

The German Productivity Paradox – Facts and Explanations

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Abstract

Despite massive digitization efforts, the German economy has experienced a marked slowdown in its productivity growth. This paper analyzes the reasons behind this disconcerting development. A major factor is the turnaround of the labor market that commenced around 2005. The successful integration of five million predominantly low-productivity workers into the labor market induced an attenuating effect on productivity growth. This does not explain the slowdown entirely, however. As a potentially important countervailing force, technological advances associated with digitization would have had the potential to lift productivity growth more strongly, but they frequently translated into employment growth instead.

JEL-Codes: O400, E240, C320.

Keywords: labor productivity, labor markets, technology shocks, digitalization, structural VARs.

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1 Introduction

Economic growth remains the key to economic prosperity, and growth in labor productivity remains the key to economic growth. In tune with this observation, the world has experienced tremendous progress in living standards since the onset of the industrial revolution. Productivity growth has been the predominant factor in this era of progress, and next to alleviating social inequities, its stimulation has been the focal point of economic policy. This seems especially true for most advanced economies, since in light of their near stagnant labor forces today economic growth needs to rest on labor productivity growth (IMF, 2015). The basis for this source of growth is slowly eroding as well, since population ageing might impede the pace of innovation and technology adoption during the next decades.

Disconcertingly, since the 1970s all major advanced economies have shared a similar experience: a secular decline of productivity growth rates (Figure 1a). This decline has become even more pronounced well before the onset of the financial crisis of 2008/09 (IMF, 2015). Some commentators have already concluded that the world's economic growth potential might suffer from a case of secular stagnation (Gordon, 2015; Summers, 2014). As Figure 1a documents, however, this deceleration has not proceeded completely synchronously. This raises the question whether advanced economies might be able to avoid this fate by pursuing appropriate countervailing policies.

Indeed, the experience of the U.S. indicates that information and communication technology (ICT) played an important role. Figure 1b demonstrates that hourly productivity in other economies, especially Germany and France, reached the US level in the middle of the 1990s, while they had been lagging behind by some 30 percent at the beginning of the 1970s.¹ Starting around 1995, however, the U.S., unlike other countries experienced an acceleration in productivity growth. In the following decade the U.S. economy realized a burst of innovation and massive reallocation of production factors related to the production and use of ICT (Cette et al., 2016). Since the mid-2000s, U.S. productivity growth has once again fallen back behind the figures of other economies. A wide range of contributions has suggested competing candidate explanations for this development.

A first group of studies moves financing conditions into the center of attention. It relates the decline in productivity growth to the Great Recession, claiming that due to financial constraints businesses have reduced their efforts regarding innovations and the adoption of new technologies. Anzoategui et al. (2016), for instance, argue in the wake of the Great

¹It should be mentioned that France and Germany still have significantly lower levels of GDP per worker. It is not unlikely that increasing the working time per worker could lower aggregate hourly productivity in both countries as there may exist diminishing returns to hours worked and to the employment rate (Bourlès and Cette, 2007).

Recession firms primarily cut their investments in research and development (R&D), since investment into physical and working capital displays a higher short-run return. [Fort et al. \(2013\)](#) provide evidence that the financial crisis was particularly detrimental for startups and young firms, since fluctuations in housing prices tend to affect them through a wide range of credit channels.

A second group emphasizes the role of ICT. It starts from the observation that the deceleration in productivity growth already began before the Great Recession, in the years 2004 and 2005 ([Fernald, 2015](#); [Gordon, 2012](#)). This slowdown was particularly characteristic for industries that either produce or intensively use ICT. [Fernald \(2015\)](#) interprets this result as a return to normal productivity growth, after ICT had provided an exceptional boost to productivity around the millennium. Similarly, [Gordon \(2012\)](#) implicates a slower pace of growth of the productivity frontier since around the year 2000 as the main reason for the slowdown in productivity growth.

In contrast, a third group of studies maintains that the most productive firms still realize large productivity gains, but that other less productive firms are not keeping pace with the frontier ([Andrews et al., 2015](#)). As a consequence, the productivity gap between the most productive (frontier firms) and the less productive firms within each industry tends to widen. Thus, the major culprit is not a decline in innovation activity but rather insufficient diffusion. This might be the consequence of firms displaying comparatively meagre efforts regarding technology adoption. It might also reflect a sluggish reallocation of production factors, since otherwise competition would drive out the least productive companies and force the laggards to catch up. Corroborating this candidate explanation, [Decker et al. \(2014\)](#) document for the last decades a rising productivity dispersion within U.S. industries but declining business dynamism.

A final prominent candidate explanation for the sluggish U.S. productivity trend is measurement error that systematically underrepresents genuine productivity growth. Measurement errors might arise for three reasons: First, quality changes aggravate the price measurement especially of ICT. Yet, [Byrne et al. \(2016\)](#) find little evidence that such mismeasurement is driving the deceleration in estimated U.S. productivity growth. Second, recent productivity growth does not capture the costless services provided by large ICT firms, such as Facebook, which increase consumer benefits but are not included in GDP. [Syverson \(2017\)](#) argues, however, that these benefits are by far too small to explain the missing productivity gains since the mid-2000s. Third, it is difficult to measure value added in a large part of the economy, comprising health care, education, financial services and professional services.

Only a few contributions address the case of other advanced economies. For Europe, [Cette et al. \(2016\)](#) suggest that the ICT innovation boom that characterized the U.S. before

the Great Recession had not spilled over to Europe. In European economies, structural rigidities in labor and product markets impeded favorable resource reallocation. Low real interest rates and abundant credit, in particular in Spain and Italy, caused an additional misallocation of capital: First, the low interest rates together with massive capital inflows induced a greater importance of the non-tradable goods sector, in particular the construction sector, at the cost of a shrinking tradable goods sector (Kalantzis, 2015). Second, Gopinath et al. (forthcoming) find an increasing trend of capital misallocation since the launch of the Euro even for the tradable goods sectors (manufacturing) of Italy, Portugal and Spain.

Germany is a particularly interesting case, as its economic performance provides such an impression of ambivalence. On the one hand, it even realized declining unemployment during the Eurozone crisis, it has been experiencing a protracted economic expansion, and the ratio of public debt to GDP is now in line with the Maastricht criterion. Many German industrial companies are viable competitors in world markets, carried by their engineering competencies and their fast pace of developing and adopting new technologies, epitomized in the expression “Industry 4.0”. On the other hand, potential growth and in particular productivity growth have remained quite modest, despite considerable investments into ICT capital. Moreover, it is already apparent that the German population will age dramatically during the next two decades, foreshadowing an even lower potential growth rate.

One particularity of Germany is the resilient economic development it has displayed in recent years. By stark contrast to other advanced economies, the German expression of the Great Recession was of shorter duration, and no second recession hit the economy in the course of the Eurozone crisis between 2011 and 2013. After declining by 5.6 percent in 2009, the German economy experienced a strong rebound in production with growth rates of 4.1 and 3.7 percent in 2010 and 2011, respectively. Moreover, the unemployment rate increased only slightly in the year 2009, while employment increased from 39.3 million people in 2005, the year with the highest recorded unemployment rate in German post-war history, to 44.3 million in 2017. Some studies even talk about the “German labor market miracle” (Burda, 2016).

Considering this impressive record, it seems quite paradoxical that the German economy has experienced a marked slowdown in its productivity growth, despite its massive digitization efforts. If this paradox remained unresolved, this would be bad news for innovation policy, since it often rests on attempts to intensify the digitization of the economy. So far, convincing explanations for the slowdown are lacking. The observation, for instance, of a coincidence of a sluggish German productivity trend and relatively weak private investment is leaving the underlying reasons unresolved. Thus, calling for policy measures to stimulate investment activity seems quite premature (Bach et al., 2013). Viable prescriptions for economic policy necessitate a more detailed look.

This paper uses growth decompositions, descriptive statistics and structural vector autoregressions to detect the main factors behind the recent deceleration of German productivity growth. First, we show that the sluggish productivity trend in the U.S. exerted only minor effects on German productivity growth: German developments are mainly reflecting idiosyncratic sources. Second, our results suggest that a sizeable part of the slowdown in German productivity growth is a mere side effect of the labor market performance since the year 2005. The successful integration of five million predominantly low-productivity workers into the labor market attenuated productivity growth. In our assessment, the labor market reforms implemented at the beginning of the 2000s had a substantial impact on this development.

Third, we provide an analysis of the effects of digitization on the German economy. We find that technological progress originating in the ICT-producing sector had significant positive effects on both GDP and employment. This result corroborates the common intuition that digitization is a driving force of economic prosperity. The net effect on labor productivity growth was modest, however, as the positive effects on output and labor input almost cancel each other out. Thus, technology shocks in the ICT-producing sector apparently act like investment-specific technology shocks. [Fisher \(2006\)](#) and [Altig et al. \(2011\)](#) find similar results for the U.S. Moreover, for the years after 2012, only limited productivity growth originated in the ICT-producing sectors. The decline in the intensity in these impulses also contributes to the explanation of the decelerated German productivity growth.

We structure our analysis as follows. Section 2 presents stylized facts regarding labor productivity growth in an international perspective, and econometric results regarding the link between U.S. and German productivity growth. Section 3 analyzes the effects of the successful German labor market reforms initiated at the beginning of the millennium. Section 4 studies the importance of information technologies on German productivity growth. Section 5 concludes.

2 Productivity growth: stylized facts and international links

The empirical analysis of productivity developments needs to bridge a long distance between the aggregate growth path of hourly productivity and the various sources underlying its expansion. In this section, we use an international comparison to document the important influence that employment fluctuations and the sectoral composition of employment exert for aggregate productivity. These observations call for the disaggregated analysis that we pursue

in the remainder of the paper. We also contemplate the role of the U.S. as the predominant global economy and the world’s knowledge frontier: Our analysis reveals that it is indeed sensible to analyze German productivity data and their domestic sources separately from U.S. developments.

2.1 Basic decompositions

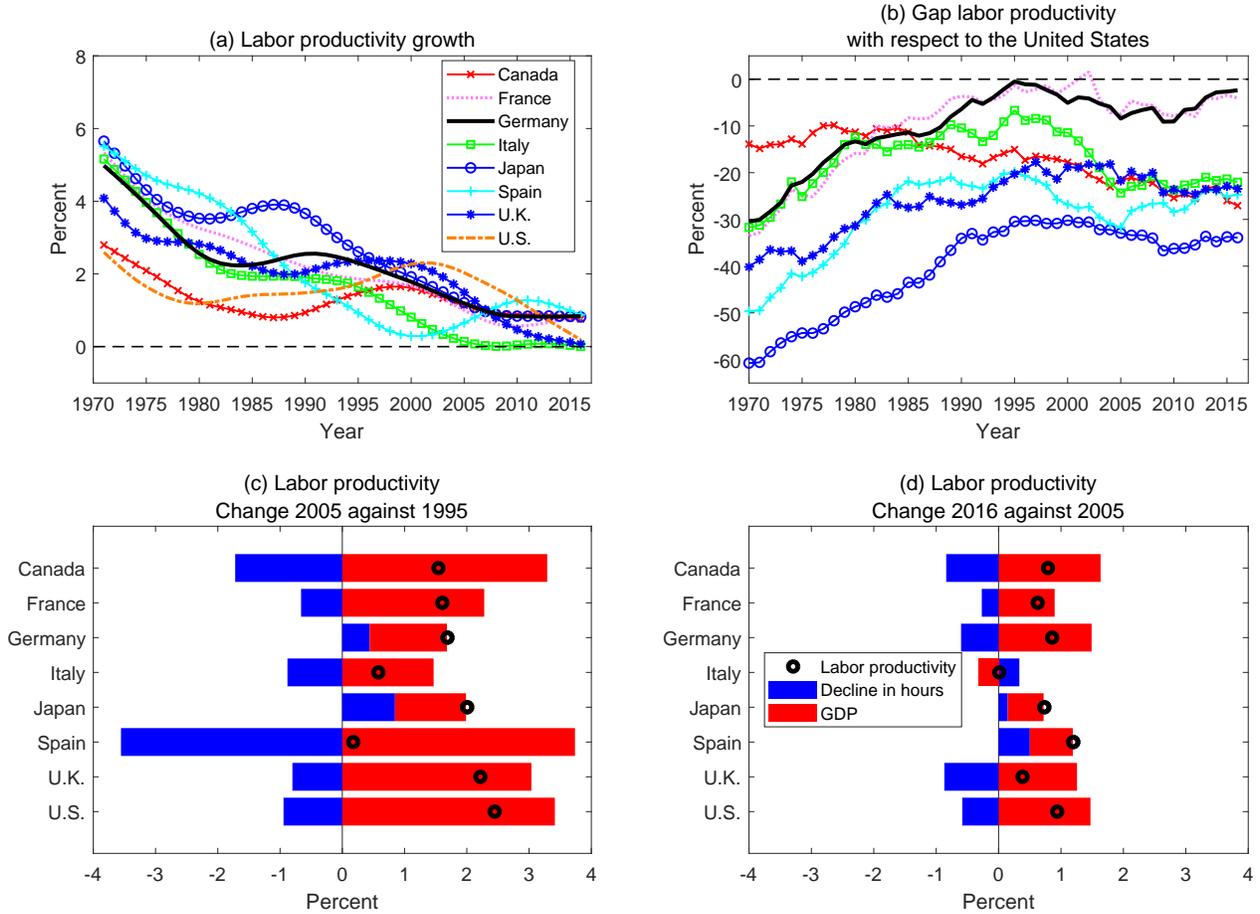
Any thorough analysis of aggregate productivity growth needs to pay attention to the dual nature of productivity growth. Advances in technology act as a driving force for economic activity, finding their reflection in measures of hourly productivity. But they might also boost employment growth, leading to a countervailing effect on those productivity measures. Indeed, alterations on the labor market unrelated to technological progress might even encourage erroneous inferences regarding the pace of productivity growth. In particular, if companies react to a protracted economic downturn by shedding employment, this adverse fortune will typically fall on their least productive workers: Measured hourly productivity might even rise, although there are no technological advances to celebrate whatsoever.

To illustrate these concerns, Figure 1c and 1d decompose hourly productivity growth rates for a range of advanced economies into contributions related to the rise in GDP and the decline in labor volume. These figures separately display the periods from 1995 to 2005 and from 2005 to 2016, respectively, for three reasons: First, the period from 1995 to 2005 is widely associated with the ICT-fueled productivity acceleration in the U.S. and is also marked by higher productivity growth worldwide. Second, given our focus on Germany, it seems wise to exclude the first years after German reunification that witnessed a strong catchup process in East Germany. Third, the implementation of the most important labor market reforms that Germany experienced after its reunification (“Hartz reforms”) was finished in the year 2005.

Figure 1c documents that between 1995 and 2005, only Germany and Japan simultaneously realized productivity growth and a reduction in working hours. By contrast, other advanced economies, most prominently the U.K. and the U.S., heavily increased their labor volume, suggesting that part of the productivity increase in those countries translated into substantial employment growth. Thus, the German productivity performance in that decade is even more dismal than aggregate productivity figures might indicate. The other interesting case is Spain, where the boom in economic activity almost completely translated into employment growth. This was obviously not sustainable: Spanish unemployment rates exploded in the wake of the Great Recession.

Pertaining to the period after 2005, Figure 1d not only documents lower productivity

Figure 1: Labor productivity in selected countries



Notes: Labor productivity is defined as real GDP divided by working hours. To compute trend growth we use the Hodrick-Prescott-filter with a λ equal to 100. For Germany we use West German data for the time period before 1991. The upper right panel depicts the labor productivity gap of the respective countries relative to the U.S. using hourly labor productivity in purchasing power parities of the year 2010. The lower two panels use the average annual growth rate of labor productivity for the considered time periods. The numbers of the growth contributions related to the rise in GDP and the decline in working hours are stated in percentage points. Data sources are Eurostat and the OECD.

growth rates throughout this range of economies, but also quite different decomposition results. Spain now becomes the one economy in this set to accompany Japan in combining productivity gains and reduced employment. Germany, in particular, realized both rising employment and increasing labor productivity. Apparently, the aggregate productivity figures are hiding an even stronger expansion of technological progress. Thus, this decomposition 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 illustrations in Figure 3a and Figure 3b corroborate this cautioning. Focusing on the contrast between the U.S. and Germany, they depict actual annual hourly productivity growth rates, distinguishing the contributions related to the changes in GDP and in working hours, respectively. Overall, German labor productivity seems to be highly procyclical, i.e., rising in booms and falling in recessions. As mentioned by [Burda and Hunt \(2011\)](#) both economies reacted quite differently in the recession of 2008/09: First, given the decline in GDP the reduction in working hours was much more pronounced in the U.S. than in Germany. Second, the decline in working hours in the U.S. was accompanied by an increase in the unemployment rate (extensive margin of labor adjustment), whereas in Germany it was principally due to a reduction in hours per worker (intensive margin). Finally, the recession led to a strong decline in German labor productivity whereas it was still rising in the U.S.²

2.2 The U.S. as the knowledge frontier

The highly synchronous, albeit heterogeneous deceleration of productivity growth among advanced economies raises the question whether there are common forces behind that development. One possible explanation could be that the slow productivity progress in the U.S., the global frontier of technology and knowledge ([Cette et al., 2016](#)), exerts negative effects on other countries. More concretely, [Fernald \(2015\)](#) shows that after 1973 the mean of U.S. hourly productivity growth displayed two structural breaks, dating back to the fourth quarter of 1995 and the fourth quarter of 2003.³ He argues that both breaks relate to the productivity acceleration around the millennium that was captured by Figure 1a.

For Germany, we do not detect such a statistically significant deceleration and acceleration in productivity growth over time. Nevertheless, labor productivity of the German economy has only risen moderately since 2005. While gross value added per hour worked

²[Fernald and Wang \(2016\)](#) present explanations for this observation. Reduced variation in factor utilization (factor hoarding), increased labor market flexibility, changes in the structure of the economy and shifts in relative variances of technology and non-technology shocks appear to play key roles.

³Specifically, [Fernald \(2015\)](#) uses the Bai-Perron test for multiple structural changes and tests the mean of the quarterly growth rates since 1973.

(hourly productivity) still rose by an annual average of 1.7 percent from 1995 to 2005, it only rose by 0.8 percent per year from 2005 to 2016.⁴ The annual increase in gross value added per employee (employee productivity) also declined between the two periods, from 0.9 percent to 0.5 percent. The low rates of growth in employee productivity reflect the considerable rise in part-time employment in both periods. The diagnosis of a slower growth in labor productivity still holds even if the calculation does not include the severe recession of 2009: In that case, the average increase in hourly productivity would be 1.3 percent for 2005 to 2016.

Yet another aspect that should be at the center of attention is the sectoral composition of the analyzed economy. Table 1 retains the distinction between the two periods and documents productivity developments separately in the manufacturing and services sectors. Almost all countries considered experienced a slowdown in productivity growth in both sectors since 2005. Compared to the services sector, increases in hourly productivity in the manufacturing sector are considerably higher in all analyzed economies. This particularly holds for Germany, although other countries such as the U.K. and France realized even larger productivity increases in the manufacturing industry. There the economic significance of manufacturing noticeably declined from 1995 to 2016, though, while it retained its important role for German economic output.

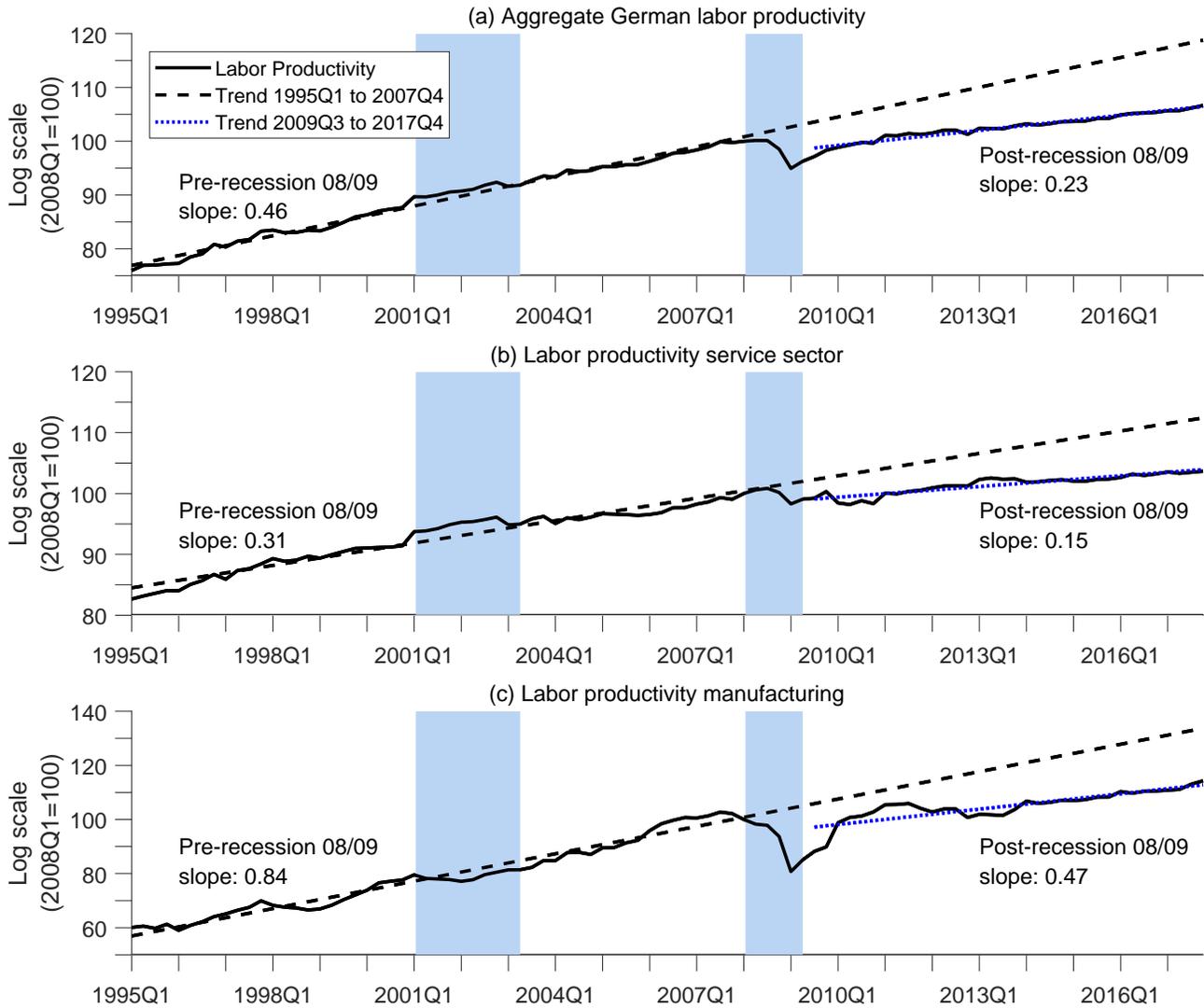
The predominant factor in the overall slowdown of German productivity growth is its deceleration in the services sector. Yet, in addition to this secular trend, after the first quarter of 2009 the level of aggregate German productivity has experienced a downward shift which is mainly due to the development in the manufacturing sector.⁵ Figure 2 provides a graphical illustration of these facts. It shows the log-levels of real hourly productivity for the total German economy, the services sector and manufacturing since the year 1995. Additionally, each panel depicts for the quarterly time series the corresponding time trends for two periods, ranging from the first quarter of 1995 to the fourth quarter of 2007 (pre-recession period) and starting in the third quarter of 2009 (post-recession period).

Focusing again on the contrast between the U.S. and Germany, Figures 3c to 3f decompose the evolution of trend productivity growth according to the contributions of individual economic sectors, separately for the total economy and for manufacturing. Trend growth is

⁴Please note the difference between gross value added and gross domestic product at the aggregate level. For hourly productivity defined by the gross domestic product per hour worked we find with 1.9 percent from 1995 to 2005 a higher annual average of productivity growth.

⁵The German Council of Economic Experts (GCEE, 2015) discusses the possibility that the decline in productivity growth in manufacturing might be the result of an end in the restructuring process of the value chains as vertical integration in this sector has increased since 2009. Criscuolo and Timmis (2017) discuss the transmission channels of participating in global value chains and productivity. Furthermore, they provide evidence that the expansion of global value chains has stalled after the Great Recession in 2008/09. It is, however, out of the scope of this paper to answer this question.

Figure 2: German labor productivity since 1995



Notes: This figure shows the log-levels of hourly real labor productivity for the total German economy, the service sector and manufacturing (solid line). The sample period is 1995q1-2017q4. Each panel shows the corresponding time trends for the subperiods 1995q1 to 2007q4 (pre-recession, black dashed line) and 2009q3 to 2017q4 (post-recession, blue dotted line). The corresponding slopes of the time trends are depicted as well. We use data from the Federal Statistical Office (DESTATIS). Shaded regions denote recessions as dated by the German Council of Economic Experts (GCEE): 2001q1-2003q2 and 2008q1-2009q2.

Table 1: Productivity growth in manufacturing and in the service sector

Country	1995-2005			2005-2016			Reporting share of	
	all economic sectors	including manufacturing	service sectors	all economic sectors	including manufacturing	service sectors	manufacturing 1995	2016
	in percent							
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
U.K.	2.2	3.6	2.1	0.4	1.7	0.6	19.0	9.5
U.S.	2.3	5.9	1.2	0.9	2.3	0.4	15.9	12.0

Notes: Labor productivity is defined as real value added per working hour. This table shows the average annual growth rates for the periods 1995 to 2005 and 2005 to 2016 for selected countries. The share of manufacturing is determined with the nominal share of that sector in total gross value added. Data sources are Eurostat and the Bureau of Economic Analysis (BEA).

determined with the Hodrick-Prescott-filter, with the smoothing parameter λ set equal to 100.⁶ To compute the growth contributions of individual sectors, we use as weights their respective employment shares in the total economy for the current and previous year. For the U.S. we use data from the Bureau of Labor Statistics (BLS) for working hours and from the Bureau of Economic Analysis (BEA) for value added. In addition, we further re-classified the economic sectors from the North American Industry Classification System (NAICS) to the Statistical Classification of Economic Activities in the European Community (NACE).⁷

The decompositions in Figure 3c and 3d provide a more detailed record of the contrast between the acceleration of trend productivity growth that the U.S. experienced around the millennium and its steady decline in Germany: First, in Germany business services and the ICT sector only achieved relatively modest productivity gains. German business services actually delivered negative growth contributions. Second, in the years before 2003 the sectors retail and wholesale trade had contributed more to U.S productivity growth than it was the case in Germany. Trend productivity growth in both U.S. sectors was quite strong in the 1990s, but it slowed down after the turn of the millennium. In Germany, by contrast,

⁶In Appendix B we show the same figure with unfiltered growth rates and 5-year averages. The main results remain unchanged.

⁷We crosschecked our numbers with those provided by EU-Klems since the year 1998. The correlation coefficients of the annual growth rates for all considered economic sectors are significantly higher than 0.9.

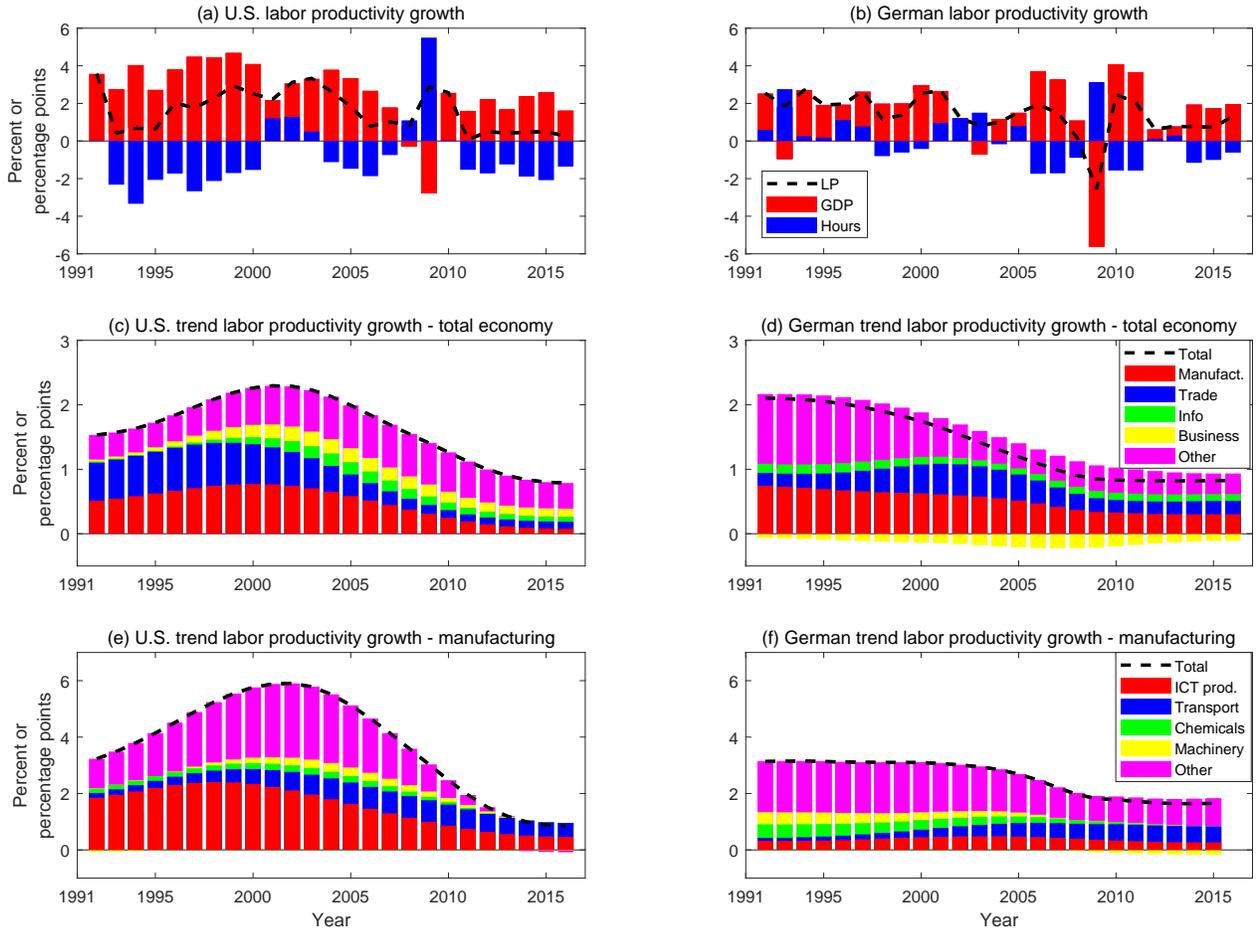
productivity growth in the trade sectors accelerated after 2000. In recent years, the growth contributions of the trade sectors are quite low in both countries.

Third, a great part of the slowdown in U.S. productivity after the year 2005 reflects developments in the manufacturing sector.⁸ Figures 3e and 3f decompose the growth record of the manufacturing sectors further. Figure 3e shows that the 9-year surge in productivity growth in the U.S. economy, starting after 1995, was strongly linked to the development in the industries producing computers and semiconductors (ICT-producing manufacturing). Productivity growth in this sector reached double-digit figures in some years and was accompanied by a rapid drop in semiconductor prices. In Germany, ICT-producing manufacturing also realized significant productivity growth around the millennium. However, due to its smaller importance, its contributions to aggregate manufacturing productivity growth were much smaller than in the U.S. We find less dramatic differences for other manufacturing sectors. In recent years productivity growth increased in the transport equipment sector, while it has been quite weak in the sectors machinery and production of chemicals.

If there were indeed important productivity spillover from the U.S. to Germany, they would probably affect the productivity trends at the level of individual economic sectors. Yet, Table 2 demonstrates that since 1995 for many economic sectors there has apparently been only a weak relationship between the U.S. and Germany. The contemporaneous correlation coefficients of the annual growth rates are quite low and in many cases even negative. For total manufacturing, there is only a small positive relationship of 0.11. We only find high positive correlation coefficients for some manufacturing sectors, e.g., machinery and transport equipment. We also detect important differences in the economic structure of both economies. In Germany, the manufacturing and the trade sectors contribute more to nominal GDP. In contrast, the economic sectors real estate, business and finance services are more important for the U.S. economy.

⁸Baily and Montalbano (2016) show that those industries (manufacturing, wholesale and retail trade) which have contributed strongly to the acceleration of productivity growth after 1995 were also important to the subsequent slowdown.

Figure 3: Comparison of U.S. and German productivity growth



Notes: The first row shows the actual growth rates of hourly real labor productivity for the U.S. and Germany. We consider the time period 1991 to 2016. The numbers for GDP growth and the decline in working hours are stated in percentage points. The second and third row depict the growth contributions of single economic sectors to trend productivity growth in the total economy and manufacturing. Trend growth is determined with the Hodrick-Prescott-filter and a λ equal to 100. Trade contains retail and wholesale trade. Info is the abbreviation for information and communication services. The expression Business encompasses professional services and business services. The ICT-producing manufacturing sector includes computers, semiconductors and electronic products. To determine the growth contributions we use as weights the respective employment shares for the actual and previous years of the single economic sectors in the total economy (second row) and total manufacturing (third row). For German manufacturing we only have data for the subsectors until the year 2015. For the U.S. figures we use data from the Bureau of Labor Statistics (BLS) and the BEA. For the German figures we use data from DESTATIS.

Table 2: U.S. and German productivity growth at a disaggreate level

Sector	Share in GDP		U.S. Ø growth rate		Share in GDP		Germany Ø growth rate		Corr. coeff.
	1995	2015	1995-2005	2005-2016	1995	2015	1995-2005	2005-2016	
	in percent								
Total	100.0	100.0	2.5	0.9	100.0	100.0	1.7	0.9	-0.04
among:									
Trade	12.9	12.0	5.1	0.9	14.4	14.5	3.0	1.6	0.16
Info	4.7	4.7	3.7	2.7	3.5	4.2	4.0	4.1	-0.13
Finance	6.4	7.2	4.4	0.8	4.3	3.7	-1.8	1.3	-0.15
Real estate	12.0	13.1	1.3	1.6	9.9	9.8	1.7	1.2	-0.10
Business	9.1	12.2	2.0	1.1	8.7	9.9	-1.6	-1.3	0.27
Manufacturing	16.5	12.0	6.1	1.9	20.6	20.8	3.1	1.8	0.11
among:									
ICT prod.	2.0	1.5	26.3	8.9	1.2	1.3	10.7	7.0	0.44
Transport	2.1	1.6	5.0	5.0	2.8	4.6	1.7	4.6	0.69
Chemicals	2.1	2.1	3.2	1.4	2.4	2.3	5.2	0.4	0.21
Machinery	1.3	0.8	2.6	0.7	2.8	3.2	1.8	-1.1	0.57
Metal industry	1.9	1.1	2.1	0.6	2.6	2.5	2.1	0.9	-0.02

Notes: Trade contains retail and wholesale trade. Info is the abbreviation for information and communication services. The expression Business encompasses professional services and business services. Real estate contains real estate, rental and leasing. The Metal industry covers the production of basic metals and fabricated metal products. The ICT-producing manufacturing sector includes computers, semiconductors and electronic products. Finance is an abbreviation for the economic sector finance and insurance. The shares in GDP are computed on the basis of nominal values. Labor productivity of a specific sector is defined as real value added divided by total hours worked. The correlation coefficients in the last column are determined by using the growth rates for the time period between the years 1992 and 2016. For German manufacturing subsectors we only have data until the year 2015. Data sources are BLS, BEA and DESTATIS.

2.3 A structural time-series analysis

While these descriptive statistics suggest that the spillover effects from the U.S. productivity slowdown on German labor productivity are likely to be minor, we study this issue more thoroughly, using structural vector autoregressive models (SVAR).⁹ We can rest this analysis on an extensive literature regarding the identification of U.S. productivity shocks on macroeconomic variables; [Ramey \(2016\)](#) provides a comprehensive literature overview. In our analysis, we focus on two empirical approaches that try to identify neutral technology shocks. The first approach uses the long-run identification assumption proposed [Gali \(1999\)](#). Since this assumption has been criticized in some contributions,¹⁰ we also rely in a second approach on the utilization-adjusted total factor productivity measure constructed by [Fernald \(2014\)](#) and use a Cholesky identification scheme.¹¹

In the first approach, we use three variables in the SVAR. Like [Gali \(1999\)](#), we rely on a measure of U.S. labor productivity, $LP_t^{U.S.}$, and a variable for U.S. labor input, $L_t^{U.S.}$. $LP_t^{U.S.}$ is defined as nonfarm business-sector hourly productivity divided by a measure of the civilian noninstitutional population aged 16 and above. $L_t^{U.S.}$ corresponds to hours of all persons in the nonfarm business sector and is also normalized by the civilian noninstitutional population aged 16 and above. As a third variable we consider German labor productivity, LP_t^{Ger} . We define German labor productivity as German GDP divided by the total number of hours worked.

Formally, we estimate the following VAR model on quarterly data ranging from the first quarter of 1970 to the fourth quarter of 2016:

$$y_t = \mu + A(L)y_{t-1} + \underbrace{\nu_t}_{B\epsilon_t}, \quad (1)$$

where μ is a vector of constants, $A(L)$ is a lag polynomial of degree $p = 4$, and $\nu_t \stackrel{iid}{\sim} (0, \Sigma)$ is a vector of reduced form residuals. The vector of endogenous variables y_t contains $LP_t^{U.S.}$, $L_t^{U.S.}$ and LP_t^{Ger} . All variables are expressed in log-differences.

To identify the structural shocks, ϵ_t , we need to identify the contemporaneous impact matrix B . To do so, we impose one long-run restriction and two short-run restrictions. First, we assume that shocks which can be assigned to German developments, ϵ_t^{Ger} , have no contemporaneous impact on U.S. variables. However, ϵ_t^{Ger} is allowed to have long-run effects

⁹[Corsetti et al. \(2016\)](#), [Enders and Müller \(2009\)](#) and [Miyamoto and Nguyen \(2017\)](#) use SVARs to study the international transmission of technology shocks. In contrast to us, however, they have a particular interest in the reactions of GDP, private consumption, the trade balance and the terms of trade.

¹⁰For a discussion on this issue see e.g. [Uhlig \(2004\)](#), [Erceg et al. \(2005\)](#) and [Fernald \(2007\)](#).

¹¹The measure of [Fernald \(2007\)](#) controls for variation in factor utilization of capital and labor. It is closely related to the annual measure of [Basu et al. \(2006\)](#).

on U.S. variables. Second, we impose the restriction that apart from the ϵ_t^{Ger} only the U.S. technology shocks, $\epsilon_t^{U.S.tech}$, have a long-run effect on U.S. labor productivity. To determine the contemporaneous impact matrix B we solve a linear equation system which relates the long-run effects of ϵ_t , summarized in matrix C , to the short-run of these shocks, captured by B . This can be done as follows:

$$\begin{matrix} LP_t^{U.S.} : \\ L_t^{U.S.} : \\ LP_t^{Ger} : \end{matrix} \underbrace{\begin{bmatrix} C_{1,1} & 0 & C_{1,3} \\ C_{2,1} & C_{2,2} & C_{2,3} \\ C_{3,1} & C_{3,2} & C_{3,3} \end{bmatrix}}_C = \underbrace{\begin{bmatrix} K_{1,1} & K_{1,2} & K_{1,3} \\ K_{2,1} & K_{2,2} & K_{2,3} \\ K_{3,1} & K_{3,2} & K_{3,3} \end{bmatrix}}_K \underbrace{\begin{bmatrix} B_{1,1} & B_{1,2} & 0 \\ B_{2,1} & B_{2,2} & 0 \\ B_{3,1} & B_{3,2} & B_{3,3} \end{bmatrix}}_B \underbrace{\begin{matrix} - \epsilon_t^{U.S. tech} \\ - \epsilon_t^{U.S. non-tech} \\ - \epsilon_t^{Ger} \end{matrix}}_{\epsilon_t}. \quad (2)$$

In this linear equation system, we already take into account the long-run restriction, $C_{1,2} = 0$, as well as the two short-run restrictions, $B_{1,3} = B_{2,3} = 0$. To determine the matrix K , we use the coefficient estimates of the lag polynomial $A(L)$:

$$K = \left(I - \sum_{i=1}^p A_i \right)^{-1}, \quad (3)$$

where I is the unity matrix. Finally, we express the coefficient $B_{1,2}$ as a function of the other elements of B_0 such that the linear equation system (2) is fulfilled.

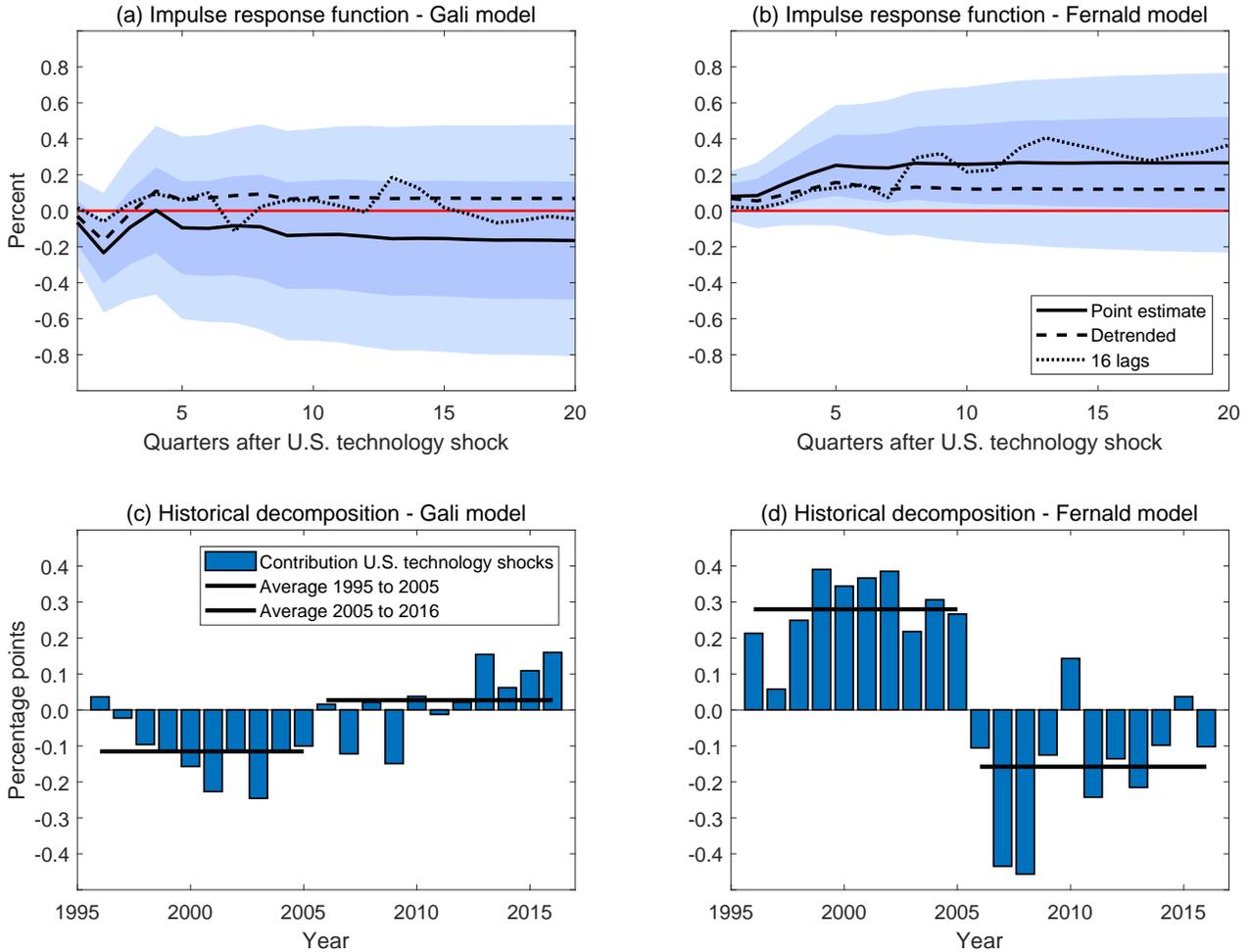
In the second approach, we replace $LP_t^{U.S.}$ by a measure of total factor productivity as proposed by [Fernald \(2014\)](#). As this variable is already purged from varying capacity utilization and demand effects, we identify the structural shocks by assuming that ϵ_t^{Ger} has no short-run effects on U.S. variables and that shocks originating from U.S. labor input, $\epsilon_t^{U.S. non-tech}$, do not affect total factor productivity on impact.¹²

Figures 4a and 4b show the dynamic reactions of German labor productivity after a U.S. technology shock.¹³ For both accumulated impulse response functions, we assume that the initial positive U.S. technology impulse raises the respective productivity measure by one percent. To account for conditional heteroscedasticity in the data, we construct our confidence bands using the recursive design wild bootstrap proposed by [Gonçalves and Kilian \(2004\)](#). Additionally, the figures 4a and 4b test the robustness of our results by changing the number of lags to 16 and by removing a possible trend in the growth rate of German labor productivity. Both adjustments only have negligible effects on our baseline results. Irrespective of the concrete specification chosen, we only find insignificant results. Regarding the point estimates, using the technology measure of [Fernald \(2014\)](#), we find a positive, albeit insignificant spillover effect of somewhat more than 0.2 percent after 20 quarters.

¹²Assuming other orderings do not affect our results.

¹³For the variables U.S. hours and U.S. labor productivity we find the same results as [Gali \(1999\)](#).

Figure 4: The effects of U.S. technology shocks on German labor productivity



Notes: This figure shows the results for two identification schemes. The left-hand side of this figure (Gali model) determines U.S. technology shocks with a long-run identification assumption proposed by [Gali \(1999\)](#). The estimation is based on model (1) and contains the variables U.S. labor productivity, U.S. labor input and German labor productivity. To compute the results on the right-hand side (Fernald model), we replace U.S. labor productivity by a measure of total factor productivity as proposed by [Fernald \(2014\)](#). In this case a Cholesky decomposition is used to identify technology shocks. Both SVAR models include four lags. All variables are expressed in log-differences. We use seasonally and working day adjusted quarterly data for the years 1970 to 2016. The upper row shows the accumulated impulse response functions of German labor productivity to a one-percent U.S. technology shock. Dark and light blue shaded areas: 68-percent and 95-percent-confidence bands, respectively, are constructed using a recursive design wild bootstrap [Gonçalves and Kilian \(2004\)](#). The lower row displays the cumulative effects of the U.S. technology shocks on German annual productivity growth. Data is described in Table 4 of Appendix A.

To illustrate the implications of our point estimates for the estimated effects of the slowdown in productivity growth in the U.S. on German productivity growth, we conduct a historical decomposition. This decomposition delivers for each time period t the estimated effect of the sequence of identified U.S. productivity shocks on quarterly German productivity growth. Formally, this decomposition is defined as

$$\begin{aligned} HIRF_t^{LP^{Ger}} &= \sum_{j=0}^t \hat{\epsilon}_j^{U.S. \text{ tech.}} \cdot IRF_{t-j}^{LP^{Ger}} & (4) \\ &= \hat{\epsilon}_0^{U.S. \text{ tech.}} \cdot IRF_t^{LP^{Ger}} + \hat{\epsilon}_1^{U.S. \text{ tech.}} \cdot IRF_{t-1}^{LP^{Ger}} + \dots + \hat{\epsilon}_t^{U.S. \text{ tech.}} \cdot IRF_0^{LP^{Ger}} & (5) \end{aligned}$$

where $IRF_h^{LP^{Ger}}$ is the simple h -period-ahead impulse response of German labor productivity growth on a U.S. technology shock today and $\hat{\epsilon}_t^{U.S. \text{ tech.}}$ is the U.S. technology shock in period t , e.g., the first quarter 1995.

For the sake of simplicity, we show the annual growth contributions of the U.S. technology shocks on German labor productivity growth. To do so, we transform the quarterly growth contribution $HIRF_t^{LP^{Ger}}$ into an index

$$I_t^{LP^{Ger}} = I_{t-1}^{LP^{Ger}} \cdot (1 + HIRF_t^{LP^{Ger}}), \quad (6)$$

where the index is initialized at 1, and then calculate the growth rate of the annual averages of this index.

The last row of Figure 4 depicts the annual growth contributions and also provides separate average figures for the earlier and later decades, respectively. While the insignificant impulses using the shock identification proposed by [Gali \(1999\)](#), do not provide any meaningful insights, the approach based on total factor productivity, suggests that U.S. productivity shocks might have exerted a negative influence on German productivity growth after 2005, at the order of slightly less than 0.2 percentage points per year. The estimated spillover effects in the preceding period 1995 to 2005 had been positive, amounting to roughly 0.3 percentage points per year. Even taken at face value, these effects would be quite small, since the actual German productivity growth numbers during those periods were 1.9 and 0.8 percent, respectively. Thus, in the further analysis of German productivity growth, it is perfectly sensible to abstract from any possible spillover effects that might originate from U.S. productivity shocks.¹⁴

¹⁴In Appendix C we use an identification approach proposed by [Francis et al. \(2014\)](#) that maximizes the contribution of technology shocks to the forecast-error variance of labor productivity at a long but finite horizon.

3 Accounting for the German labor market miracle

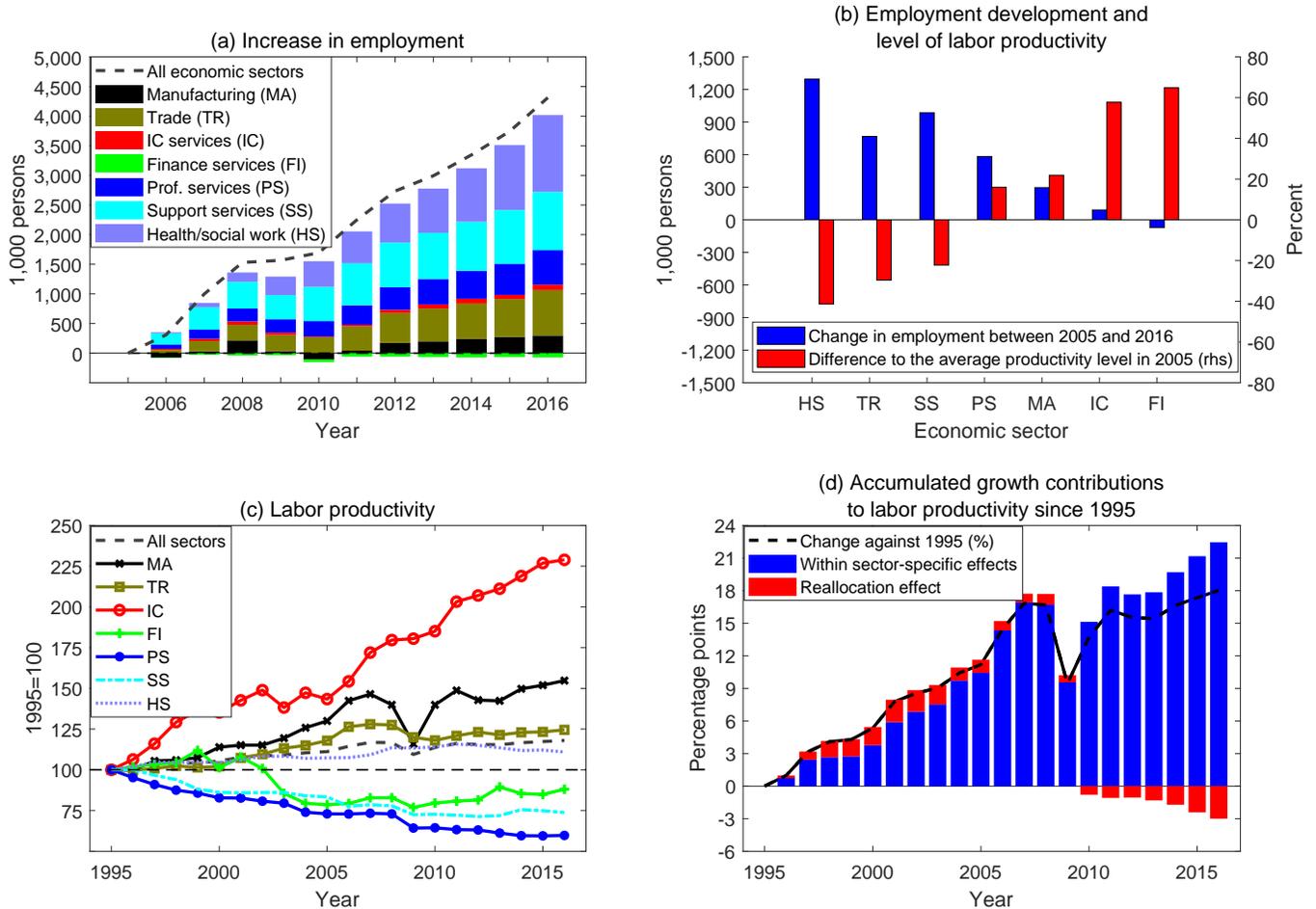
Since our analyses suggest that the slowdown in U.S. productivity growth had only limited effects on German productivity, other explanations are needed for the deceleration of Germany productivity growth. The German economy evolved quite differently from the U.S., and other large European countries like France, Italy or Spain. A particularly remarkable facet of this development was the strong performance of the labor market in the years during and after the Great Recession. Starting around 2005, Germany experienced a protracted transition to a new structural labor market equilibrium, with higher employment, especially among the low-skilled, and lower unemployment rates. There are good reasons to presume that this transition was responsible for a period of comparatively low productivity growth.

3.1 Transition to a new labor market equilibrium

From 2005 to 2017 German employment increased by approximately five million workers, i.e. by more than ten percent. During this time period, total hours worked only increased by 8.2 percent, though, since many of the new jobs were part-time jobs. Figure 5a displays the sectoral composition of this massive employment growth. New jobs were mainly created in the services sectors, not in the highly productive manufacturing sector; employment growth was strongest in trade, transportation, accommodation, healthcare and administrative and support services. Thus, jobs were created disproportionately often in labor-intensive and less productive services sectors (Figure 5b). Moreover, the increase in the number of less productive workers might have exerted a negative impact on sector-specific labor productivity growth in the labor-intensive service sectors (Figure 5c).

These developments warrant a less distraught view on the decelerated productivity growth of the last decade, if it indeed reflects a transition towards a new, more favorable labor market equilibrium. The growing literature that discusses the reasons for the sustained increase in German employment corroborates this interpretation. [Burda and Seele \(2017\)](#) and [Burda \(2016\)](#) start by providing a list of candidate explanations: First, a favorable world economic situation induced a higher demand for German products and stimulated labor demand. Second, in the era of “wage moderation” real wage increased more slowly and new elements of flexibility reduced real wage rigidities, strengthening the competitiveness of German firms ([Dustmann et al., 2014](#)). Third, the German labor market reforms introduced at the beginning of the 2000s improved the functioning of the labor market. After studying the relationships between changes in wages, participation rates and employment rates, [Burda and Seele \(2017\)](#) and [Burda \(2016\)](#) conclude that the German labor market reforms play a major role in explaining the labor market trend since the mid-2000s.

Figure 5: Development of labor productivity in selected economic sectors



Notes: The upper left panel shows the accumulated change of employment compared to 2005. The lower left panel depicts the level of labor productivity for selected economic sectors. Labor productivity is defined as real gross value added per worker. The calculations in the lower right panel are done with equation (7). The reference year is 1995. We use data from DESTATIS.

These labor market reforms (“Hartz reforms”) were an important part of the comprehensive reform package dubbed “Agenda 2010” that also comprised reforms in the tax system and the social security systems.¹⁶ The Hartz reforms consisted of four packages:¹⁵ The packages “Hartz I” and “Hartz II” deregulated the temporary working agencies and improved the incentives of the unemployed to become self-employed. The accumulated increase of roughly one million workers that the sector support services has experienced since 2005 is mainly due to the regulations introduced by “Hartz I” (Figure 5a). The aim of the third package “Hartz III” was to improve the matching efficiency on the labor market by restructuring the Federal Employment Agency. Finally, the major reform package “Hartz IV” attempted to strengthen the incentives of unemployed workers to search for a job. Its main elements were a decrease in the duration of unemployment benefits for short-term unemployed (“Arbeitslosengeld I”) and a merger of the unemployment assistance for long-term unemployed with social assistance (“Arbeitslosengeld II”).

Several quantitative studies focus on estimating the effects of the “Hartz IV” reforms, mainly on the basis of heterogeneous agents models. All studies agree that the labor market reforms effectively reduced the equilibrium unemployment rate. They disagree, however, regarding the extent to which the “Hartz IV reforms” reduced German equilibrium unemployment. While [Krause and Uhlig \(2012\)](#) and [Krebs and Scheffel \(2013\)](#) find significant reductions in the unemployment rate of 2.8 and 1.4 percentage points, respectively, the analysis of [Launov and Wälde \(2016\)](#) suggests almost no effect. The latter study, however, argues that the other parts of the labor market reforms were able to reduce the unemployment rate significantly. Overall, the reforms of the Agenda 2010 apparently had a significantly favorable impact on the development of the German labor market, generating as a side effect a deceleration of productivity growth.

3.2 A counterfactual path of productivity expansion

It will be prohibitively difficult to construct a counterfactual capturing the development of sector-specific productivity in the hypothetical absence of the German labor market miracle. Yet, by means of a disaggregated analysis at the sector level we can at least account for the composition effect exerted by the structural shifts associated with this miracle ([De Avillez, 2012](#)). Specifically, we construct a counterfactual aggregate productivity development by taking the developments within individual sectors (“within sector-specific effects”) at face value and holding the sectoral composition constant. The difference between the actual and the constructed counterfactual development then captures the effect of the employment

¹⁵[Burda and Hunt \(2011\)](#) and [Jacobi and Kluge \(2007\)](#) discuss the single labor market reforms in more detail.

shifts between sectors (“reallocation effect”). Arguably, it is the development net of the reallocation effect which should be in the focus of our considerations regarding productivity growth.

In our analysis we consider 20 sub-sectors.¹⁶ It seems reasonable to presume that the new workers were less productive than the incumbent workers, since they were previously unsuccessful at offering their skills on the labor market (Burda and Seele, 2017). The counterfactual development of total labor productivity over time is therefore constructed with reference to a benchmark year as follows:

$$\left(\frac{LP_t^{total} - LP_0^{total}}{LP_0^{total}}\right) = \underbrace{\sum_{i=1}^{20} \left(\frac{LP_t^i - LP_0^i}{LP_0^{total}}\right) n_0^i}_{\text{sub-sector-specific effects}} + \underbrace{\sum_{i=1}^{20} (n_t^i - n_0^i) \frac{LP_t^i}{LP_0^{total}}}_{\text{reallocation effect}}, \quad (7)$$

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 . Finally, n_t^i is the relative proportion of the labor force or hours worked in sub-sector i .

Figure 5d reports the results of the decomposition for the reference year 1995. Apparently, the reallocation effect has not been responsible for the major bulk of the productivity advances that were realized since 1995. Rather, the productivity gains over the past 25 years have largely resulted from developments within the individual sectors. Yet, the reallocation effect affects our assessment of the deceleration of productivity growth, since it first provided a slightly positive contribution to labor productivity in the period from 1995 to 2005, as employment increasingly shifted to the productive economic sectors. Thereafter, its contribution was rather negative, due to the structural shift towards the relatively unproductive services sectors.

Table 3 corroborates this impression by reporting detailed growth contributions to labor productivity for the two periods 1995 to 2005 and 2005 to 2016, respectively. The growth contributions arising from the reallocation effect are negative for the years between 2005 and 2016. Compared to the previous 10 years, this negative reallocation effect has caused the annual increase in macroeconomic productivity (person concept) to decline by around 0.3 percentage points since the year 2005. This result is the same whether we construct the productivity figures per hour or per person employed. The analysis of the within sector-specific effects shows that in comparison to the period 1995 to 2005, between 2005 and 2016 the combined growth contributions of the sectors trade, transportation, accommodation, healthcare, administrative and support services have annually shaved off 0.2 percentage points of productivity growth per person employed.

¹⁶For these 20 sub-sectors we only have data until the year 2016 available.

Table 3: Growth contributions to aggregate labor productivity (in percentage points)

	Share (in percent)	Per person employed		Per hour	
		1995-2005	2005-2016	1995-2005	2005-2016
Within sector-specific growth contributions					
Manufacturing	22.4	0.7	0.4	0.8	0.4
Service sector	69.8	0.2	0.4	0.8	0.6
including:					
Wholesale and retail trade, transport and storage, accommodation	16.5	0.3	0.1	0.5	0.2
Information and communication	4.6	0.2	0.2	0.2	0.2
Professional, scientific and technical activities	6.3	-0.2	-0.1	-0.1	-0.1
Administrative and support service activities	4.3	-0.1	-0.0	-0.0	-0.0
Human health and social work activities	6.6	0.0	0.0	0.1	0.0
Reallocation effect		0.1	-0.3	0.2	-0.2
Development of labor productivity (in percent)					
Actual development		1.1	0.5	1.9	0.9
Development without structural shifts		0.9	0.8	1.6	1.1

Notes: The calculations of the within sector-specific growth contributions and the reallocation effects are done with equation (7). The development without structural shifts shows the development of aggregate productivity without the reallocation effect. The share of the corresponding sector in total gross value added is determined with the numbers of the year 2005. Please note the difference at the aggregate level between gross domestic product and gross value added. We use data from DESTATIS.

These results indicate that the annual decline in the growth rate of productivity per person employed, from 1.1 percent during the period 1995-2005 to only 0.4 percent since 2005 can largely be explained by the composition effect resulting from the successful integration of less productive workers into the labor market. A similar conclusion emerges in the analysis of hourly productivity. 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. And yet, some of the deceleration remains to be explained.

4 Digitization and productivity

So far, we have seen that a large part of the slowdown of German productivity growth merely reflects a composition effect, induced by the successful labor market integration of five million workers. While it would hardly be preferable to reverse this massive creation of new, predominantly low-productivity jobs, it is nevertheless disconcerting that the perceived

widespread digitization of the German economy did not offset these dampening influences on productivity growth. After all, the use of ICT goods and services has increased massively over time. In order to move towards a resolution of this remaining productivity paradox, we analyze the effects of digitization on productivity growth more closely. It turns out that to understand this sluggish reaction to digitization we have to address separately both elements of productivity, economic output and employment.

4.1 Conceptual considerations

Higher investment in ICT can raise aggregate labor productivity growth via many channels. Most directly, it creates aggregate productivity gains by raising total factor productivity growth in the industries that produce ICT goods. This technological progress causes a decline in the relative price of ICT investment goods and, thus, affects capital deepening in ICT-intensive sectors, i.e., sectors that make greater use of ICT. This channel is often related to investment-specific technological change, as [Greenwood et al. \(1997\)](#) and [Fisher \(2006\)](#) emphasize. In the ICT-intensive sectors this investment-specific technological change in turn raises growth in capital intensity and labor productivity, but not growth in total factor productivity.

A higher ICT-capital intensity can lift growth in total factor productivity indirectly, however, by fostering complementary innovations, such as business organization, or by enabling new business ideas. In this case, firms take advantage of the improved ability to manage information and communications ([Bloom et al., 2012](#)). In addition, reallocation movements towards higher-productivity establishments can raise productivity as shown by [Foster et al. \(2006\)](#) for the U.S. retail sector.

Many studies use growth accounting frameworks to determine the contribution of ICT to aggregate productivity growth. These studies show that in Germany as compared to the U.S., the ICT-producing and ICT-intensive sectors contributed relatively little to aggregate labor productivity growth ([Eicher and Roehn, 2007](#)). By contrast, U.S. productivity growth in the second half of the 1990s was heavily concentrated in the ICT-producing manufacturing sector, as quality-adjusted computer prices began to fall rapidly ([Jorgenson, 2001](#)). [Stiroh \(2002\)](#) shows with U.S. industry data that the gains in productivity in the ICT-producing sectors were followed at the turn of the century by significant productivity surges in ICT-intensive sectors like wholesale and retail trade or business services. No corresponding acceleration of productivity growth in the ICT-intensive sectors happened in Germany, though ([GCEE, 2015](#)).

4.2 Empirical model

To find out why the perceived increase in the digitalization of the German economy has not caused higher productivity growth in recent years we apply an SVAR framework. We are particularly interested in how technological progress originating from the ICT-producing sectors is transmitted to other sectors of the economy (henceforth: the “non-ICT sector”). In detail, the ICT-producing sector comprises the sector manufacture of computer, electronic and optical products, and the two services sectors telecommunication and IT services (computer programming, consultancy, related activities).¹⁷ The ICT-producing sectors typically display an extraordinarily high labor productivity and total factor productivity growth. Moreover, due to these large gains in productivity, the price level (deflator of gross value added) of the ICT-producing sector has been declining sharply over the years.¹⁸

To answer our research question, we need to isolate technological progress originating from the ICT sector from productivity advancements created in the remaining economy. In our empirical approach, we distinguish between both technology shocks by using the relative price of produced value added between the ICT and the non-ICT sector, $Price_t^{ratio}$. Specifically, we assume that technology shocks originating from the ICT sector (ICT technology shocks, ϵ_t^{ICT}) have a contemporaneous impact on $Price_t^{ratio}$, while this is not the case for non-ICT technology shocks, $\epsilon_t^{non-ICT}$. This assumption reflects the fact that ICT productivity gains are associated with price declines in this goods category which are captured by hedonic price measurement.¹⁹ Our approach is motivated by the literature studying the effects of investment-specific technology shocks (Fisher, 2006). However, in contrast to these studies, we do not rely on the deflator of equipment investment. For our analysis this price variable is not useful as it also contains price information for cars and other equipment.²⁰ Regarding our research question, we are only interested in a specific type of investment-specific technology

¹⁷To define the ICT-producing sectors, we adopt the definition of [DESTATIS \(2017\)](#) which follows the OECD definition. However, owing to data limitations we are not able to incorporate the ICT wholesale trade sector, the software publishing sector and the repair of computers and communication equipment in our measure of the ICT sector. In the year 2015 our considered ICT-producing sectors generated about 70 percent of the total sales in ICT sector according to the definition of [DESTATIS \(2017\)](#). The remaining 30 percent are almost entirely due to the missing ICT wholesale sector. Regarding investment expenditures our sector definition encompasses more than 97 percent of the total ICT sector.

¹⁸Appendix D provides evidence for the two characteristics of the ICT sector in the German economy.

¹⁹In Germany DESTATIS conducts a hedonic price adjustment only for ICT goods and used cars ([Ademer et al., 2017](#)).

²⁰The lower two panels of Figure 12 in Appendix D provide a graphical illustration of the two price measures. The deflator of gross value added for the ICT sector has an annual correlation coefficient with the investment deflator for equipment and intellectual property of 0.38. The correlation coefficient increases to 0.44 if we instead use the investment deflator, the sum of the growth contributions for the investment goods computer, electronic and optical products and software.

shocks, namely the type which is related to ICT goods and services.²¹ Furthermore, in contrast to Fisher (2006), we incorporate in our analysis two labor productivity measures, one for the ICT-sector, LP_t^{ICT} , and one for the non-ICT sector, $LP_t^{non-ICT}$.

Specifically, our VAR model has five variables. We consider $LP_t^{non-ICT}$, LP_t^{ICT} , $Price_t^{ratio}$, hours per worker, $Hours_t$, and total employment, $Empl_t$.²² We estimate our VAR model with quarterly data beginning with the first quarter of 1991 and ending in the fourth quarter of 2015. An earlier starting point of our sample would not be useful as DESTATIS has not conducted a hedonic price adjustment for ICT goods for the years before 1991. Our sample ends in 2015 as there is no further data available regarding the ICT sector. We additionally face the problem that many time series only have an annual frequency. The construction of the quarterly data series is explained below.²³ Finally, all variables are expressed in log-differences and the VAR model includes four lags.

To identify ϵ_t^{ICT} and $\epsilon_t^{non-ICT}$, we use six long-run restrictions and four short-run restrictions. We impose the restrictions that only these two technology shocks have long-run effects on LP_t^{ICT} and $LP_t^{non-ICT}$. We distinguish between both technology shocks by assuming that only ϵ_t^{ICT} has a contemporaneous impact on $Price_t^{ratio}$. For the remaining variables $Price_t^{ratio}$, $Hours_t$, and $Empl_t$ we impose a triangular impact matrix. However, the ordering of the variables is not crucial for our results.

The linear equation system which relates the long-run effects of the structural shocks ϵ_t , summarized in matrix C , to the short-run effects, defined by B , of these shocks reads as follows:

$$\begin{array}{l}
 LP_t^{non-ICT} \\
 LP_t^{ICT} \\
 Price_t^{ratio} \\
 Hours_t \\
 Empl_t
 \end{array}
 : \underbrace{\begin{bmatrix} C_{1,1} & C_{1,2} & 0 & 0 & 0 \\ C_{2,1} & C_{2,2} & 0 & 0 & 0 \\ C_{3,1} & C_{3,2} & C_{3,3} & C_{3,4} & C_{3,5} \\ C_{4,1} & C_{4,2} & C_{4,3} & C_{4,4} & C_{4,5} \\ C_{5,1} & C_{5,2} & C_{5,3} & C_{5,4} & C_{5,5} \end{bmatrix}}_C = \underbrace{\begin{bmatrix} K_{1,1} & K_{1,2} & K_{1,3} & K_{1,4} & K_{1,5} \\ K_{2,1} & K_{2,2} & K_{2,3} & K_{2,4} & K_{2,5} \\ K_{3,1} & K_{3,2} & K_{3,3} & K_{3,4} & K_{3,5} \\ K_{4,1} & K_{4,2} & K_{4,3} & K_{4,4} & K_{4,5} \\ K_{5,1} & K_{5,2} & K_{5,3} & K_{5,4} & K_{5,5} \end{bmatrix}}_K \underbrace{\begin{bmatrix} B_{1,1} & B_{1,2} & B_{1,3} & B_{1,4} & B_{1,5} \\ B_{2,1} & B_{2,2} & B_{2,3} & B_{2,4} & B_{2,5} \\ 0 & B_{3,2} & B_{3,3} & 0 & 0 \\ B_{4,1} & B_{4,2} & B_{4,3} & B_{4,4} & 0 \\ B_{5,1} & B_{5,2} & B_{5,3} & B_{5,4} & B_{5,5} \end{bmatrix}}_B \underbrace{\begin{bmatrix} -\epsilon_t^{non-ICT} \\ -\epsilon_t^{ICT} \\ -\epsilon_{1,t}^{other} \\ -\epsilon_{2,t}^{other} \\ -\epsilon_{3,t}^{other} \end{bmatrix}}_{\epsilon_t} .
 \tag{8}$$

The equation system (8) contains the six long-run restrictions in matrix C and the four short-run constraints in matrix B . The essential condition to distinguish between both

²¹Justiniano et al. (2011) distinguish in their analysis between an investment-specific technology shock that affects the transformation of consumption into investment goods and a marginal efficiency investment shock. The latter shock considers the transformation of savings into the future capital input and contains also disturbances to the functioning of the financial market. Based on their model Justiniano et al. (2011) find that the marginal efficiency investment shocks are the most important driver of U.S. business cycle fluctuations. In our analysis, however, we focus on investment-specific technology shocks as our research question deals with the effects of digitization.

²²Our main findings do not change if we use total hours worked instead of hours per worker and total employment.

²³Details regarding data construction are also discussed in Table 5 of Appendix A.

technology shocks is expressed by the element $B_{3,1} = 0$. We need to rewrite six elements of B as a function of the other elements of B such that the linear equation system (8) is fulfilled.

4.3 The Data

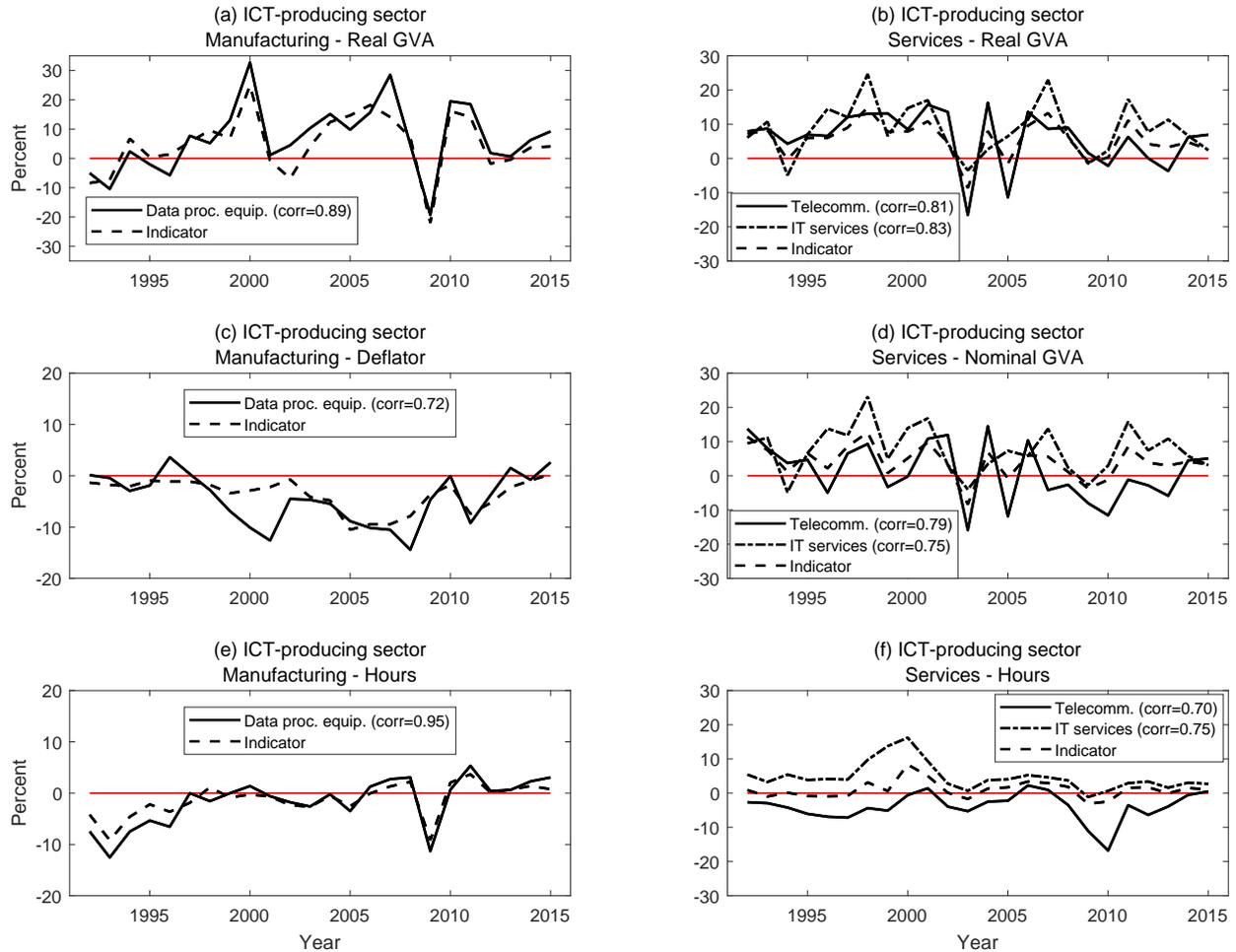
To construct the data set, it is necessary to determine quarterly time series for gross value added, the price deflators and working hours for the three ICT-producing sectors. As the Federal Statistical Office provides only annual data for these sectors we interpolated these annual time series by the using the Chow-Lin interpolation procedure and higher frequency indicators. As a prerequisite these indicators have to possess a high time-series correlation at an annual basis with our considered main series. For the ICT-producing manufacturing sector, we use the industrial production index and the producer price index for the manufacture of computer, electronic and optical products as indicators for real gross value added and the price deflator. As our measure of total hours worked we use total manufacturing hours. For both ICT-producing services sectors we use corresponding time series of the total information and communication sector as the respective indicator series for gross value added (nominal and real) and hours worked.²⁴

To gauge the validity of our constructed series, each panel of Figure 6 compares the single indicator series with our main series, together with the time series correlation coefficient. All indicator series are highly correlated with their respective main series, all correlation coefficients exceed 0.7 at an annual level. For the total hours worked and gross value added series for the manufacture of electronic and optical products, we even find correlation coefficients of 0.9 or above. With these indicator series at hand, we determine quarterly time series for real gross value added, the price deflators and working hours for all three ICT-sectors using the Chow-Lin interpolation procedure.

In a next step, we use the quarterly time series of all these ICT-producing sectors to construct the aggregate time series for the summarized ICT-producing sector. In doing this, we take into account that the real gross value time series has to be constructed as a chain index. It is then possible to determine the corresponding data series for the non-ICT sector by using the aggregate time series for the ICT-producing sector and the quarterly time series for the total economy.

²⁴Beside telecommunication and IT services, the total information and communication sector contains the sector publishing activities, motion picture, video and television program production, sound recording, music publishing activities as well as programming and broadcasting activities.

Figure 6: Comparison between main- and indicator series used for Chow-Lin interpolation



Notes: In this figure we consider the annual growth rates for the time period 1992 to 2015. The abbreviation “Data proc. equip.” defines the manufacture of computer, electronic and optical products. For the ICT-producing manufacturing sector, we use the production index and producer price index for the manufacture of computer, electronic and optical products as indicators for real gross value added and the deflator. For total hours worked, we employ as indicator the hours series regarding total manufacturing. The abbreviation “IT services” contains computer programming, consultancy and related activities. For both ICT-producing service sectors, we use corresponding time series of the total information and communication sector as the respective indicator series for gross value added (nominal and real) and hours worked. In each panel we present for each time series of the respective ICT-producing sector the correlation coefficient with the corresponding indicator. The data source is DESTATIS.

4.4 Results

Figure 7b and Figure 7a depict the accumulated impulse response functions of labor productivity of the ICT-producing and the non-ICT sector after an ICT technology shock. The impulse response functions suggest that an ICT technology shock leads to a sizeable and permanent increase in labor productivity in the ICT-producing sector, whereas the reaction in the non-ICT sector is only positive at the beginning and insignificant throughout. Furthermore, according to the point estimates after roughly 16 quarters the initial positive reaction of productivity in the non-ICT sector has almost vanished. At first glance, it therefore seems that technological progress in the ICT sector has no effects on the remaining economy.²⁵

Figures 7c and 7d display the historical contributions of the ICT technology shocks on labor productivity growth in both sectors for the years after 1995. Two results stand out: First, despite the fact that ICT shocks seem to play a crucial role in explaining the movements in annual labor productivity growth in the ICT-producing sector, we have not seen such strong positive effects in recent years. From a historical perspective, the strongest contributions were observed in the years 1997, 2007 and 2010. But even the actual growth rates do not suggest that the ICT sector has experienced significant productivity gains in recent years. This observation challenges to some extent the popular impression that the pace of digitization has accelerated in recent years (“digital revolution”).

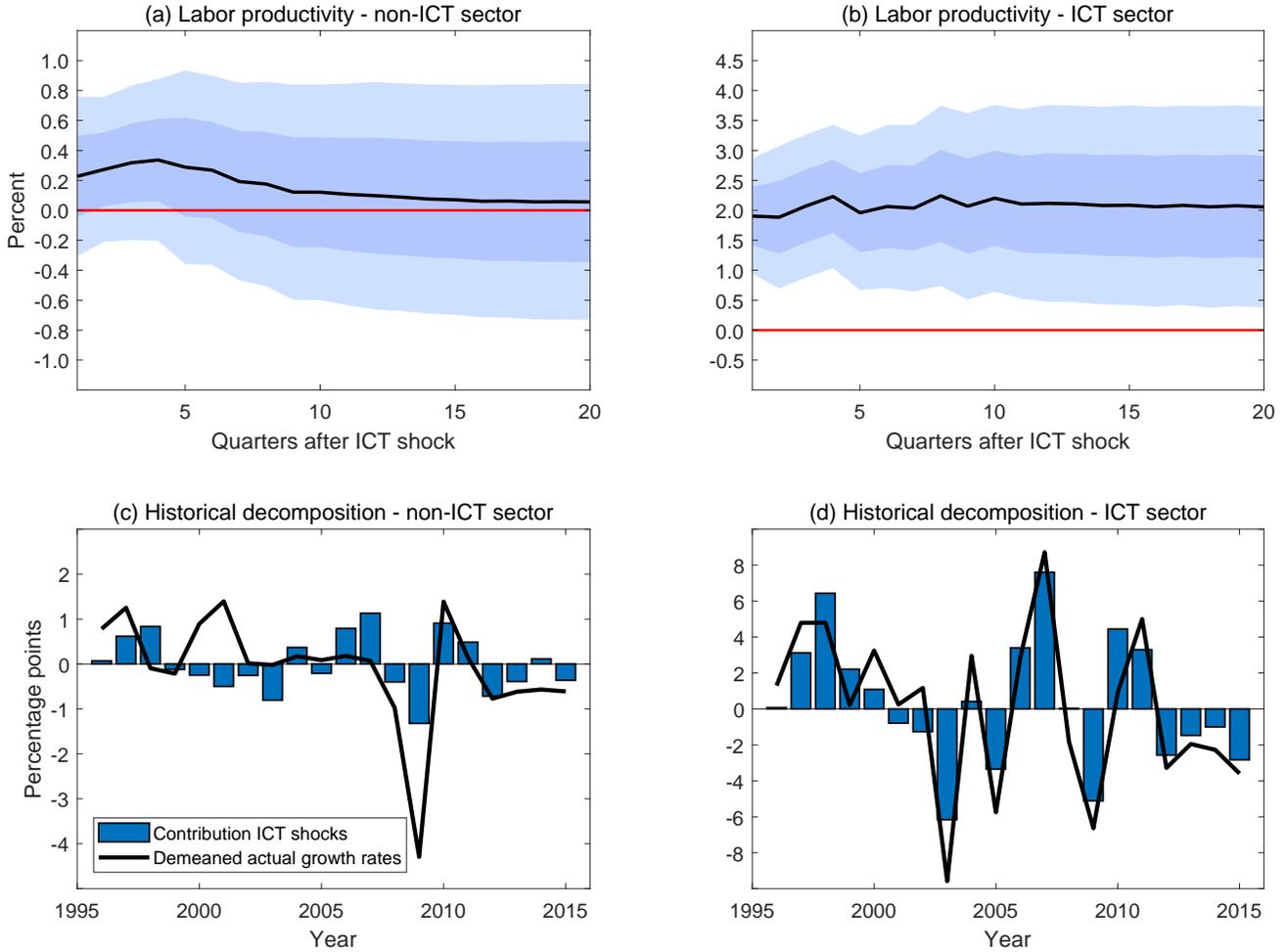
Second, the effects of ICT technology shocks on the productivity growth rates in the non-ICT sector are limited. This is hardly surprising, as the corresponding impulse response function was already insignificant. After all, these results suggest that in the years after 2012 we have not witnessed great technological progress originating in the ICT sector. Furthermore, the transmission of productivity advancements from the ICT-producing sector to the non-ICT sector apparently tend to be quite modest. These results might be an explanation, albeit an unpleasant one, for the German productivity paradoxon.

But what are the reasons for this findings? Figure 8 provides a possible answer. It displays the reactions of gross value added and employment of the total economy after an ICT technology shock. The impulse response function for gross value added is determined by using a subset VAR in which we impose the restrictions that this variable is not included in the equations of the initial VAR model. Our results indicate that both production and employment rise considerably after an ICT technology shock. Furthermore, the size of both dynamic reactions is almost the same. As a result, the net effect on productivity is almost zero.

Fisher (2006) and Altig et al. (2011) find similar results for the U.S. Interestingly,

²⁵For the non-ICT technology shock we find for labor productivity in both sectors permanent positive reactions. Results are available upon request.

Figure 7: Effects of an ICT technology shock



Notes: The upper two panels depict accumulated impulse response functions. The lower two panels show historical decompositions. The VAR model contains labor productivity of the non-ICT sector and the ICT sector, the relative price of produced value added between the ICT sector and the non-ICT sector, hours per worker and total employment. We estimate the VAR model with quarterly data beginning with the first quarter of 1991 and ending in the fourth quarter of 2015. All variables are expressed in log-differences and the VAR model includes four lags. The identification assumptions for the ICT technology shock are summarized in equation (8). Dark and light blue shaded areas: 68-percent and 95-percent-confidence bands, respectively, are constructed using a recursive design wild bootstrap [Gonçalves and Kilian \(2004\)](#).

theoretical DSGE models such as [Smets and Wouters \(2007\)](#) predict similar outcomes. In these models, labor input rises by almost the same amount as output after an investment-specific technology shock. The intuition behind this result is that the new investment goods lead to a higher labor demand as the marginal product of labor increases. To sum up, our results show that the digitization of the German economy seems to have strong positive effects on German GDP and employment. However, it seems questionable if the new ICT goods exert a sizeable positive effect on productivity.

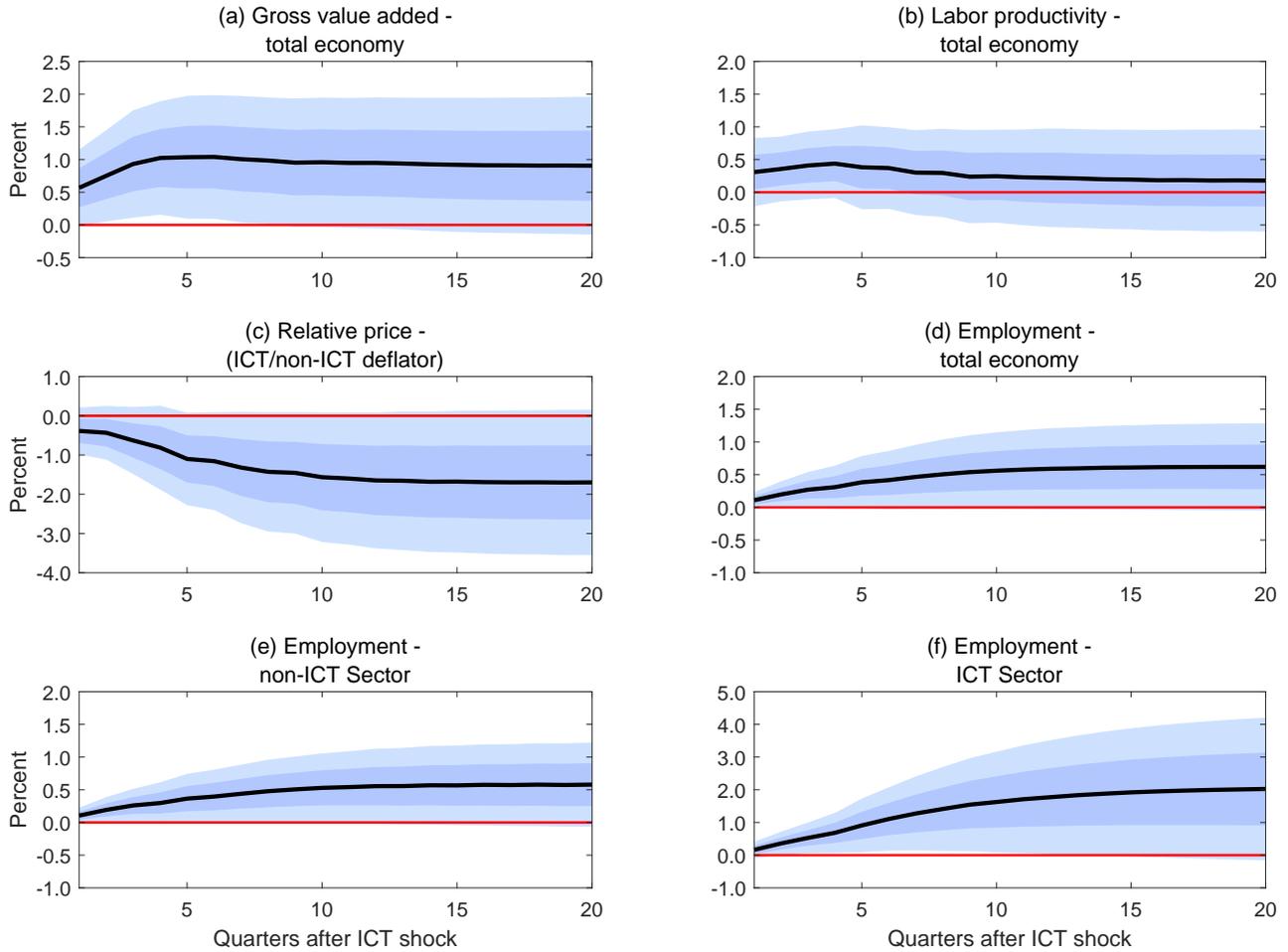
4.5 Robustness Checks

So far, our baseline calculations have shown that ICT productivity shocks positively affect total gross value added and employment, while the positive impact on labor productivity seems to be limited. In this section, we check how much our conclusions depend on our identification assumptions. We can classify these assumptions into two categories: The first category concerns the long-run identification assumption proposed by [Gali \(1999\)](#) which has been criticized by an extensive literature. Given the complexity of our SVAR that includes five variables and necessitates the identification of two technology shocks, the approach of combining several long- and short-run restrictions nonetheless provides a useful starting point. Nevertheless, a simple Cholesky decomposition indicates what would happen, if we did not impose any long-run restrictions in our SVAR framework.

In our first robustness check, we therefore omit all long-run restrictions and identify our SVAR by using a standard Cholesky decomposition. For all accumulated impulse response functions, we assume that the initial impulse corresponds to a one percent increase in labor productivity of the ICT-producing sector. We order the two labor productivity measures above the relative price, hours per worker and employment, and consider two cases: In the first exercise (a) we order labor productivity of the non-ICT sector first and of the ICT sector second. This specification assumes that ICT technology shocks affect non-ICT labor productivity only with one quarter delay. In the second exercise (b) we change the positions of the productivity measures. In this case ICT technology shocks are allowed to have an immediate impact on non-ICT labor productivity.

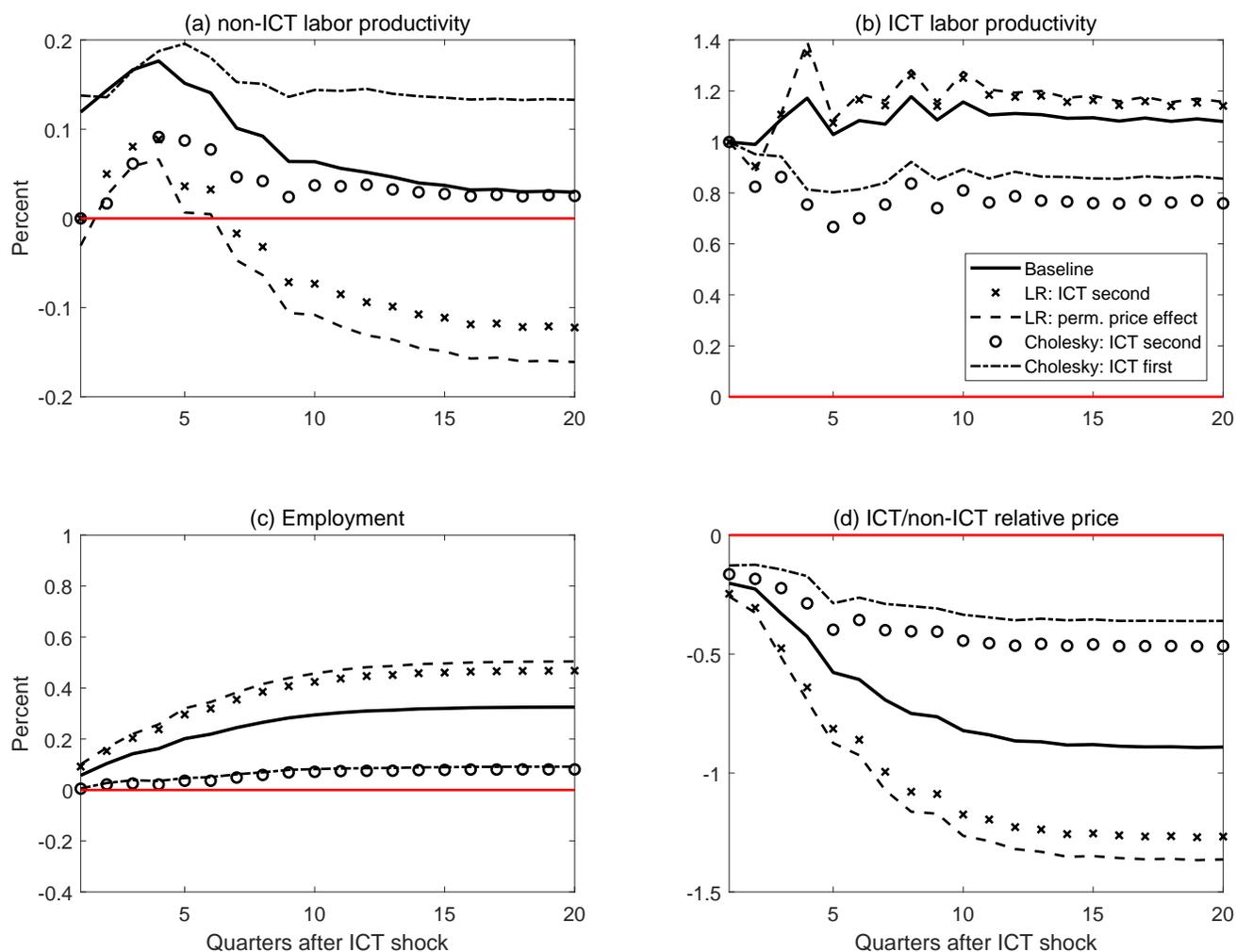
Figure 9 shows the results. The dotted lines display the results of identification scheme (a), the dashed lines show the dynamic reactions for identification scheme (b). Regarding the effects of labor productivity of the non-ICT sector, the ordering of the ICT labor productivity variable plays a crucial role. Imposing the restriction (a) that ICT technology shocks have no immediate impact on non-ICT labor productivity yields an insignificant reaction for this variable. For the alternative identification scheme (b), however, we obtain for the first

Figure 8: Responses of macroeconomic variables to an ICT technology shock



Notes: This figure depicts the accumulated impulse response functions for several macroeconomic variables. The VAR model contains labor productivity for the non-ICT sector and the ICT sector, the relative price of produced value added between the ICT sector and the non-ICT sector, hours per worker and total employment. The impulse response functions of employment in the non-ICT and ICT sector are determined by using a subset VAR in which we impose the restrictions that these variables are not included in the equations of the initial VAR model. We estimate our VAR model with quarterly data beginning with the first quarter of 1991 and ending in the fourth quarter of 2015. All variables are expressed in log-differences and the VAR model includes four lags. The identification assumptions for the ICT technology shock are summarized in equation (8). Dark and light blue shaded areas: 68-percent and 95-percent-confidence bands, respectively, are constructed using a recursive design wild bootstrap [Gonçalves and Kilian \(2004\)](#).

Figure 9: Robustness Checks



Notes: This figure shows the accumulated impulse response functions for several SVARs after an ICT technology shock which leads to a one percent increase in labor productivity of the ICT sector. The VAR model contains labor productivity of the non-ICT sector and the ICT sector, the relative price of produced value added between the ICT sector and the non-ICT sector, hours per worker and total employment. We estimate our VAR model with quarterly data beginning with the first quarter of 1991 and ending in the fourth quarter of 2015. All variables are expressed in log-differences and the VAR model includes four lags. In total, we show five variants for the identification of the ICT technology shock. In addition to the baseline SVAR we provide two variants of a standard Cholesky decomposition and two additional SVARs in which we modify the baseline assumption that non-ICT technology shocks are not allowed to have a contemporaneous effect on the relative price.

quarters an impulse response function similar to those of the baseline calculations. Moreover, the positive reaction of non-ICT labor productivity seems to be permanent, albeit small. For both identification approaches the positive reactions of employment are significantly smaller as compared to the baseline results. To sum up, in both cases the dynamic responses of employment and labor productivity do not contradict our baseline findings.

In a further exercise (c) we replace the assumption that non-ICT technology shocks have no immediate impact on the relative price by a further long-run restriction. Specifically, we adapt the assumption of Fisher (2006) and impose the restriction that only ICT technology shocks are able to shift the relative price in the long-run. Figure 9 shows that this identification assumption yields a stronger positive reaction of employment compared to the baseline results. For the relative price we find a more pronounced decline in the relative price of the ICT-producing sector. Both results are accompanied by a slight long-run decline in labor productivity in the non-ICT sector. Nonetheless, these findings are in line with our main results.

The second category of identification assumptions concerns the issue of disentangling ICT and non-ICT technology shocks. In our baseline SVAR we use a short-run restriction regarding the relative price to separate between both technology shocks. In our final robustness check (d), we do not impose restrictions on the dynamic behavior of the relative price. Alternatively, we assume that in addition to all long-run restrictions, ICT technology shocks do not exert any short-run effect on non-ICT labor productivity. The cross-lines in Figure 9 show that the results hardly change as compared to the previous robustness tests. We, therefore, conclude that this identification assumption corroborates our baseline findings.

5 Concluding remarks

This paper addresses the question as to why the German economy has experienced a marked slowdown in productivity growth in recent years, despite the general perception that increasing digitization causes rapid technological change. Our analysis provides the following list of explanations:

1. We find only small spillover effects from U.S. technology changes on German labor productivity. This suggests that the German situation seems to be special compared to other advanced economies.
2. A sizeable part of the slowdown in German productivity growth is a side effect of the labor market performance since the year 2005. The successful integration of five million

people into the labor market caused an attenuating effect on productivity growth as many of these new workers exhibit comparatively low levels of productivity.

3. Technological progress originating in the ICT-producing sector has significant positive effects on GDP and employment. The net effect on labor productivity, however, is modest. Consequently, increasing digitization leads to higher production and employment, but not to sizeable higher productivity.
4. For the years after 2012 technological progress in the ICT-producing sectors seems to be low which might also be an explanation for the German productivity paradox.

While our analysis provides several plausible answers to the German productivity paradox, it raises several further research questions. One possible question concerns the limited spillover effects in labor productivity between the U.S. and German economy. A deeper look into industry data could deliver further insights into this point. Furthermore, we think that more research regarding the reasons for the permanent shift in the productivity level of the highly export-oriented German manufacturing is needed. One explanation could lie in the link between world trade, global value added and productivity growth.

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A Data Sources

Table 4: Variables used in SVARs of Section 2.3: description and sources

Variable	Description	Source
Total factor productivity	quarterly data series for the U.S. business sector, adjusted for variations in factor utilization, labor effort and capital's work-week; seasonally adjusted; the time series begins in Q1 1947 and is available at https://www.frbsf.org/economic-research/indicators-data/total-factor-productivity-tfp/	Fernald (2014)
Population aged 16 and above (CNP16OV)	civilian noninstitutional population; thousands of persons; quarterly; not seasonally adjusted; time series begins in Q1 1947	Federal Reserve Bank of St. Louis
U.S. output (OUTNFB)	nonfarm business sector: real output; index 2009=100; seasonally adjusted; time series begins in Q1 1947	Federal Reserve Bank of St. Louis
U.S. labor input (HOANBS)	nonfarm business sector: hours of all persons; index 2009=100; seasonally adjusted; time series begins in Q1 1947	Federal Reserve Bank of St. Louis
German GDP	total economy; constant prices; post-1991 data (which refer to reunited Germany) are extended backwards by using growth rates of the pre-1991 data (which refer to West Germany only); seasonally adjusted; time series begins in Q1 1970	DESTATIS
German working hours	total economy: hours of all persons; millions; post-1991 data (which refer to reunited Germany) are extended backwards by using growth rates of the pre-1991 data (which refer to West Germany only); seasonally and working day adjusted; time series begins in Q1 1970	DESTATIS

Notes: All series were downloaded from the cited sources in November 2017 at the most recent vintage available at that time.

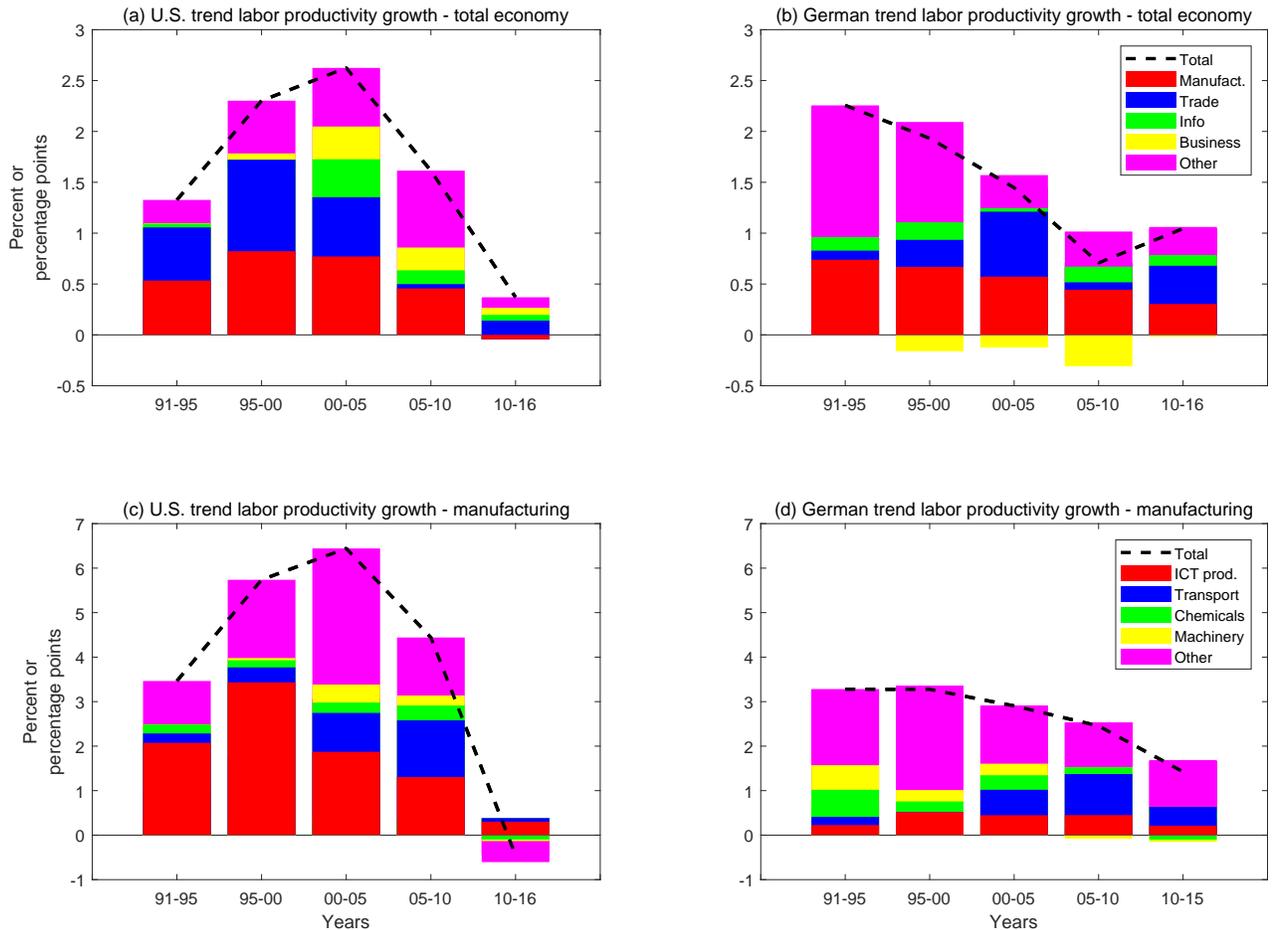
Table 5: Variables used in SVARs of Section 4.2: description and sources

Variable	Description	Source
Gross value added ICT manufacturing	annual time series for ICT manufacturing is converted into a quarterly data series using the real production index for the manufacture of computer, electronic and optical products (c.e.o. products), Chow-Lin procedure, the annual correlation between both time series is 0.89; constant prices; seasonally and working day adjusted; period Q1 1991 to Q4 2015	DESTATIS
Deflator ICT manufacturing	deflator gross value added corresponds to nominal gross value added divided by real gross value added; annual time series for ICT manufacturing is converted into a quarterly series using the producer price index of c.e.o. products, Chow-Lin procedure, the annual correlation between both time series is 0.72; seasonally adjusted; period Q1 1991 to Q4 2015	DESTATIS
Hours worked ICT manufacturing	quarterly data series is constructed using the hours worked series for the total manufacturing, Chow-Lin procedure, the annual correlation between both time series is 0.95; seasonally adjusted; period Q1 1991 to Q4 2015	DESTATIS
Employment ICT manufacturing	quarterly data series is constructed using the employment series for the total manufacturing, Chow-Lin procedure, the annual correlation between both time series is 0.95; seasonally and working day adjusted; period Q1 1991 to Q4 2015	DESTATIS
Gross value added ICT services	annual time series for the two ICT subsectors are converted into a quarterly data series using the real gross value added time series for the total German information and communication sector (IC sector), Chow-Lin procedure, the annual correlation between both time series are 0.81 (telecommunication) and 0.83 (IT services); constant prices; seasonally and working day adjusted; period Q1 1991 to Q4 2015	DESTATIS
Nominal gross value added ICT services	quarterly data series are constructed using the nominal gross value added time series for the total IC sector, Chow-Lin procedure, the correlation between these time series are 0.79 (telecommunication) and 0.75 (IT services); constant prices; seasonally and working day adjusted; period Q1 1991 to Q4 2015	DESTATIS
Hours worked ICT services	quarterly data series are constructed using the hours worked series for the total IC sector, Chow-Lin procedure, the annual correlation between these time series are 0.70 (telecommunication) and 0.75 (IT services); constant prices; seasonally and working day adjusted; period Q1 1991 to Q4 2015	DESTATIS
Employment ICT services	quarterly data series are constructed using the employment series for the total IC sector, Chow-Lin procedure, the annual correlation between these time series are 0.53 (telecommunication) and 0.85 (IT services); constant prices; seasonally and working day adjusted; period Q1 1991 to Q4 2015	DESTATIS
Gross value added total ICT sector	growth rate is computed using the sum of the weighted quarterly growth rates of real gross value added of the ICT manufacturing and the ICT services, the corresponding weights are the proportions in nominal gross value added of all three ICT sectors of the previous quarter, period Q1 1991 to Q4 2015	DESTATIS

Notes: ICT manufacturing corresponds to manufacture of computer, electronic and optical products. ICT service sector includes the two service sectors telecommunication and IT services (computer programming, consultancy and related activities). All series were downloaded from the cited sources in November 2017 at the most recent vintage available at that time.

B U.S. and German labor productivity growth

Figure 10: Comparison of labor productivity growth U.S. and Germany



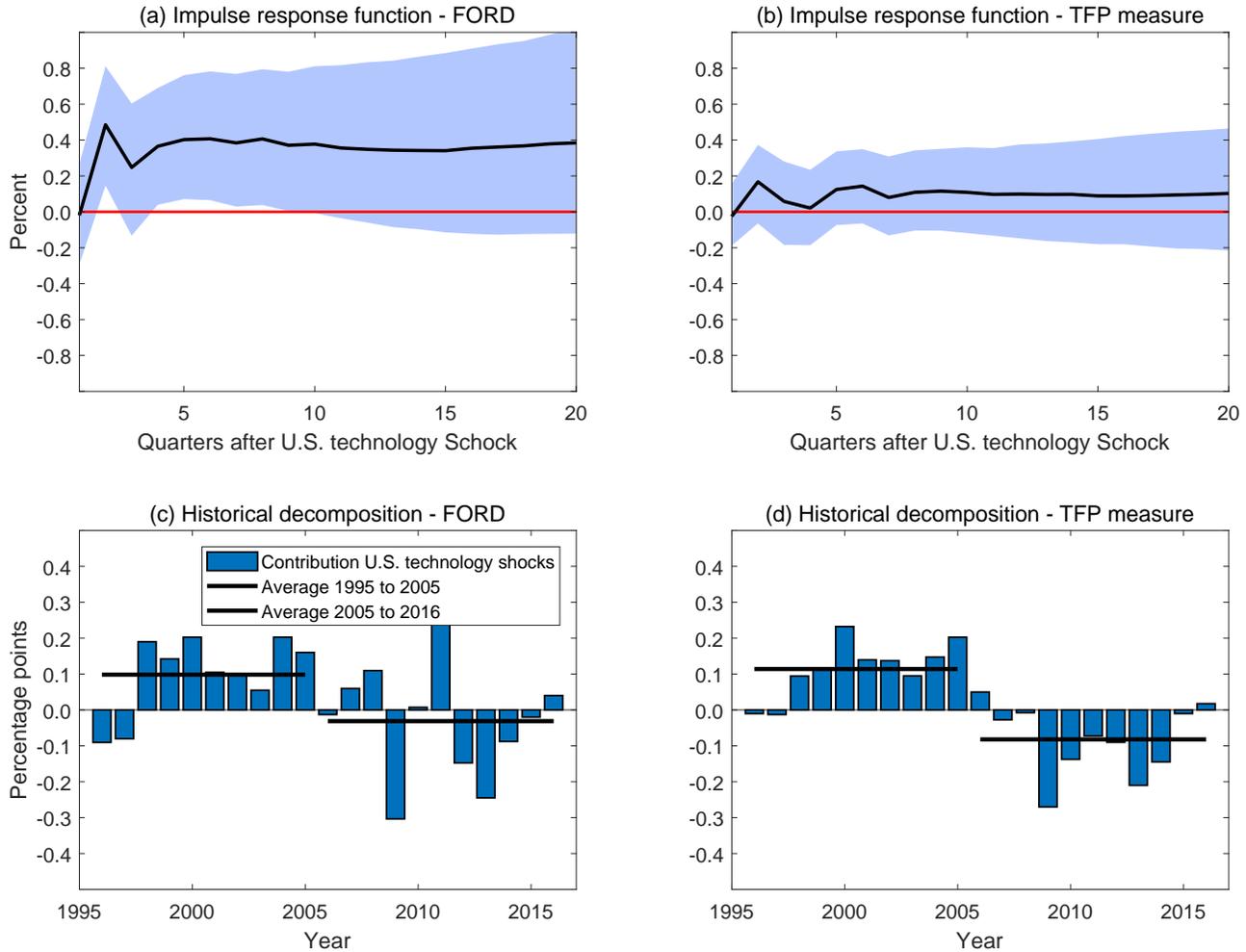
Notes: The first and second row depict the growth contributions of single economic sectors to productivity growth in the total economy and manufacturing. We show the 5-year-averages of the respective growth contributions. Trade contains retail and wholesale trade. Info is the abbreviation for information and communication services. The expression Business includes professional services and business services. The ICT-producing manufacturing sector includes computers, semiconductors and electronic products. To determine the growth contributions, we use as weights the respective employment shares for the actual and previous year of the single economic sectors in the total economy (first row) and total manufacturing (second row). For German manufacturing, we only have data until 2015. For the U.S. figures we use data from the BLS and the BEA. For the German figures we use data from DESTATIS.

C Max Share identification scheme

In this appendix we modify our analysis of Section 2.3 by using the Max Share identification technique proposed by [Francis et al. \(2014\)](#). They identify technology shocks as those shocks that maximize the forecast-error variance for labor productivity for a predetermined horizon h . In the following, we basically replicate their study and modify their estimation in two ways:²⁶ First, we incorporate German labor productivity as we are interested in the response of this variable. Second, we use the total factor productivity measure of [Fernald \(2014\)](#) in one estimation instead of hourly labor productivity. The other variables are log-levels of the nominal consumption-to-output ratio, the nominal investment-to-output ratio and an updated time series of the hours data from [Francis and Ramey \(2009\)](#) which is provided by [Wolters \(forthcoming\)](#). Both SVAR models include four lags. The sample begins in the first quarter of 1970 and ends in the fourth quarter of 2016. The upper row shows the impulse response functions of German labor productivity to a one-percent U.S. technology shock. The 68-percent-confidence bands are constructed using the method of [Sims and Zha \(1999\)](#). The lower row displays the cumulative effects of U.S. technology on annual German productivity growth. To sum up, our baseline statements do not change. The slowdown in U.S. productivity growth in recent years had modest negative effects on German labor productivity growth.

²⁶The replication files of their paper can be downloaded from the following website: <https://dataverse.harvard.edu/dataverse.xhtml?alias=restat>

Figure 11: The effects of U.S. technology shocks - FORD identification



Notes: This figure shows the results for the identification approach proposed by Francis et al. (2014) that maximizes the contribution of technology shocks to the forecast-error variance of labor productivity at a predeterminate horizon. The left-hand side of this figure (FORD model) uses the empirical model of Francis et al. (2014) and adds as additional variables the log-level of German labor productivity. The other variables are the log-levels of the U.S. variables real hourly productivity, the nominal consumption-to-output ratio, the nominal investment-to-output ratio and an updated time series of the hours data from Francis and Ramey (2009) which is provided by Wolters (forthcoming). For the results on the right-hand side (TFP measure), we replace U.S. labor productivity by a measure of total factor productivity proposed by Fernald (2014). Both SVAR models include four lags. The upper row shows the impulse response functions of German labor productivity to a one-percent U.S. technology shock. The 68-percent-confidence bands are constructed using the method of Sims and Zha (1999). The lower row displays the cumulative effects of the U.S. technology on annual German productivity growth.

D Characteristics of the ICT-producing sector

The ICT producing sectors are characterized by high productivity growth. To illustrate this, we determine for 37 economic sectors the annual percentage changes in total factor productivity and compare the numbers of the ICT producing sectors with those computed for other parts of the German economy. We consider the time period between 1991 and 2015. Our ICT producing sectors are the manufacture of computer, electronic and optical products as well as the service sectors telecommunication and IT services (computer programming, consultancy and related activities).

To compute the growth rate in total factor productivity, $\Delta TFP_{i,t}$, we assume a Cobb-Douglas production function with constant returns to scale. Formally, the growth rate in gross value added, $\Delta GVA_{i,t}$, of sector i for period t can be decomposed as:

$$\Delta GVA_{i,t} = \Delta TFP_{i,t} + \alpha_i \Delta K_{i,t} + (1 - \alpha_i) \Delta L_{i,t}, \quad (9)$$

where $L_{i,t}$ corresponds to total hours worked and $K_{i,t}$ defines the gross capital stock. The production elasticity of labor, $1 - \alpha_i$ is determined by the labor income share. For each economic sector i we use the compensation of all employees and adjust that number by the income of self-employed people. Finally, we divide this total labor income by the gross value added. For the various economic sectors we compute sector-specific production elasticities. These elasticities are not time-variant.²⁷ We obtain $\Delta TFP_{i,t}$ by rearranging equation (9).

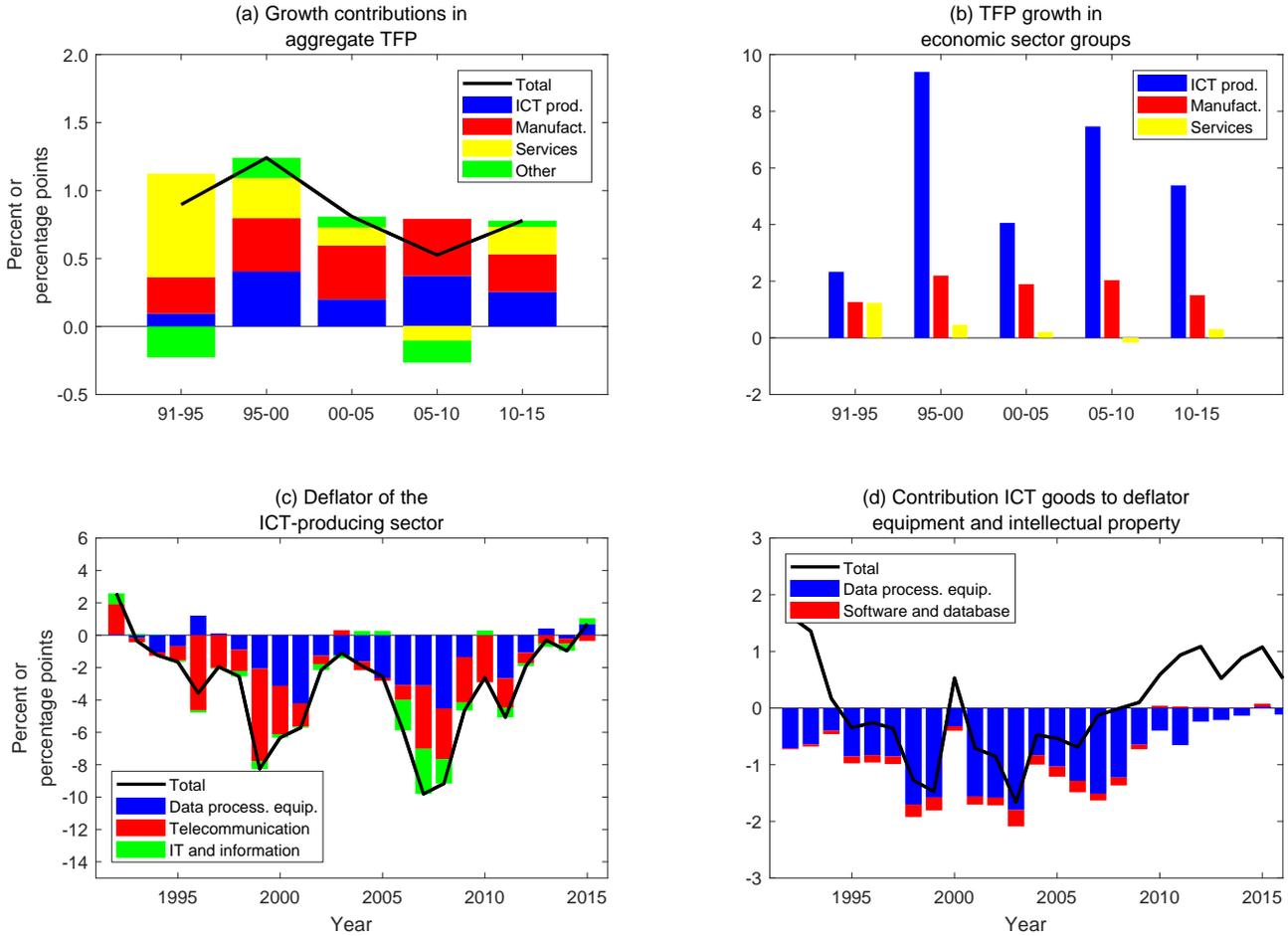
The upper right panel of Figure 12 shows the resulting growth for total factor productivity growth. We compare the numbers of the ICT producing sectors with manufacturing and services without ICT producing industries. Evidently, the annual growth rates in the ICT sector are much higher than in other sectors of the economy. For the years 2010 to 2015, we have seen in the ICT producing industries productivity advancements of more than 5 percent while for instance the productivity gains in the remaining manufacturing sectors amounted to 1.5 percent.

The proportion of the ICT sector in total gross value added corresponds to roughly 5 percent in recent years. Nonetheless, owing to the extraordinary high growth rates in total factor productivity the ICT producing sectors were a major driver in technological progress in the German economy. The upper left panel of Figure 12 illustrates this.

Significant parts of the productivity gains in the ICT producing sectors are reflected in declines of their gross value added deflators. This can be attributed to the hedonic price

²⁷Owing to the assumption of constant production elasticities and the consideration of growth rates, it seems appropriate only to consider the production function with gross value added and not the production value.

Figure 12: Main characteristics of the ICT sector



Notes: The abbreviation “Data process. equip.” defines the economic sector manufacture of computer, electronic and optical products. Total factor productivity growth is determined with equation (9). To compute the growth contributions the proportions in nominal gross value added are used. Data source is DESTATIS.

adjustment which applied in these production areas. The lower left panel of Figure 12 displays the annual growth rates of the ICT sector deflator and its growth contributions. In particular, in the years 2007 and 2008, we have observed strong price declines which were mainly due to developments in economic sectors manufacture of computer, electronic and optical products and telecommunication. For the sake of comparison, the lower right panel of Figure 12 depicts the investment deflator for equipment and intellectual property. In addition, we provide information regarding the growth contributions resulting from price developments of software as well as computer, electronic and optical products. Particularly, the strong price declines of data processing equipment have caused the negative growth rates

of the investment deflator in the years between 1995 and 2007. The deflator of gross value added for the ICT sector has an annual correlation coefficient with the investment deflator for equipment and intellectual property of 0.38. The correlation coefficient increases to 0.44 using the sum of the growth contributions for the investment goods computer, electronic and optical products and software instead of the investment deflator.