 2010, one sees that over half of the decline can be explained by changes in the observable knowledge determinants of TFP, with the greatest declines coming in the contribution from skills and from foreign spillover effects. The same factors are clearly at play at the level of the euro area as a whole.

Table I.3: **Potential growth and its determinants in Germany (1991-2010)**

	Total potential growth	Contributions to potential growth			Trend TFP decomposition (structural / knowledge determinants)			
		Total labour (hours) contribution	Capital accumulation contribution	TFP contribution (1)	Skills	Domestic R&D capital stock	Foreign R&D capital stock	Unexplained trend component
1991	3.2	0.3	0.9	2.0	0.3	1.1	0.4	0.1
1992	2.9	-0.1	1.0	1.9	0.3	0.9	0.4	0.3
1993	2.4	-0.2	0.8	1.7	0.3	0.7	0.4	0.3
1994	2.0	-0.5	0.9	1.6	0.2	0.6	0.4	0.4
1995	1.9	-0.4	0.8	1.4	0.2	0.5	0.4	0.4
1996	1.8	-0.3	0.7	1.3	0.1	0.4	0.3	0.4
1997	1.7	-0.3	0.7	1.2	0.1	0.4	0.3	0.4
1998	1.7	-0.2	0.7	1.2	0.1	0.4	0.4	0.4
1999	1.8	-0.2	0.8	1.2	0.0	0.5	0.4	0.3
2000	1.8	-0.2	0.8	1.2	0.0	0.4	0.4	0.4
2001	1.7	-0.1	0.6	1.2	0.0	0.4	0.3	0.4
2002	1.5	0.0	0.4	1.1	0.0	0.4	0.3	0.4
2003	1.3	0.0	0.4	1.0	0.0	0.4	0.4	0.2
2004	1.2	0.0	0.3	0.9	0.0	0.3	0.3	0.2
2005	1.1	0.0	0.3	0.8	0.0	0.3	0.3	0.2
2006	1.2	0.0	0.4	0.8	0.0	0.3	0.3	0.1
2007	1.3	0.1	0.5	0.7	0.0	0.4	0.3	0.0
2008	1.2	0.1	0.5	0.6	0.0	0.4	0.3	0.0
2009	0.8	0.1	0.3	0.5	0.0	0.4	0.2	-0.1
2010	1.2	0.2	0.5	0.5	0.0	0.4	0.2	0.0

(1) The official method focuses on isolating the cyclical component.

Source: Commission services

Finally, Graph I.6 gives an overview of the total results for Germany and the US, showing the official trend TFP estimates together with the observed trend component (driven by skills and domestic and foreign knowledge capital) and the unobserved trend component. Graph I.6 suggests that the structural approach produces relatively plausible results for Germany, with the observed trend component closely tracking the official trend TFP estimates. Part of this result could be due to our focus on scientific R&D researchers, which are a key driver of TFP trends in manufacturing industries, this sector being pivotal in explaining Germany's overall innovation performance.

The approach is less successful in explaining US trend TFP developments. This could be due to our exclusion of non-scientific intangible investments from our intangible investments total. As explained earlier, these investments (such as non-scientific R&D, firm-specific resources, brand equity and computerised information systems) have been cited in the literature as being a key driver of the productivity revolution in US service industries, such as retail and wholesale trade and financial services. An alternative explanation is that the official model may be overestimating trend TFP in the US over this period, with historical trend revisions likely in the future as the evidence on underperforming investments from the post-1995 period starts to accumulate. An assessment of the 'real' underlying rate of TFP growth in the US is also complicated by the fact that, unlike the calculations for Germany, the official estimate is not based on the Kalman filter approach. It could turn out that with future data revisions, and with better filtering techniques, perhaps a greater part of actual TFP developments in the US since the mid-1990s reflected cyclical factors rather than a genuine structural break in the US private services sector. ([19])

Overall, over half of the TFP decline in Germany since the mid-1990s can be explained by a deterioration in the contribution to knowledge production from skills and from domestic and foreign capital stocks. Despite domestic innovation levels holding up reasonably well over the period, there has been a sharp deterioration in the contribution from foreign innovation capital, reflecting in particular the slowdown in US R&D efforts. The combination of these innovation patterns with the deterioration in the skill composition of the German labour force produces knowledge-induced TFP results that are very much consistent with the results for Germany from the official, cyclically focused TFP methodology. Finally, whilst this section has focused on Germany (given its influence on overall euro-area patterns), the analyses carried out for some other Member States confirm the useful complementary role which this structural approach can provide in better understanding TFP patterns in all those euro-area countries for which data currently exist. Similar results to those for Germany also hold for other euro-area countries in the sample. In particular, there is a slowdown in the contribution of skill upgrading to TFP as well as a slowdown in the growth rate of R&D inputs.

I.3. Conclusions and policy implications

Trends in total factor productivity in the euro area since the 1990s are worrying and call for determined policy action. In the long run, TFP is the main driver of income per capita and the deceleration of TFP growth by about 1 pp over the past two decades is in itself a serious source of concern. But it is particularly worrying at the present time given that the euro area is facing a number of serious medium- to long-term growth challenges. These include the negative effect of the crisis on potential output, persistent downside pressures on demand due to balance sheet consolidation in the private or the public sector in many Member States and the impact of population ageing on labour supply and investment.

To tackle these challenges, the Commission has placed productivity growth at the centre of its Europe 2020 strategy. In its recent ‘Initiative for growth, governance and stability’, it has renewed its call for growth prospects and productivity to be enhanced by pursuing strong structural reforms, acknowledging that progress so far has been slow.

Against this background, the structural analysis of TFP presented in this section offers further empirical backing for calls for rapid implementation of productivity-enhancing structural reforms. Focusing on knowledge investments, it identifies three areas where policy measures could have a substantial effect on productivity.

First, it confirms previous empirical work regarding the importance of the skill composition of the labour force for productivity. It also highlights the negative contribution of the skill composition to growth since the beginning of the previous decade. Though part of this result reflects the temporary effect of reforms aimed at bringing back low-skilled workers into employment, it is also an indication of a more enduring structural trend. This clearly backs the call for better educational attainment and, in particular, the Europe 2020 targets of reducing school drop-out rates below 10 % and lifting the share of 30-34-year-olds with third level education to at least 40 %.

Second, the analysis also shows quantitatively the importance of innovation capital for growth and highlights the high rate of return on public R&D. Although recent trends in R&D investment have been rather conducive to productivity gains in some euro-area Member States, this is not the case for others where further effort is needed to counteract a trend towards decelerating knowledge investments. It is also important to make sure that ongoing public finance consolidation does not excessively affect public R&D spending as this would weigh on productivity prospects further down the road. Overall, the analysis vindicates the Europe 2020 target of lifting the combined share of public and private investment in R&D and innovation to 3 % of EU GDP.

A final finding of the analysis is the important role of cross-border knowledge spillovers. A worrying decline in innovation capital at the world level is weighing on TFP growth in all the euro-area Member States. In some of them, the trend is magnified by a low capacity to absorb cross-border spillovers. Further work is needed to better understand the determinants of the absorption capacity for technology and to design policy measures that could enhance it. In any

([19]) The results for the US are not representative for the total sample of countries for which results are currently available. Results similar to those for Germany, in terms of closely tracking the official trend TFP estimates, have been found in a significant number of the sample countries.

event, strong knowledge spillovers, combined with a declining trend in the accumulation of innovation capital worldwide, support the case for concerted international coordination in this area, both at the European and the world levels. Efforts to boost the stock of knowledge in a country would bring higher returns in terms of growth if matched by similar efforts in other countries.

Overall, the analysis shows that policies aimed at fostering knowledge investment and technology absorption should be an important part of productivity-enhancing reforms. It is, nevertheless, important to stress that knowledge investment is an important but not the sole driver of productivity. A comprehensive policy package to boost TFP growth should therefore also contain complementary measures aimed at a more efficient use of factor inputs in production processes, including the removal of obstacles to competition, the encouragement of entrepreneurship and enterprise creations and, more generally, the establishment of a more business friendly environment.