The slowdown of German productivity growth[1]

Steffen Elstner[2] Lars P. Feld[3] Christoph M. Schmidt[4]

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Abstract

Labor productivity growth in Germany has decelerated significantly in recent years. This paper shows that two structural developments have contributed to this slowdown. Firstly, more than three million people have been successfully integrated into the German labor market since the year 2005. Many of these employees exhibit comparatively low levels of productivity. Secondly, the process of restructuring value chains in the manufacturing sector may have come to an end. The vertical integration in manufacturing has not decreased any further since the recession in 2009. It is an important task of economic policy to exploit unused potential and creating suitable conditions for facilitating sustainable productivity increases.

[1] Working papers reflect the personal views of the authors and not necessarily those of the German Council of Economic Experts.

[2] Staff of German Council of Economic Experts.
[3] Walter Eucken Institute, Albert-Ludwigs-University Freiburg and German Council of Economic Experts.
[4] RWI, Ruhr-University Bochum and German Council of Economic Experts.

1. Introduction

In recent years, almost all industrialized countries have experienced a slowdown in labor productivity growth. For the US two main explanations exist for the deceleration in productivity gains. The first explanation stresses the fact that this development already began in the years 2004 and 2005 (Fernald, 2015). It was observed particularly in industries that produce information and communication technology (ICT) or that use ICT intensively. Fernald (2015) interprets this result as a return to normal productivity growth after almost a decade of exceptional IT-fueled gains. This argument is also mentioned by Gordon (2012). Both authors further emphasize that the effects of the Great Recession in the years 2008 and 2009 on US productivity growth were only minor.

In contrast to this, the second explanatory approach argues that in the wake of the Great Recession businesses cut their investments in the development and adoption of new technologies (Anzoategui et al., 2016). This decline in research and development (R&D) activity led to a weak development of productivity as it takes time for new technologies to diffuse. Put differently, the Great Recession has long-lasting effects on US productivity growth.

Regarding this latter point, the German economy has not shown a significant reduction in R&D investment at the aggregate level during and since the Great Recession. In general, the economic situation in Germany evolved quite differently compared to other industrialized economies, in particular to the rest of the Euro-area. The recession in Germany was of shorter duration and no second recession arose in the course of the Euro-area crisis in the years between 2011 and 2013. After a deep slump in German gross domestic product (GDP) by 5.6 percent in 2009, the economy experienced a strong rebound in production with growth rates of 4.1 and 3.7 percent in the years 2010 and 2011, respectively. Moreover, the unemployment rate increased only slightly in the year 2009. The strong performance of the labor market in the years during and after the Great Recession is an outstanding feature of the German economy as compared to the U.S or to large European economies like France, Italy or Spain.

Notwithstanding, the gain in labor productivity in Germany has also decelerated significantly in recent years. There are currently no signs of a trend reversal. At the same time, we have observed a relatively weak investment activity in the private sector. Due to these observations, some voices call for more policy measures to stimulate German investment activity and thus productivity growth. However, the slowdown in productivity growth could also be the result of structural shifts within the economy and subdued technological progress, i.e., comparatively low economic innovation for creating new products and processes. As demographic change is set to contract labor volume significantly in the medium term, it is likely that the competitiveness of businesses and thus also material prosperity are under long-term threat. It is therefore important to understand the reasons for the slowdown in the growth of macroeconomic labor productivity to identify ways to improve productivity.

Empirical analyses indicate that several factors have had a dampening effect on the development of labor productivity in recent years. These include the successful integration of over three million people into the labor market as a result of the labor market reforms in the middle of the last decade. A significant decline in the average productivity of the entire working population is therefore a likely side-effect. There are huge differences in the developments of individual economic sectors. While the manufacturing sector recorded high increases in labor productivity, which only started to decline in the past seven years, productivity in the service sector has exhibited weak development since the turn of the millennium.

To study the reasons for the slowdown in German productivity growth the paper is structured as follows. In section 2 we present facts about labor productivity growth in Germany. Sector 3 analyzes the effects of the successful German labor market reforms at the beginning of the millennium. The subsequent section 4 takes a closer look at German manufacturing and discusses the effects of outsourcing on productivity gains. Section 5 studies the importance of information technologies on German productivity and considers the role of Industry 4.0. Section 6 concludes.

2. Stylized Facts

2.1 Productivity growth: key terms and relationships

The development of macroeconomic productivity can be measured using single or multi-factor metrics. Single-factor productivity measures establish a relation between output and a single input factor, for example macroeconomic labor productivity, which is the ratio of GDP to labor input.[5] Multi-factor productivity measures establish a relation between output and all input factors, and usually assume a specific production function. The resulting variable is called total factor productivity (TFP). To illustrate the factors influencing labor productivity, we assume below that aggregate output can be represented using a Cobb-Douglas production function with constant economies of scale. The production function Y_t is defined as follows:

$$Y_t = A_t \cdot K_t^{\alpha} \cdot (E_t H_t)^{1-\alpha},$$

where A_t is TFP and K_t is the capital stock. The product $E_t H_t$ defines labor input as the product of the average quality of labor per hour worked, E_t, and the labor volume, H_t. The production elasticity of capital is indicated by α. To determine the labor income share, $1-\alpha$, we use the compensation of all employees, adjusted by the income of self-employed people, and divide this by gross value added. To derive labor productivity, indicated by y_t, we divide Y_t by the labor volume. The percentage change in labor productivity can be expressed using logarithmic differentiation:

$$\Delta ln y_t = \Delta ln A_t + \alpha \Delta ln k_t + (1-\alpha)\Delta ln E_t.$$

An increase in labor productivity can thus have three different causes: firstly, it can result from an increase in capital per hour worked (capital deepening), $\Delta ln k_t$. This illustrates the relationship between investment and labor productivity, although investment does not consist of homogenous capital goods. For example, investment in ICT as well as in R&D have a

[5] Throughout the paper, we define labor productivity as GDP per hour worked (hourly concept).

much greater effect on productivity than investment in housing. Secondly, an increase in labor productivity can be due to an increase in TFP, ΔlnA_t, which is largely intended to measure technological advance as a result of process and product innovation. This figure, however, can also incorporate productivity gains from a declining vertical integration in value added chains (outsourcing). Lastly, an increase in the skills of the workforce (labor quality), ΔlnE_t, can also increase labor productivity. Consequently, reforms that facilitate access of less-skilled workers to the labor market are likely to have a dampening composition effect on macroeconomic labor productivity.

Moreover, the three causes mentioned are very closely related to each other. For a company, for example, a higher skill level of the employees can increase innovation activity and create incentives to invest in ICT or equipment in order to make production processes more efficient. Investments in ICT can, by the same token, create new potential for product and process innovations. For this reason, breaking down productivity development should always be viewed as a purely descriptive exercise. Causal statements cannot be made.

2.2 The importance of labor productivity growth for the German economy

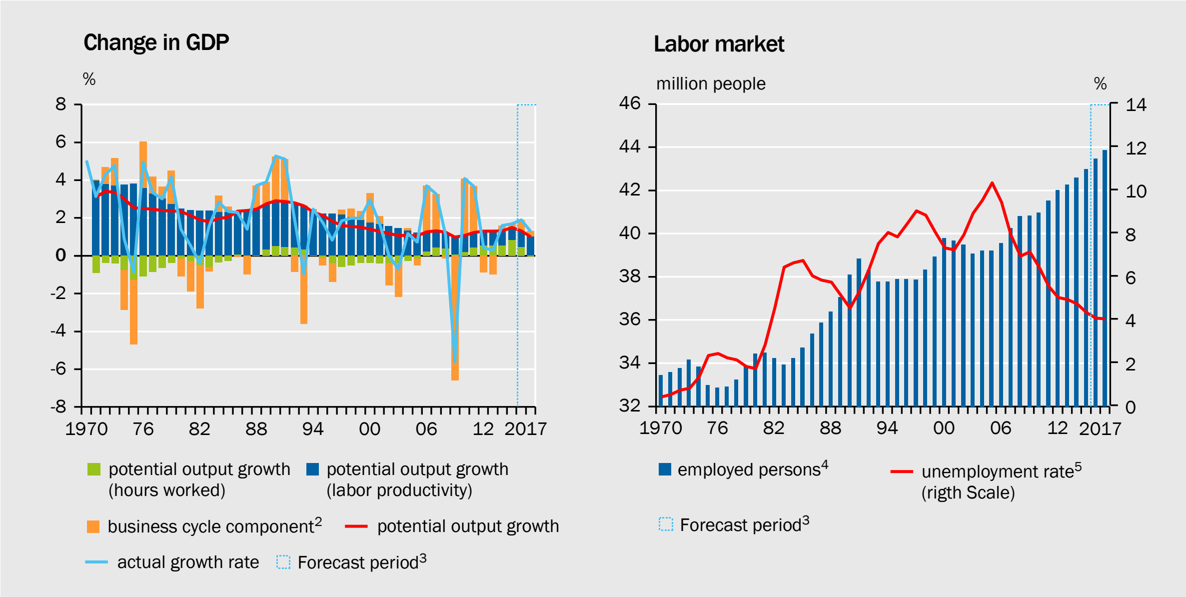
In the last decades increases in German GDP were primarily obtained by growth of labor productivity. The left panel of Figure 1 illustrates this finding. It shows that in general since the year 1970 the growth contribution of changes in labor volume (green bars) to potential output growth (red line) was negative. In contrast to this, we have seen that during the last 45 years gains in labor productivity (blue bars) explained a significant share in potential GDP growth. Since the year 2005, however, the picture changed slightly. During that period, we observe expansive growth impulses coming from changes in labor volume and a deceleration in productivity growth. To sum up, in the last years the German economy was characterized by a strong labor market with an increasing number of employed persons and at the same time by a relatively low growth rate of labor productivity. The right panel of Figure 1 provides an illustration of the good situation on the German labor market und shows that the unemployment rate is falling almost continuously since the year 2005.

According to the forecast of the German Council of Economic Experts (GCEE) employment will further rise in the year 2016 by 500,000 persons and will reach a new record level of 43.6 million people (GCEE, 2016). This corresponds to a growth rate of 1.2 percent compared to the preceding year. In the year 2015, employment increased by 400,000 persons or 0.9 percent. For GDP growth, the GCEE predicts an expansion of 1.9 percent in the year 2016 after 1.7 percent in the year 2015. All these numbers indicate that labor productivity growth (hourly concept) will increase by 0.9 percent this year after 0.8 percent in the last year. For potential labor productivity growth, the GCEE estimates advances of 0.7 and 0.8 percent in the years 2015 and 2016, respectively. Since the beginning of the 1990s the growth rate of potential labor productivity has fallen from more than 2 percent to 0.8 percent in the year 2009 and remains at this level since then. The upper-two panels of Figure 2 depict this development.

As shown above it is possible to decompose labor productivity growth into two components by assuming a Cobb-Douglas production function: TFP and capital deepening (capital intensity). For capital deepening, we distinguish between building and machinery including cars, R&D and software. Unfortunately, determining the contributions of labor quality growth is not possible due to data limitations. For the US, Fernald (2015) finds that labor quality growth increased considerably during the last recession as low-skilled workers disproportionately lost their jobs. This development had a significant positive impact on US labor productivity growth. In our analysis changes in labor quality show up in changes of TFP.

Figure 1

Indicators of macroeconomic development[1]



1 – Until 1990 former territory of the Federal Repubilc of Germany. 2 – Difference between actual growth rate of output and potencial output growth. 3 – Forecast by the GCEE. 4 – Numbers until 1990 optional by backward chaining. 5 – Unemployed people as a share of the active working population.

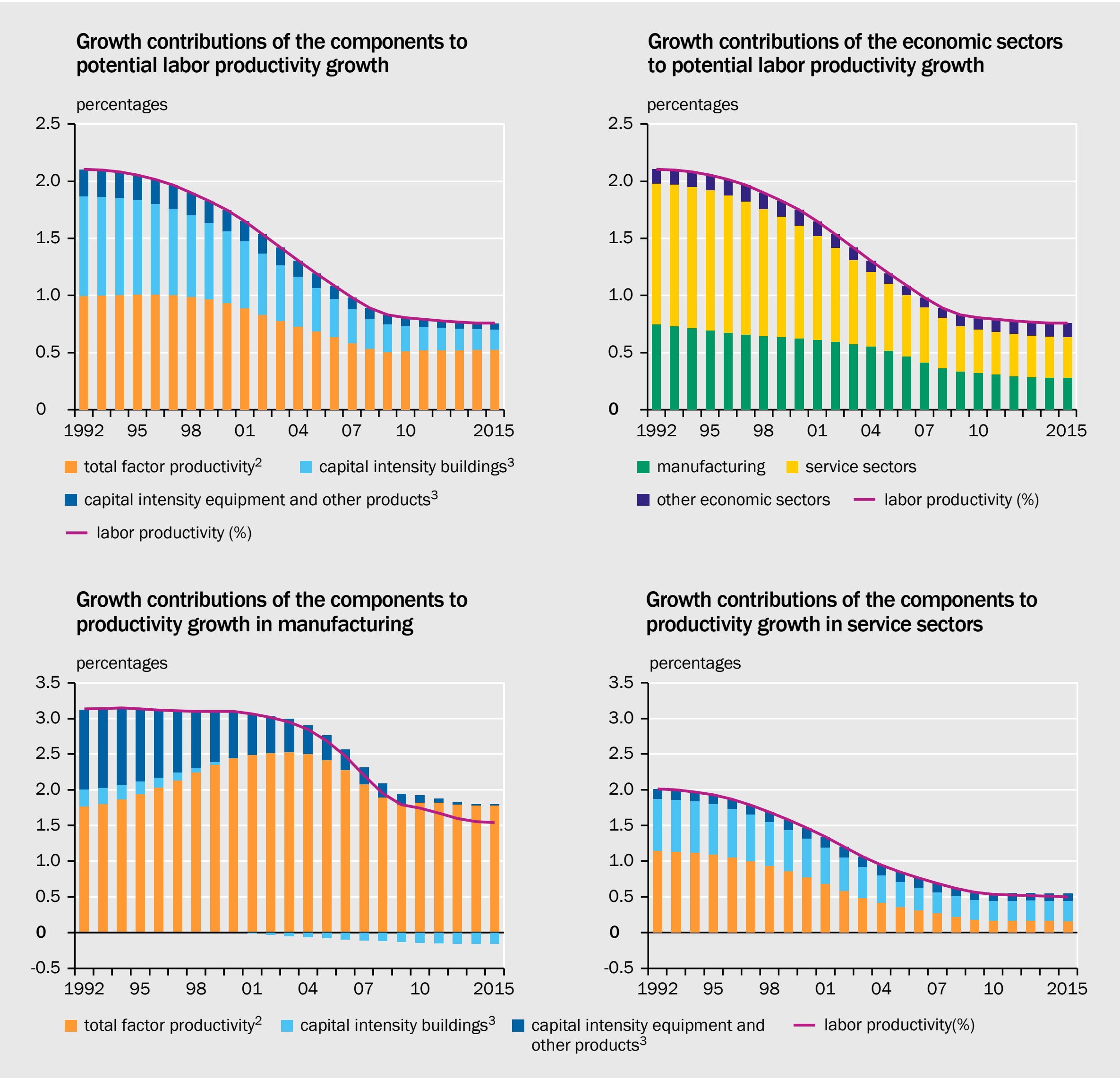
Sources: Federal Statistical Office of Germany, own calculations

The upper-left panel of Figure 2 shows the contributions of capital deepening and TFP to potential labor productivity growth. It is evident that the contributions of all factors have declined. For instance, the growth contribution of capital deepening decreased from more than one percentage point in the year 1992 to 0.3 percentage points in the year 2009 and stays at this level since. For TFP we have seen a decline from roughly one percentage point in the year 1992 to 0.5 percentage points in the year 2015.

The deceleration in the growth rate of capital intensity is often related to a so-called "investment gap" in Germany (DIW, 2013, 2014). This states that investment activity in Germany lags behind given the prevailing macroeconomic conditions. In the summer of the year 2014, the German government therefore established a commission of experts to "boost investment in Germany". Their task was to develop policy recommendations to bolster private and above all public investment in Germany. In doing so, the commission should support economic policy by developing an investment strategy (BMWi, 2015). The GCEE raised a critical voice in the public discussion on investment weakness (GCEE, 2014), mainly declaring that the discussion on “investments gaps” neither makes academic sense nor generates viable solutions for economic policy. In particular, this discussion frequently created the impression that private investment volume can be arbitrarily controlled in a market economy by means of economic intervention, and does not result from rational decisions of private economic actors. This discussion primarily assumed that investment in physical capital creates the basis for productivity increases and not the other way round. The relation between investment and economic productivity, however, is by no means trivial. A deeper analysis at the level of economic sectors is therefore warranted.

Figure 2

Potential labor productivity growth[1]



1 – Percentage change of labor productivity (hourly concept) compared to the previous year, HP-filter, λ =100. 2 – For further details see Annual Report 2014 Box 10. 3 – Real gross capital stock divided by hours worked. The following steps are done to derive the growth contribution of capital intensity: First the potential growth rate of capital intensity is determined with the HP-filter. Second, this potential growth rate is weighted by one minus the labor income share. To calculate the labor income share the compensation of all employees, adjusted by the income of self-employed people, is divided by gross value added. Third, to compute the relative weights of the growth contributions of the gross capital stock of buildings and equipment, respectively, the nominal fractions of the gross capital stock of the previous year are used.
Sources: Federal Statistical Office of Germany, own calculations

Such deeper analysis of single economic sectors reveals a weakening in productivity growth for both manufacturing and the service sectors in the course of the last two decades. The upper-right panel of Figure 2 depicts the results. The corresponding developments of TFP and capital deepening, however, differ between the manufacturing and the service sectors. The lower panels of Figure 2 illustrate this.

The productivity trend in manufacturing is marked by relatively high increases in TFP. Apart from the period around the turn of the millennium with higher productivity gains, we observe a stable growth rate of 1.8 percent. This, however, is accompanied by a considerable deceleration in the increases of capital deepening. The growth rate of total capital deepening, including buildings and machine, was even negative in recent years. This reflects the weak development of business investment.

Aside from the automotive industry, we see a modest decline in capital intensity in almost all important economic sectors of German manufacturing in the years between 2010 and 2014. It is possible to provide possible explanations for this development:

- Since the 1990s there is a strong outsourcing process in German manufacturing. This means that many businesses outsourced that upstream value chains primarily abroad. This makes the existing capital stock for the affected production sectors superfluous.
- The energy costs in Germany are high in an international comparison and have a negative effect on German investment.
- The domestic sales opportunities are expected to be dampened in the upcoming years due to demographic change. To satisfy demand it is therefore not necessary to expand the capital stock considerably.
- Additionally, demographic change is presumably accompanied by a reduction in the supply of young professionals and engineers. Businesses anticipate this development and adjust their capital stock in advance to compensate for a lower supply of professionals in the future.
- Since the Great Recession, the development of world trade and production of main trading partners is only modest. This has probably led to an adjustment in export expectations in the strong export-oriented manufacturing sector.

Consequently, the reasons for the declining growth rate of capital deepening in German manufacturing are more structural and less cyclical.

In contrast to manufacturing the productivity trends in the service sectors are characterized by low TFP growth and stable increases in capital deepening. It should be noted that statements regarding productivity developments in these sectors need to be treated with caution since the measurement of value added in some service areas is by far not as accurate as in manufacturing. A main reason for the weak development in TFP is a so called “composition effect”. This composition effect reflects the successful integration of considerably more than three million low-skilled workers into the German labor market since the year 2005. This development has a negative impact on labor quality growth in the service sectors and is especially pronounced in the economic sectors trade, transportation, accommodation, healthcare and administrative and support services (especially temporary work).

2.3 International comparison

The development of German labor productivity is not special in an international comparison. The two upper panels of Figure 3 show that slower labor productivity growth has been observed in almost all major industrialized countries since the beginning of the new millennium at the latest. Particularly, productivity growth has already declined prior to the onset of the financial crisis. Fernald (2015) demonstrates that the slowdown in productivity growth in the US was evident as early as 2004 and that it was not only limited to the financial and real estate sectors. He attributes the development primarily to the decline in innovation, which commenced in the mid-1990s with the diffusion of ICT. For the US, it is therefore rather a process of normalization following a period of soaring productivity.

The International Monetary Fund (IMF, 2015a) also states that slower productivity development in industrialized countries commenced well before 2008. One reason for this trend is the normalization of productivity development in the US due to less ICT innovation. Another explanation is that many industrialized countries experienced a structural shift away from highly productive economic sectors, such as manufacturing, to areas with lower productivity, such as many service sectors. The IMF concludes further that increases in workforce skill levels in many countries contributed less to productivity growth than they had in the past.

Table 1

Real labor productivity (value added per hours) in selected countries[1]
Average annual growth in %

Country	1995 – 2005			2005 – 2014			Reporting:	
	all economic sectors	including		all economic sectors	including		share of manufacturing[2]	
		manu-facturing	service sectors		manu-facturing	service sectors	1995	2014
Denmark	1.2	2.7	0.8	0.4	3.6	0.3	17.0	13.9
Germany	1.9	3.1	1.3	0.8	1.6	0.6	22.8	22.6
Finland	2.6	6.2	1.2	0.2	0.9	– 0.0	25.4	16.7
France	1.8	4.4	1.2	0.8	2.4	0.7	16.2	11.2
Italy	0.5	0.9	0.3	0.1	1.0	– 0.3	20.9	15.4
Netherlands	1.7	3.8	1.6	0.6	1.4	0.6	17.2	12.1
Austria	1.8	3.3	1.0	1.0	2.5	0.8	20.0	18.4
Spain	0.0	1.1	0.0	1.6	2.0	1.0	17.6	13.2
United Kingdom	2.2	3.6	2.1	0.4	1.7	0.6	19.0	9.5
United States	2.3	5.9	1.2	0.9	2.3	0.4	15.9	12.0

1 – Own calculations. 2 – Share of total gross value added.

Sources of data: BEA, Eurostat

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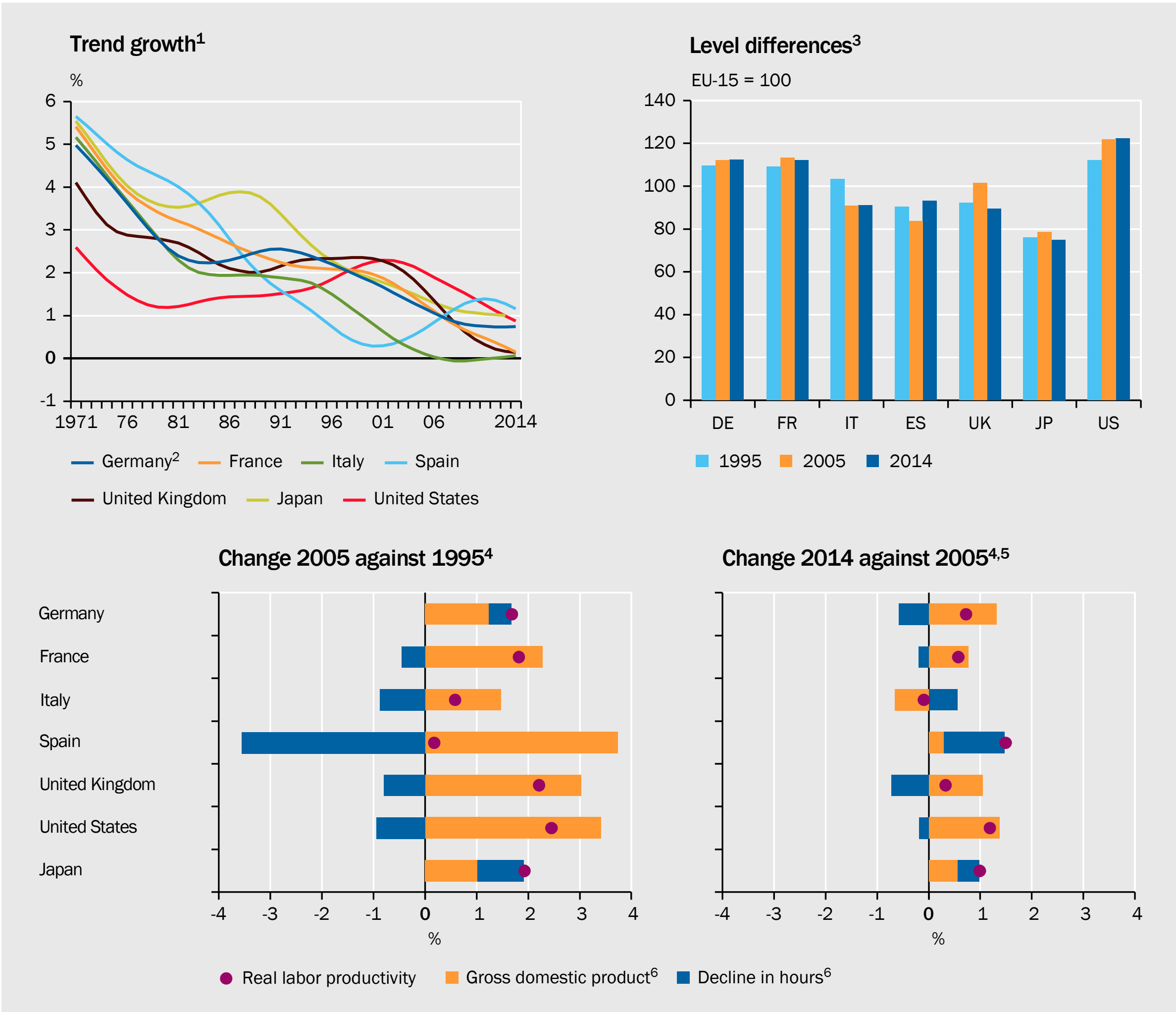
Table 1 provides an analysis of the value added contributions of individual sectors in an international comparison. It shows the importance of manufacturing for Germany's macroeconomic productivity growth. Compared to the service sector, the increases in hourly productivity in the manufacturing sector are considerably higher in all analyzed countries. Other countries such as the UK and France also achieved large productivity increases in the manufacturing industry. The economic significance of manufacturing for these countries, however, noticeably declined from 1995 to 2014.

Figure 3

Labor productivity per hours worked in selected countries



1 – Change in real GDP per hours worked to the previous year. HP-filter, λ = 100. 2 – Until 1990 the former West Germany. 3 – DE-Germany, FR-France, IT-Italy, ES-Spain, UK-United Kingdom, JP-Japan, US-United States. Nominal GDP per hours worked (for Japan 2013) in purchasing power parities. 4 – Average annual change. 5 – For Japan 2013. 6 – Percentage points.

Source: European Commission

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Breaking hourly productivity growth rates down into contributions related to the rise in GDP and the decline in labor volume highlights considerable differences between the industrialized countries. The lower-left panel of Figure 3 depicts the developments for the period from 1995 to 2005. In this period, productivity growth was only accompanied by a reduction in hours worked in Germany and Japan. Other industrialized countries heavily increased their labor volume and thus also employment rates. Part of the productivity increase in those countries was thus used to increase employment.

A completely different picture has developed since 2005 shown in the lower-right panel of Figure 3. The rise in employment in Germany and the UK was accompanied by a slower rise in labor productivity. However, the contrast between growth contributions of overall economic activity is even more significant. From 1995 to 2005, high increases in labor productivity went hand in hand with high economic growth, in the UK and the US above all. The contribution of economic growth declined most significantly in those two countries between 2005 and 2014. In Germany, in contrast, it remained stable at a moderate level. This breakdown therefore suggests that changes in employment and its composition are likely to play a relatively important role in explaining the trend in German labor productivity growth.

The most recent increases in productivity in Spain demonstrate to which large extent cyclical and structural labor market developments influence macroeconomic productivity growth. The drastic rise in labor productivity since 2007 can largely be explained by "dismissal productivity". This phenomenon arises when a certain value added is produced with considerably fewer workers. Conversely the observed drop in productivity in many countries in the year 2009 is likely due to labor hoarding, leading to temporary underutilization of labor capacities. The subsequent recovery in labor productivity demonstrates that these countries were only temporarily less productive.

3. The effects of the German labor market reforms on productivity

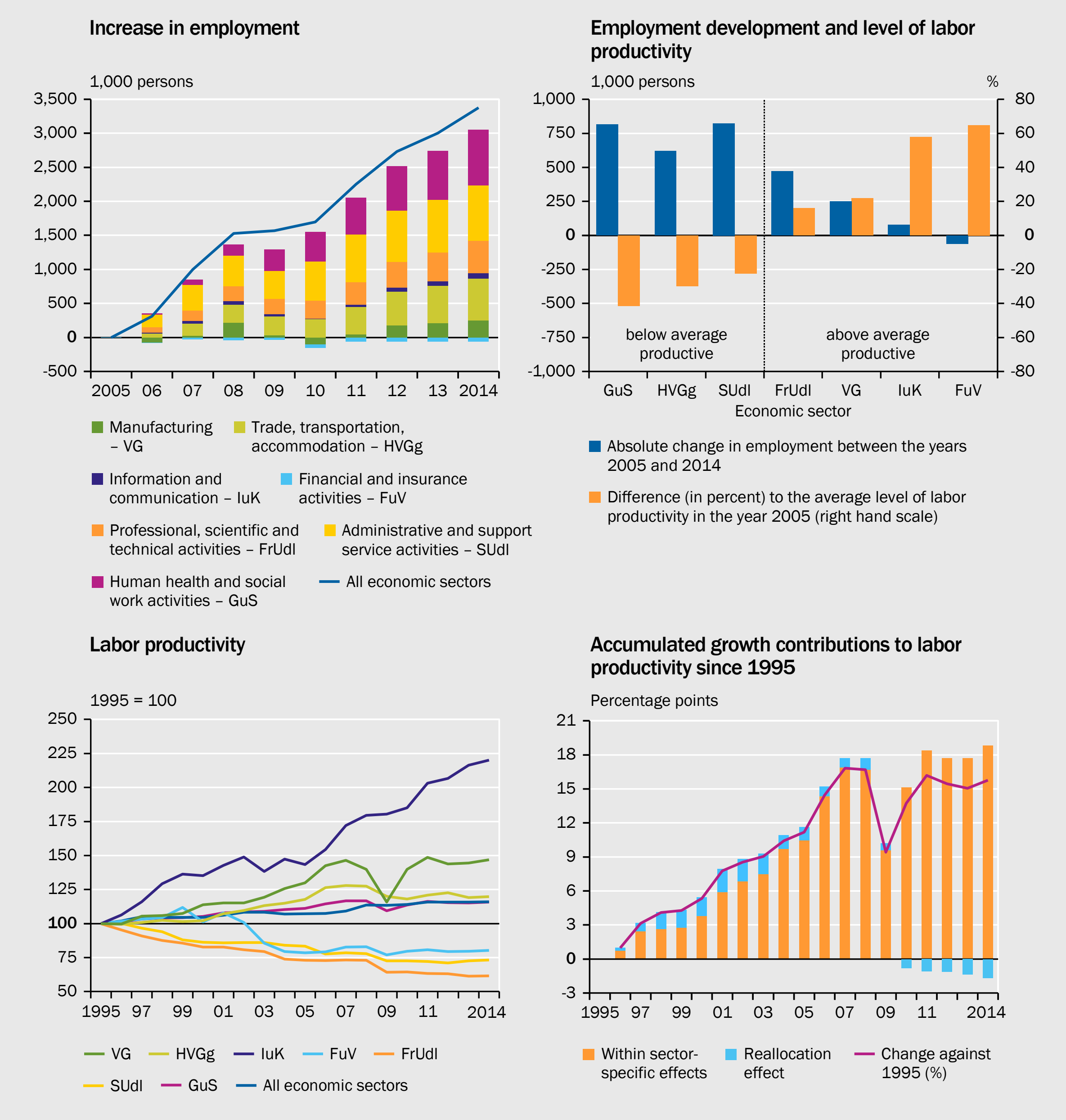
Structural factors due to fundamental changes in the labor market (GCEE, 2013) were largely responsible for the declining trend in labor productivity growth in Germany since 2005. It can be assumed that the labor force increase of 3.4 million workers between the years 2005 and 2014 was a key factor in the weaker productivity development. As these persons were previously unsuccessful at offering their skills on the labor market, it is reasonable that they were less productive than the average worker in the year 2005. This resulted in a composition effect among workers, which had a dampening effect on growth rates in labor productivity in the multi-year transitional phase to the new structural labor market equilibrium. Put differently, we have seen lower labor quality growth due to this composition effect.

There are two factors underlying this composition effect. Firstly, jobs were created especially in labor-intensive and less productive service sector areas. This can be seen in the upper-right panel of Figure 4. The upper-left panel of the same figure shows the number of workers increased considerably above all in the economic sectors trade, transportation, accommodation, healthcare and administrative and support services (especially temporary work). This consequently resulted in a structural shift in the German economy, as these sectors gained relative importance in terms of employment, at the expense of the highly productive manufacturing sector. Secondly, the increase in the number of less productive employees had a negative impact on sector-specific labor productivity in the relevant labor-intensive service sectors. The lower-left panel of Figure 4 illustrates this development.

It is possible to obtain a general idea of the size of the composition effect by means of a disaggregated analysis at the sector level (De Avillaz, 2012). We examine which aggregated development would have resulted due solely to the effects within the individual economic sectors (within sector-specific effects) and what significance the shift in employment between the sectors had (reallocation effect). The within sector-specific effects thus reflect the development of macroeconomic labor productivity for the hypothetical situation in which the employment shares of the national economy had not changed over time.

Figure 4

Employment development and labor productivity[1] for selected economic sectors



1 – Real gross value added per person employed.

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Specifically, we decompose the change in labor productivity at a certain time into effects specific to the individual economic sectors (sub-sectors) and a reallocation effect. The sub-sector-specific effects reflect how high the aggregate productivity gain would be in a given economic structure. The reallocation effect, in contrast, describes those productivity effects that result from structural shifts within the total economy. These structural shifts represent changes in the relative proportions of the economic sub-sectors as measured by the number of employed persons or hours worked. In our analysis, we consider 20 sub-sectors. Total labor productivity is then measured as follows:

$$\left(\frac{LP_t^{total} - LP_0^{total}}{LP_0^{total}}\right) = \sum_{i=1}^{20}\left(\frac{LP_t^i - LP_0^i}{LP_0^{total}}\right) n_0^i + \sum_{i=1}^{20}\left(n_t^i - n_0^i\right)\frac{LP_t^i}{LP_0^{total}},$$

with LP_t^{total} denoting aggregate labor productivity at time t and LP_t^i representing the labor productivity of sub-sector i at time *t*. n_t^i is the relative proportion of the labor force or hours worked in sub-sector *i*. The first term on the right side of the equation describes the sub-sector-specific effects and the second term defines the reallocation effect.

The results of the decomposition of German productivity growth are presented in the lower-right panel of Figure 4. It shows that the reallocation effect has not been very significant to productivity advances since 1991. The productivity gains over the past 25 years largely stemmed from developments within the individual sectors. The reallocation effect made only a slightly positive contribution to the increase in labor productivity in the period from 1995 to 2005. Employment during this period increasingly shifted to the productive economic sectors.

However, a reversal of the reallocation effect has been evident since the turn of the millennium. Table 2 summarizes the growth contributions of labor productivity for both subperiods. The structural shift towards the relatively unproductive service sectors had a significantly negative effect on labor productivity. The growth contribution from the reallocation effect for the years between 2005 and 2013 is therefore negative. Overall, this negative reallocation effect has caused the annual increase in macroeconomic productivity (person concept) to decline by around 0.3 percentage points since 2005 compared to the previous 10 years. This result is the same whether productivity is calculated per hour or per person employed.

The analysis of the within sector-specific effects shows that the growth contributions of the economic sectors trade, transportation, accommodation, healthcare and administrative and support services (particularly temporary work) in total have contributed an annual 0.3 percentage points less to the rise in overall productivity per person employed since the year 2005 than it was the case for the years between 1995 and 2005. Along with the reallocation effect, this indicates that the annual decline in the growth rate of productivity per person employed, from 1.1 % for the period 1995-2005 to 0.4 % since 2005, can largely be attributed to the composition effect, which is the result of the successful integration of less productive workers into the labor market. A similar conclusion can be drawn for hourly productivity. This is a side-effect of the German labor market miracle.

The productivity gain generated by the manufacturing sector has declined considerably since the year 2005. The manufacturing sector's overall contribution to growth of macroeconomic labor productivity has declined by 0.4 percentage points. A closer study of this sector is thus appropriate. Moreover, the growth contribution from the service sectors for both periods is noticeably weak although it accounts for a large share of German output. The question here is whether there are structural problems and whether eliminating them could contribute to considerably raising productivity.

Table 2

Growth contributions to aggregate labor productivity
Percentage points

	Share[1]	Per person employed		Per hour	
	%	1995 – 2005	2005 – 2014	1995 – 2005	2005 – 2014
Within sector-specific growth contributions					
Manufacturing	22.4	0.7	0.3	0.8	0.4
Service sector	69.8	0.2	0.3	0.8	0.6
including:					
Whosesale and retail trade, repair of motor vehicles, transport and storage, accommodation	16.5	0.3	0.0	0.5	0.1
Information and communication	4.6	0.2	0.3	0.2	0.3
Professional, scientific and technical activities	6.3	– 0.2	– 0.1	– 0.1	– 0.1
Administrative and support service activites	4.3	– 0.1	– 0.1	– 0.0	– 0.0
Human health and social work activities	6.6	0.0	0.1	0.1	0.1
Reallocation effect		0.1	– 0.2	0.2	– 0.2
Development of labor productivity (%)					
Actual development[2]		1.1	0.4	1.9	0.8
Development without structural shifts[3]		0.9	0.7	1.6	1.0

1 – Share of the corresponding sector in total gross value added in the year 2005. 2 – Average annual change of total gross value added per person employed and per hour, respectively. 3 – Without the reallocation effect. Difference in total due to rounding.

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4. An end to outsourcing in manufacturing

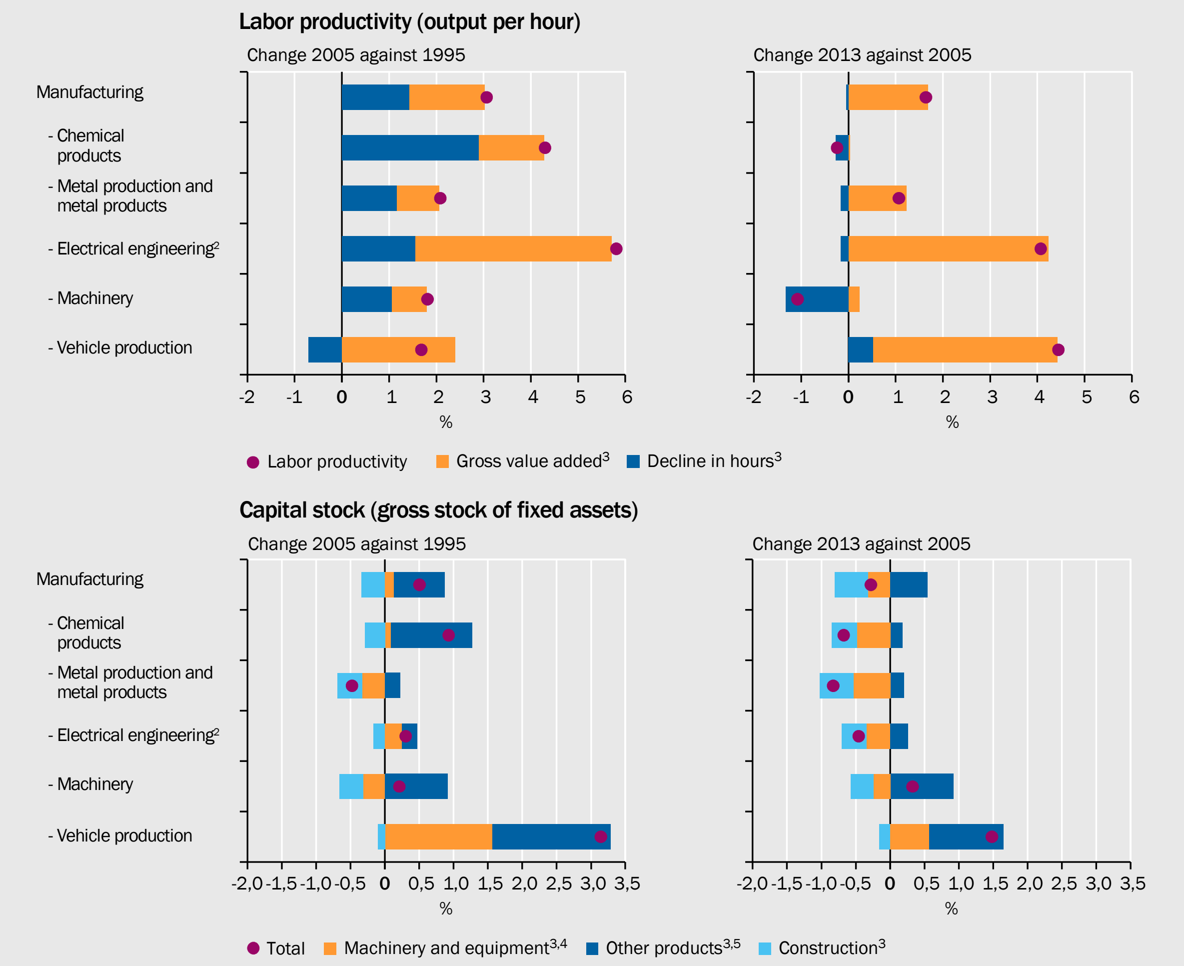
As the manufacturing sector is a major driver of macroeconomic productivity, the noticeable slowdown in its productivity growth in recent years has had a particularly detrimental effect. The two upper panels of Figure 5 illustrate that the average annual increase in hourly productivity of 3.1 % for the years between 1995 to 2005 fell by roughly one half to just 1.6 % for the years between 2005 to 2014.

As this sector is highly export-oriented, it seems reasonable to assume that the moderate global economic growth and the Euro-area crisis are the reasons behind the weak productivity growth. However, no significant underutilization of production capacities can be found in the data. Capacity utilization in 2013 and 2014 stood at 82.1 % and 83.9 % respectively. As both values are close to the long-term average, normal utilization can therefore be assumed.

In fact, the decline in labor productivity in the manufacturing sector is, above all, likely due to the fact that the process of restructuring the value chains has come to an end. Vertical integration in manufacturing measured as a proportion of value added to the production value declined progressively from the mid-1990s until 2008 as it can be seen in the upper panels of Figure 6. Companies focused more and more on the final assembly of highly specialized products and increasingly outsourced upstream value chain processes.

Figure 5

Growth contributions to labor productivity and capital stock in the manufacturing sector[1]



1 – Average annual change. 2 – Manufacture of computers, electronic and optical products and electrical equipment. 3 – Percentage points. 4 – Including military weapon systems. 5 – Including research and development, software and databases, copyright, mineral exploration and cultivated assets.

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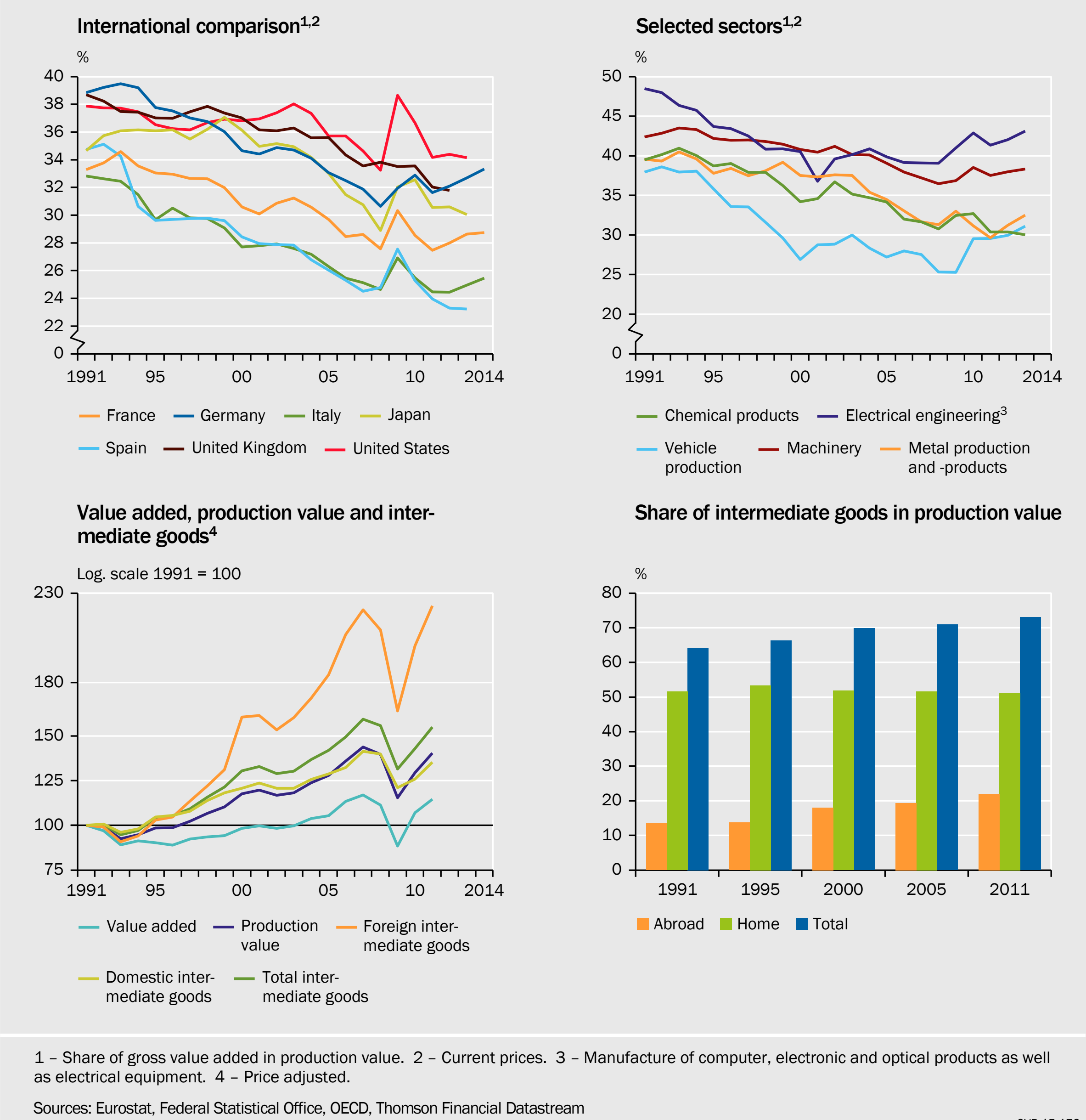
This restructuring process had a positive effect on manufacturing labor productivity, primarily in the period from 1995 to 2005. Apparently, it was precisely labor-intensive and less productive value chain steps that were outsourced. However, the sector retained final production, with the highest value added and relatively low labor utilization. This can be seen most clearly in the fact that labor volume declined despite increasing value creation. Breaking down the change rate of labor productivity for this period into the percentages contributed by the rise in gross value added and the decline in labor volume shows that both factors contributed about one half each to the average annual rise in productivity of 3.1 %. However, as the upper panels of Figure 5 show, this changed from 2005 onwards. The number of hours worked has not decreased since then, but the growth contribution of overall economic activity has remained the same.

The gross fixed capital formation of the manufacturing sector, which still grew at a moderate rate between the years 1995 to 2005, shrank during the time period 2005 to 2013. It is conceivable that outsourcing value chain steps explains a significant part of this decrease of capital stock in fixed assets. This estimate is supported by the observation of individual manufacturing sub-sectors: there is a high correlation between changes in labor volume and changes in capital stock in fixed assets. In contrast, capital stock in other assets, of which research and development constitute a large share, rose. The lower panels of Figure 5 provide evidence for this.

Figure 6

Indicators for production depth in manufacturing



1 – Share of gross value added in production value. 2 – Current prices. 3 – Manufacture of computer, electronic and optical products as well as electrical equipment. 4 – Price adjusted.

Sources: Eurostat, Federal Statistical Office, OECD, Thomson Financial Datastream

As regards macroeconomic labor productivity, it makes a difference whether these upstream value chains were outsourced primarily to the domestic service sector or to other countries. Simply shifting production steps to the domestic service sector would ultimately have no effect on macroeconomic labor productivity, as the increase in productivity in the manufacturing sector would be offset by an equally large negative development in the service sector.

However, the lower-left panel of Figure 6 shows that intermediate goods and services purchased abroad largely explains the decline in the vertical integration of the manufacturing sector. In absolute terms, domestic intermediate goods play a bigger role in production; however, its contribution to the output value of the manufacturing sector for the period 1995-2011 stagnated as it can be seen in the lower-right panel of Figure 6. The increase in labor productivity in the manufacturing sector was accompanied by a positive development in macroeconomic labor productivity as less productive value chain steps were outsourced abroad.

Outsourcing production steps abroad stopped, however, in the year 2009. Since then vertical integration in manufacturing has even risen again slightly; the development of foreign intermediate goods, in contrast, remained slow. One reason for this could be the adjustment of production structures as a result of the global recession. For instance, it was easier during the crisis for multinational companies to adjust their staff abroad than at home (GCEE, 2011). Improved labor market conditions may also have induced multinationals to bring part of their production back to Germany. Moreover, the potential in outsourcing upstream stages of production may have reached its limits. And finally, the impact of the global financial crisis may have been a factor for German companies exercising more restraint in building up new foreign production structures. This effect is likely to be manifest in other European countries above all.

However, this is not inconsistent with the finding that the German corporate sector still uses a large part of its profits to expand production capacities abroad. In fact, there may have been increased investment in those production facilities abroad primarily aimed at production of end-products for the markets in those countries, and less at intermediate goods for the German manufacturing sector. This would seem particularly plausible for direct investment outside of the euro area, such as in Asian emerging markets.

The end of the outsourcing process could be an explanation for the substantial increase in hours worked in machinery in recent years. Moreover, employment was only adjusted with a delay to the significant production increases in the years 2004 to 2007. Mechanical engineering companies at that time handled production increases through overtime, hiring temporary staff and contracting orders to third parties. This meant that a portion of hours worked were recorded in other areas of the economy such as other business services, resulting in a significant rise in mechanical engineering's hourly productivity in this period. In recent years, in contrast, more and more skilled workers have been hired to better tackle the future consequences of demographic change despite relatively weak external demand.

The observation that skilled workers are already being hoarded is true for the chemical industry as well. Moreover, this export-oriented sector suffered particularly badly from the economic slack in the euro area. The international competitiveness of the chemical industry is also largely determined by the relative development of commodity and energy costs. The sector lost competitiveness compared to the US in particular with respect to commodity costs. Uncertainty about exemptions from the renewable energy surcharge is also likely to have dampened willingness to undertake long-term investment projects.

Moreover, the German Chemical Industry Association (Verband der chemischen Industrie – VCI) has reported innovation obstacles from inside and outside of companies (Attar et al., 2015). While external factors primarily relate to regulation and bureaucracy, company-internal factors include a lack of willingness to take risks. This could be closely related to the demographic development.

The automotive manufacturing sector had a special status in productivity development since the year 2005. Particularly in this economic sector, gross value added rose drastically. The end of the outsourcing process may have muted productivity growth in this sector, too. However, this slowdown is more than offset by strong product and process innovations which are reflected in very high investments in research and development. These innovations are likely to have contributed to the automotive manufacturing sector posting considerable revenue gains outside the euro area, above all in China.

The potential for achieving productivity gains from value chain restructuring processes now seems largely exhausted. This raises the question of the extent to which process and product innovations will drive further increases in labor productivity. In this regard, the manufacturing sector is distinct from other sectors of the economy in that a higher proportion of productivity growth is realized internally and not through the entry of new innovative companies.

Studies for the US show that more than 80 % of the increases in labor productivity in the retail sector can be explained by the entry of new and exit of existing businesses (Foster et al., 2006), while about 50 % of the advances in productivity in the manufacturing sector is based on progress in existing companies (Foster et al., 2001). Regarding Germany, GCEE calculations show that the role of existing companies in advancing productivity is significantly greater in the manufacturing sector compared to the US (GCEE, 2015). A high proportion of productivity increases in Germany's manufacturing sector is realized within established companies and not through the entry of new innovative firms.

5. Digitization and productivity

Great hopes for future increases in labor productivity are pinned on digitization, not least as a result of debates on Industry 4.0. The German economy, however, has exhibited major deficits in the past as regards efficient utilization of information and communications technology, raising the question of what needs to be done in order to unleash the full potential of ICT.

5.1 Impact on the overall economy

It is not just the amount of investment that is central to the development of productivity in the overall economy, but also the composition of that capital formation (Stiroh, 2001). ICT investment plays a particularly important role in raising productivity. Policymakers believe that the increasing use of ICT to create value (digitization) holds great potential for increasing productivity in the future (Federal Government, 2014). However, the nominal share of ICT investment in gross value added in Germany has actually been on a downward trend since the turn of the millennium. It fell from 2.6 % in 2000 to 1.6 % in 2014. The picture is somewhat more positive once price effects are taken into account. Other countries such as the US have been investing more in ICT (Cardona et al., 2013; IMF, 2015b), particularly between the years 1992 and 2005. The lower level of ICT investment in Germany is therefore cited as a major cause of the weaker growth in the country's labor productivity from the mid-1990s compared to that seen in the US (Eicher and Röhn, 2007).

Investments in ICT increase efficiency in two ways. Firstly, they have a direct effect on companies' productivity level. This may be reflected by improved production infrastructure, for example, and by the development of complementary factors such as intangible capital (management skills or organizational structure). As a pervasive technology, ICT also has an indirect spillover effect on the wider economy, increasing efficiency in other areas of production. The interaction between R&D activity and ICT is an important factor in innovation. Examples include cloud computing and Industry 4.0. Transferring information via the Internet in particular has become much easier and quicker in recent years.

A variety of empirical studies support the claim that ICT investment makes a major contribution to productivity growth. The literature uses two methods of measuring the contribution of ICT investment on labor productivity growth. One approach is to use econometric estimates, normally at company level, to determine the elasticity of value added to a change in the ICT capital stock. Cardona et al. (2013) summarize a large selection of these studies and conclude that a 10 % increase in ICT investments leads to an increase in production of approximately 0.5 % to 0.6 %. They also find that this elasticity has trended upwards in recent years.

Alternatively, economists use growth accounting to determine ICT's contribution to the development of aggregate productivity. Productivity growth is initially broken down at sector level into its three inputs: TFP, capital and labor. The capital factor of production is then broken down again into ICT capital and non-ICT capital. In addition, a distinction is made between ICT-producing (approximately 5 % of total gross value added in 2013), ICT-intensive (around 39 %) and other sectors (around 56 %).[6] ICT-intensive sectors are those that have a relatively high level of ICT capital, but do not produce ICT themselves.

Older studies show that ICT-producing and ICT-intensive sectors made relatively low contributions to the growth of labor productivity in the overall economy in Germany compared to the US (Eicher and Röhn, 2007). An updated analysis with data up to 2013 produced the fol-

[6] The Appendix provides the classification of the sector and a detailed analysis of the growth contribution.

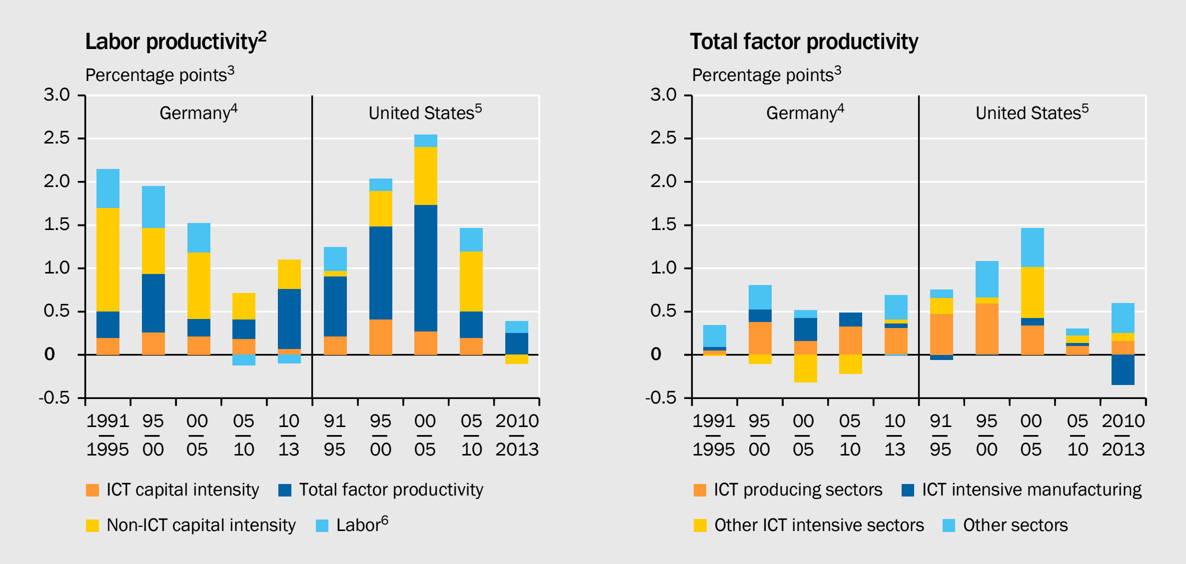
lowing findings with regard to the importance of ICT to labor productivity in the economy as a whole:

- The left panel of Figure 7 shows that in comparison to the US the contribution of ICT capital input to German productivity growth is low. This is particularly true for the period between the years 1995 to 2005.
- Technological progress in the economy as a whole (total factor productivity) is driven primarily by the ICT-producing sectors and less by the ICT-intensive sectors. The right panel of Figure 7 shows that less than 5 % of total value added explains almost half of the increase in TFP.
- In the ICT-intensive sectors, there has been only a moderate increase in TFP. These sectors are thus far behind the ICT-producing sectors.

In the latter aspect, in particular, the trend in Germany has been very different to that seen in the US economy, where major increases in TFP in ICT-producing sectors were followed around the turn of the millennium by large increases in ICT-intensive sectors (Eicher and Strobel, 2008). In the US, neutral technological progress through product innovations at ICT-producing companies has, firstly, resulted in technological progress embodied in the capital used by ICT-intensive companies. This has led to a higher ICT capital intensity.

Figure 7

Comparison of the contributions to labor productivity and total factor productivity between Germany and the United States[1]



1 – Data for United States: own calculations. 2 – Labor productivity per hours worked. 3 – Average annual growth contributions. 4 – Calculations based on the updated study of Eicher and Röhn (2007). 5 – Own calculations based on data for private economy transferred to total economy. 6 – Labor quality and reallocation of hours worked.

Sources: BEA, ifo

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Secondly, new ICT goods have triggered innovations at ICT-intensive companies. These have led to an increase in TFP at these companies (neutral technological progress). To that end, not only new products, but also more efficient structures of administration and production may have made a particular contribution. This development has primarily taken place in the service sector, primarily wholesale and business services. However, technological advances in ICT-intensive sectors have flattened out since the mid-2000s.

In Germany, ICT appears to have had hardly any spillover effects on ICT-intensive industries outside the manufacturing sector (ICT productivity paradox). However, this paradox applies only in the service sector. In manufacturing, by contrast, there have been efficiency gains. For the sake of future labor productivity, Germany should seek to identify the barriers to higher productivity in the ICT-intensive service sector.

One possible explanation could be the low level of complementary investment. This includes spending on further training of staff, intangible expenditure (for example on corporate restructuring), and investment in product design and market research. An alternative explanation for the ICT productivity paradox could be the different management structures of the two countries. In Germany, management has a greater reliance on rigid employment structures rather than flexible components of remuneration as in the US. High regulation of product and labor markets may also be a factor (Bloom et al., 2012; Bartelsmann et al., 2010). Moreover, it can be assumed that the acceptance of new technologies and the new business models associated with them will tend to decline in an ageing society.

5.2 Industry 4.0 – the fourth industrial revolution?

"Industry 4.0" has become one of the keywords of the public debate on the digital revolution. The term refers to the complete digitization and networking of value chains in the manufacturing sector using information and communication technology. The process has been triggered by enormous improvements in IT hardware. The rapid increase in processing power and storage capacity has enabled large volumes of data to be analyzed quickly with the help of intelligent algorithms (Bertschek, 2015). Industry 4.0 essentially describes an increase in TFP in the manufacturing sector, which is made possible by innovations in products and processes and triggered by greater use of ICT. Compared to the US, Germany has had a few problems in using ICT efficiently in this sector of the economy.

The technological innovations resulting from Industry 4.0 primarily affect activities in the manufacturing sector via three channels: firstly, progress in ICT means that physical objects such as robots, machinery and components can communicate with one another directly via the Internet. These "cyber-physical systems" can help to make production processes flexible and customized, which reduces set-up costs when changes to production processes are necessary. This means that average costs are lower and no longer fall as the production volume increases. In other words, economies of scale lose their significance and mass production loses its advantages over customized manufacture.

In the medium term, this type of process innovation could even have an impact on the international division of labor. A fall in domestic costs due to greater capital intensity would mean that stages of production no longer need to be outsourced to other countries. However, this is unlikely to explain the recent increase in vertical integration observed in manufacturing.

Secondly, businesses hope that the improved data available will stimulate innovation for new products. Communicative interaction between product and producer enables the creation of new, larger datasets. Companies will now be able to draw on experience and data collected on products as customers use them throughout their useful lives.

Thirdly, the customer data collected can be used to provide particular services by producers in the manufacturing sector. This could change existing business models, giving a greater role to ICT-supported services. Digitization is therefore likely to unleash new growth potential in the service sector. All in all, there is a wealth of opportunities for achieving greater product differentiation and tapping new markets.

Value added is likely to shift increasingly towards information technology in the future. High-quality machinery in the manufacturing sector will still be needed, but linking it to ICT and IT services will become increasingly important.

There is already public debate whether digitization of manufacturing could potentially unleash the fourth industrial revolution. The first three industrial revolutions involved mechanization using water and steam power (first), mass production using electrically powered assembly lines (second) and the use of electronics and information technology to further automate production (third). However, there is no general consensus as to the precise timings of previous industrial revolutions or even as to their number.

One of the main reasons for this is likely to be that there is no generally accepted definition of an industrial revolution. However, the largely uncontested aspects are likely to include major increases in labor productivity and substantial upheavals in labor and goods markets (Gordon, 2012). This leads to the emergence of new professions and products, as well as the disintegration of old business models and social structures. Traditional occupations, working models and products come under pressure, meaning considerable adjustment costs are possible on the labor market in particular. These are usually manifested in changing requirements for employee training and skills.

Company surveys have not indicated much in the way of a tangible fourth industrial revolution to date. According to a study by the Centre for European Economic Research (ZEW), only around one in five companies is familiar with the term Industry 4.0 and only 4 % of the companies are currently implementing or planning Industry 4.0 projects (ZEW, 2015). Familiarity with the term Industry 4.0 depends greatly on the size of the company. Half of the companies with more than 500 employees were aware of Industry 4.0 and a quarter are planning or already implementing Industry 4.0 projects. Such planned or existing Industry 4.0 projects are most widespread in the ICT sector (21 % of the companies), electronics (15 %) and mechanical engineering (14 %). A survey of mechanical and industrial engineering firms by the Cologne Institute for Economic Research (IW) conclude that the digital transformation is not yet of particular importance to many companies. Three-quarters of the businesses surveyed in these sectors had not yet taken steps to implement ideas related to Industry 4.0 or had only done so sporadically (IW, 2015).

Past industrial revolutions differed from political revolutions in that they took place over a relatively long period of time. In a sense, they were evolutionary rather than revolutionary. Company surveys indicate that we can expect the same from Industry 4.0 (Hüther, 2015). The quantitative effects of increasing digitization through Industry 4.0 on aggregate labor productivity are extremely difficult to assess. Studies published in the past are unconvincing in their methodological approach and should only be interpreted as rough estimates at best. The German Association for Information Technology, Telecommunications and New Media (BITKOM), for example, expects cumulative productivity gains of up to 30 % by 2025 in certain sectors of the economy (Bauer et al., 2014).

However, BITKOM's conclusions about the potential for change through Industry 4.0 are based on interviews with just eight experts and the sector-specific value chains linked to them. Although the future consequences of Industry 4.0 cannot be reliably quantified, there is no doubt that the integration of ICT in automation processes in the manufacturing sector has the potential to substantially improve labor productivity.

5.3 Role of economic policy

The digital transformation offers a great potential for increasing labor productivity. It is already making its mark in today's labor market, bringing changes to the professional landscape, forms of employment and the employee skill structure in demand. Policymakers must create a suitable framework to ensure that businesses can implement this transformation successfully. This means addressing regulatory issues such as data protection, norms and standards. It is particularly important to focus on the European level rather than simply seeking national solutions.

The digital revolution should not be hindered at national level by overly rigid regulatory barriers. The high level of regulation on the product and labor markets suggests that there are obstacles to productivity (Bloom et al., 2012; Bartelsmann et al., 2010). Making remuneration more flexible and labor markets less rigid is likely to boost competition between innovative companies, give businesses more freedom and thus unleash this potential for higher productivity.

Expanding broadband networks also has the potential to raise productivity. Czernich et al. (2011) have shown that increasing broadband coverage across the population is capable of lifting economic growth. The commission of experts tasked with bolstering investment in Germany is calling for a major expansion of very high-speed (up to 1 Gbit/s), but also very expensive fiber optic connections (Expert Commission, 2015). However, as Falck et al. (2013) found, demand for high-speed Internet connections is not keeping pace with supply. Few households seem to be requesting broadband speeds of more than 50 Mbit/s to date (Dialog Consult and VATM, 2014).

The German Federal Government aims to make broadband networks with download speeds of at least 50 Mbit/s available across the board. However, the costs and benefits of potential public subsidies must be weighed up carefully, especially in rural areas. Furthermore, given the rapid development of the technologies involved (e.g. wireless technology), it would be too early to convert the majority of broadband infrastructure to fiber optics. The relatively high cost of fiber optic connections in comparison to other technologies might subsequently prove to be an expensive mistake (TÜV Rheinland, 2012). Extensive public subsidies for widespread expansion of the fiber optic network should therefore be rejected.

Education and training policy is another area for political action in relation to digitization. It plays an important role in enabling all parts of society to participate in technological advances, and in raising average individual productivity. Education policy should aim to teach people essential IT skills at an early stage, especially in secondary schools. This means better equipping schools with IT infrastructure and developing digital teaching strategies for staff and pupils (OECD, 2015).

Further education programs should also be available to help adults gain IT skills. Taking advantage of the potential offered by digitization and technological change ultimately depends to a large degree on complementary investment in human capital. This can help to increase acceptance of new technologies and the new business models they bring with them – a highly relevant issue in an aging society.

6. Conclusion

Two structural developments have contributed to the significant decline in German productivity growth in the past few years. Firstly, more than three million people have been successfully integrated into the German labor market since 2005. Many of these employees exhibit comparatively low productivity. Secondly, the process of restructuring the value chains in the manufacturing sector may have come to an end. The vertical integration in manufacturing has not decreased any further since the recession in 2009.

However, it is still too early to make a final assessment of this latest development because there is high uncertainty as regards the causes. For example, improved labor market conditions in Germany could have induced multinational companies to bring some of their production back into the country. However, it is also conceivable that the vertical integration rebound was due to the impact of the financial crisis or an increase in protectionism.

There is a close relationship between developments in labor productivity and prosperity in an economy. An important task of economic policy is therefore exploiting unused potential and creating suitable conditions for facilitating sustainable productivity increases. For example, there are numerous barriers to entry in the service sector that prevent free competition and therefore impede productivity advances. Excessive regulation of the product and labor markets could explain why investments in ICT cannot fully exploit their productivity-increasing potential.

In addition, expanding technological knowledge in the economy is an important source for increasing labor productivity. Harnessing the full potential of the German innovation system is therefore a core task of economic policy. This requires the provision of comprehensive infrastructure for innovations covering the aspects of education, research and transfer of knowledge (GCEE, 2009). In the next few years, the question will become more prominent as to how the still high number of innovative employees in Germany can be retained or even increased through, for example, education and training despite the demographic change (GCEE, 2009).

Successfully implementing innovative ideas through start-ups is very important for productivity advances. However, there may be problems in start-up financing, as the availability of venture capital for young companies is relatively low compared to other countries. A suitable institutional framework could help to improve the financing of young businesses. This includes further developing the European stock exchange segments for start-ups and removing tax distortions, particularly by introducing an allowance for corporate equity. This is always preferable to creating new areas of subsidization.

6. References

Anzoategui, D., D. Comin, M. Gertler and J. Martinez (2016), Endogenous Technology Adoption and R&D as Sources of Business Cycle Persistence, NBER Working Paper No. 22005.

Attar, S. et al. (2015), *Innovationen den Weg ebnen*, Eine Studie von IW Consult und Santiago für den Verband der Chemischen Industrie, Köln.

de Avillez, R. (2012), *Sectoral contributions to labour productivity growth in Canada: Does the choice of decomposition formula matter?*, CSLS Research Report 2012-09, Ottawa.

Bartelsman, E.J., P.A. Gautier and J. de Wind (2010), *Employment protection, technology choice, and worker allocation*, Tinbergen Institute Discussion Paper 2010-042/3, Amsterdam.

Bauer, W., S. Schlund, D. Marrenbach and O. Ganschar (2014), *Industrie 4.0 - Volkswirtschaftliches Potenzial für Deutschland*, BITKOM und Frauenhofer IAO, Berlin und Stuttgart.

Bertschek, I. (2015), Industrie 4.0: Herausforderung und Chance für Unternehmen und Arbeitswelt, *ifo Schnelldienst* 10/2015, 3-5.

Bloom, N., R. Sadun and J.V. Reenen (2012), Americans do IT better: US multinationals and the productivity miracle, *American Economic Review* 102, 167-201.

BMWi (2015), *Investitionsstrategie*, Bundesministerium für Wirtschaft und Energie, http://www.bmwi.de/DE/Themen/Wirtschaft/investitionsstrategie.html.

Cardona, M., T. Kretschmer and T. Strobel (2013), ICT and productivity: Conclusions from the empirical literature, *Information Economics and Policy* 25, 109-125.

Czernich, N., O. Falck, T. Kretschmer and L. Woessmann (2011), Broadband infrastructure and economic growth, *Economic Journal* 121, 505-532.

Dialog Consult and VATM (2014), *16. TK-Marktanalyse Deutschland 2014*, Dialog Consult und Verband der Anbieter von Telekommunikations- und Mehrwertdiensten, Duisburg und Köln.

DIW (2014), Wirtschaftliche Impulse für Europa, *DIW-Wochenbericht* 27/2014, Deutsches Institut für Wirtschaftsforschung, Berlin.

DIW (2013), Investitionen für mehr Wachstum – Eine Zukunftsagenda für Deutschland, *DIW-Wochenbericht* 26/2013, Deutsches Institut für Wirtschaftsforschung, Berlin.

Eicher, T.S. and O. Röhn (2007), Sources of the German productivity demise: Tracing the effects of industry-level information and communication technology investment, *German Economic Review* 8, 211-236.

Eicher, T.S. and T. Strobel (2008), Der deutsche Produktivitätsabschwung: Ursachenforschung auf Branchenebene, *ifo Schnelldienst* 15/2008, 33-40.

Expert Commission (2015), *Stärkung von Investitionen in Deutschland*, Bericht der Expertenkommission im Auftrag des Bundesministers für Wirtschaft und Energie, Sigmar Gabriel, Berlin.

Falck, O., J. Haucap, J. Kühling and C. Mang (2013), Alles Regulierung oder was? Die Bedeutung der Nachfrageseite für eine wachstumsorientierte Telekommunikationspolitik, *ifo Schnelldienst* 15/2013, 42-46.

Federal Government (2014), *Digitale Agenda 2014-2017*, Berlin.

Fernald, J. G. (2015), Productivity and potential output before, during, and after the Great Recession, in: Parker, J. und M. Woodford (Hrsg.): *NBER Macroeconomics Annual 2014*, University of Chicago Press, 1-51.

Foster, L., J.C. Haltiwanger and C. J. Krizan (2006), Market selection, reallocation, and restructuring in the U.S. retail trade sector in the 1990s, *Review of Economics and Statistics* 88, 748-758.

Foster, L., J.C. Haltiwanger and C.J. Krizan (2001), Aggregate productivity growth. Lessons from microeconomic evidence, in: Hulten, C.R., E.R. Dean und M.J. Harper (Hrsg.): *New developments in productivity analysis*, University of Chicago Press, Chicago, 303-372.

GCEE (2009), Annual Report 2009, German council of Economic Experts, Wiesbaden.

GCEE (2011), Annual Report 2011, German council of Economic Experts, Wiesbaden.

GCEE (2013), Annual Report 2013, German council of Economic Experts, Wiesbaden.

GCEE (2014), Annual Report 2014, German council of Economic Experts, Wiesbaden.

GCEE (2015), Annual Report 2015, German council of Economic Experts, Wiesbaden.

GCEE (2016), Annual Report 2016, German council of Economic Experts, Wiesbaden.

Gordon, R.J. (2012), *Is U.S. economic growth over? Faltering innovation confronts the six headwinds*, NBER Working Paper 18315, Cambridge.

Hüther, M. (2015), *Industry 4.0 - Chances and Challenges*, Rede, Vortragsreihe „Dialog mit Deutschland“ der deutschen Botschaft in Rom, Rom, 4. Juni 2015.

IW (2015), Der Pioniergeist lebt, *iw-dienst* 41/2015, 6-7.

IMF (2015a), *Uneven growth: Short- and long-term factors*, World Economic Outlook, International Monetary Fund, Washington, DC.

IMF (2015b), *United States: 2015 Article IV consultation*, IMF Country Report No. 15/168, International Monetary Fund, Washington, DC.

OECD (2015), *Students, computers and learning - Making the connection*, PISA, Organisation for Economic Co-operation and Development, Paris.

Stiroh, K.J. (2001), What drives productivity growth?, *Economic Policy Review* March 2001, 37-59.

Strobel, T., S. Sauer and K. Wohlrabe (2013), The ifo investment database, *Schmollers Jahrbuch* 133, 449-460.

TÜV Rheinland (2012), *Bericht zum Breitbandatlas Ende 2012 im Auftrag des Bundesministeriums für Wirtschaft und Technologie (BMWi) - Teil 1: Ergebnisse*, Berlin.

VDI und IW (2015), *Der regionale Arbeitsmarkt in den Ingenierberufen - Juni 2015*, Ingenieurmonitor 2015/I, Verein Deutscher Ingenieure und Institut der deutschen Wirtschaft Köln, Düsseldorf und Köln.

ZEW (2015), *Industrie 4.0: Digitale (R)Evolution der Wirtschaft*, IKT-Report, Oktober 2015, Zentrum für Europäische Wirtschaftsforschung, Mannheim.

Appendix - Growth analyses: Study of causes at sector level

The findings of the growth analysis in the main body of the chapter are based on an update of the study by Eicher and Röhn (2007). For a detailed description of the calculations see this source. Only the most important points underlying the findings in the text are discussed below. The growth analysis is performed at economic sector level and unbundles labor productivity, measured as gross value added per hour worked, into its input components. Accordingly, macroeconomic labor productivity is equivalent to the weighted total of these input components; the weightings for each economic sector reflect their relative share of macroeconomic output.

In detail, the growth rate of labor productivity for the individual industry i, $\Delta \ln y_i$, results from the rate of change of TFP, $\Delta \ln A_i$, the change in the average skill level of the labor force, $\Delta \ln E_i$, and the percentage adjustment of ICT capital intensity, $\Delta \ln c_i^{ICT}$, and non-ICT capital intensity, $\Delta \ln c_i^{NICT}$. Instead of the capital stock, the concept of capital intensity (effective use of the capital, capital services) is used. Capital intensity is the product of capital stock and productivity of the relevant capital goods (measured by the user cost of capital).

The information regarding ICT and non-ICT capital intensity can be determined from the ifo Investment Database (Strobel et al., 2013). This database enables differentiation between three ICT and nine non-ICT capital goods groups at sector level. The three ICT capital goods groups are (i) office machinery, computer equipment and devices, (ii) telecommunications, radio and television sets, electronic components and (iii) software. All economic sectors that manufacture these goods are classified in the group of ICT-producing sectors of the economy. It is also possible to use the data to differentiate between ICT-intensive and other sectors of the economy. Those sectors whose ICT share of overall capital intensity is higher than the median of all sectors of the economy are labeled ICT-intensive sectors. Table 4 summarizes the classification of the industries into the relevant groups.

The growth equation for a single sector can be defined as follows:

$$\Delta \ln y_i = \mathrm{v}_i^{ICT} \Delta \ln c_i^{ICT} + \mathrm{v}_i^{NICT} \Delta \ln c_i^{NICT} + \mathrm{v}_i^{L} \Delta \ln E_i + \Delta \ln A_i.$$

The individual rates of change of the input variables of capital intensity and quality of work are each multiplied by their share of the sector's total costs (factor income shares) – v_i^{L} , v_i^{ICT} and v_i^{NICT}. The aggregated contributions to growth for labor productivity in the overall economy can be derived from the weighted totals of the individual input components across industries. The results are shown separately for ICT-producing sectors, ICT-intensive sectors and other sectors of the economy. Table 3 provides a summary of the results.

Table 3

Growth contributions to labor productivity by economic sectors

Percentage points

	1991 – 1995	1995 – 2000	2000 – 2005	2005 – 2010	2010 – 2013
Labor productivity (%)[2]	**2.2**	**2.0**	**1.5**	**0.6**	**1.0**
Reallocation of hours worked	**0.3**	**0.5**	**0.1**	**– 0.3**	**– 0.1**
Labor quality	**0.1**	**– 0.0**	**0.3**	**0.1**	**– 0.0**
ICT capital intensity	**0.2**	**0.3**	**0.2**	**0.2**	**0.1**
ICT producing sectors	0.1	0.0	0.0	0.0	0.0
ICT intensive sectors	0.1	0.1	0.1	0.1	0.0
other sectors	0.0	0.1	0.1	0.1	0.0
Non-ICT capital intensity	**1.2**	**0.5**	**0.8**	**0.3**	**0.3**
ICT producing sectors	0.1	0.0	0.0	0.0	0.0
ICT intensive sectors	0.5	0.2	0.1	0.0	– 0.0
other sectors	0.5	0.3	0.6	0.3	0.4
Total factor productivity	**0.3**	**0.7**	**0.2**	**0.2**	**0.7**
ICT producing sectors	0.1	0.4	0.2	0.3	0.3
ICT intensive sectors	0.0	0.0	– 0.1	– 0.1	0.1
other sectors	0.3	0.3	0.1	– 0.0	0.3

1 – Deviation in total sum can be due to rounding. 2 – Average annual change. Calculations based on the updated study of Eicher and Röhn (2007).

Source: ifo

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Table 4

Development of labor productivity by economic sectors in %[1]

	Share of gross value added (2013)	1991 – 1995	1995 – 2000	2000 – 2005	2005 – 2010	2010 – 2013
ICT producing sectors						
Computer, electronic and optical products	1.3	4.7	11.4	10.0	9.4	5.7
Telecommunications	1.0	11.4	16.3	5.1	12.6	6.0
IT and information services	2.6	0.0	4.5	1.0	5.3	9.3
ICT intensive sectors						
Chemical products	1.6	8.2	4.9	3.9	2.2	– 4.2
Pharmaceutical products	0.9	9.0	4.3	8.2	1.4	1.0
Electrical equipment	1.7	3.2	3.2	0.1	2.1	– 2.2
Machinery	3.5	4.0	1.8	1.8	– 1.2	– 0.9
Motor vehicles, trailers and semi-trailers	4.0	1.8	– 2.4	4.0	6.1	2.6
Other transport equipment	0.5	– 2.4	10.5	5.3	4.4	– 2.9
Furniture and other goods	0.9	– 0.4	1.9	1.0	1.2	1.8
Rep. a. installation of machinery a. equipment	0.6	6.4	7.5	7.8	– 4.2	0.0
Wholesale (excluding motor vehicles)	4.6	2.0	3.1	7.8	– 0.7	2.1
Retail (excluding motor vehicles)	3.3	0.7	0.7	– 0.2	2.0	– 0.1
Water transport	0.3	12.2	15.4	14.5	6.3	4.4
Air transport	0.2	11.6	4.7	– 5.2	0.9	–11.5
Postal and courier activities	0.5	– 0.5	2.8	– 1.2	0.4	1.2
Publishing, audiovisual and broadcasting	1.3	3.8	3.4	– 0.2	0.8	1.9
Financial services	2.6	0.6	4.6	– 1.2	0.7	2.5
Insurance and pension	1.0	4.4	– 7.1	–28.8	1.9	– 1.9
Activities auxiliary to financial and insurance services	0.6	– 1.1	–11.7	– 7.1	– 3.3	–10.7
Professional, scientific and technical services	6.1	– 0.1	– 2.7	– 2.2	– 2.8	– 1.0
Other business services	4.8	– 0.2	– 0.8	0.1	– 2.3	0.9
Repair of computers a. personal a. household goods	0.1	5.1	4.4	– 3.5	– 0.8	– 0.1
Other sectors						
Agriculture, forestry and fishing	0.8	– 5.1	5.4	2.8	1.8	2.2
Mining and quarrying	0.2	7.5	– 0.9	– 2.0	6.8	– 3.6
Food, beverage and tobacco processing	1.6	– 0.9	0.5	– 1.2	– 1.1	3.7
Textiles and apparel industry	0.3	6.0	3.4	3.8	2.0	– 0.1
Wood, cork, except furniture; straw, plaiting materials	0.2	5.8	3.2	2.5	– 0.7	– 2.5
Paper and paper products	0.4	0.3	4.6	1.7	2.5	3.0
Printing and reproduction of recorded media	0.3	1.8	2.3	2.0	3.0	2.4
Coke and refined petroleum products	0.2	–30.1	6.5	– 1.1	– 4.3	–21.2
Rubber and plastic products	1.0	3.4	2.0	3.5	2.3	0.5
Other non metallic mineral products	0.6	5.7	2.2	2.3	0.2	2.3
Basic metals	0.8	7.2	4.4	– 0.2	– 1.6	3.5
Structural metal products	2.0	1.2	2.9	1.1	1.0	1.4
Electricity, gas, steam and air conditioning supply	2.0	5.2	8.0	3.4	2.1	– 3.1
Water collection, treatment and supply	0.2	3.8	3.4	1.0	0.0	1.1
Sewerage, waste treatment; materials recovery	0.8	– 8.8	– 5.5	1.5	– 0.4	2.5
Construction	4.5	– 1.0	0.4	0.4	– 0.4	0.2
Wholesale, retail trade, repair of motor vehicles	1.6	– 2.5	1.5	5.5	0.0	1.6
Land transport and transport via pipelines	1.9	5.5	3.3	0.6	1.3	1.2
Warehousing and support activities for transportation	1.8	1.3	1.4	8.8	0.2	1.3
Accommodation and food service activities	1.5	– 2.7	– 1.3	– 1.2	– 2.5	2.7
Real estate activities	11.2	2.0	– 0.2	3.6	1.4	2.7
Public administration; compulsory social security	6.2	3.4	2.0	1.3	1.8	2.7
Education	4.5	0.7	– 0.3	– 1.2	– 1.8	– 1.8
Human health and social works activities	7.4	1.7	1.9	1.0	1.3	1.4
Arts, entertainment and recreation	1.4	– 1.7	– 0.7	– 1.7	– 0.8	1.4
Activities of membership organisations	1.1	3.7	2.3	0.1	0.6	1.2
Other personal service activities	1.3	1.9	– 2.6	– 0.0	– 1.0	– 2.0

1 – Average annual change. The calculations are based on an update of the study by Eicher and Röhn (2007).

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