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IZA DP No. 11194

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ABSTRACT

Technological Innovation and Inclusive Growth in Germany

Technological innovation has historically contributed to inclusive economic growth in Germany. In more recent decades, however, this contribution has weakened due to the declining impact of technological innovation on labor productivity growth. Fearing that this declining impact would undermine the international competitiveness of the economy, real labor compensation was progressively curbed since the mid-1990s. This occurred *inter alia* through the government's erosion of the social welfare state, as well as through offshoring and reduced fixed capital investment of the corporate sector. The outcome was rising income and wealth inequalities. Between the mid-1990s and 2010 the rise in wage inequality was faster in Germany than in the United States, the United Kingdom, and Canada. To restore inclusive growth, two broad policy measures are recommended: first, to have appropriate compensatory social welfare policies in place; and second, to improve the effectiveness of technological innovation to raise labor productivity. This paper identifies three reasons why technological innovation has become less and less effective:(i) historical legacies, (ii) weaknesses in the education system, and (iii) entrepreneurial stagnation. Improving the impact of technological innovations on labor productivity growth will require a more diversified education system, a deepening of active labor market policies, better immigration policies, and a greater contestability of markets. Ensuring these recommendations in a coordinated fashion suggests the need for an appropriate industrial-innovation policy.

JEL Classification: D31, L26, O33, O38, O52

Keywords: entrepreneurship, Germany, inequality, innovation, social protection, technology

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1 Introduction

Economic growth in Germany is no longer as inclusive as it used to be. Between 1990 and 2010 average annual per capita GDP growth amounted to a slow 1.0 percent and was moreover not equally shared: *all* measures of income and wealth inequality rose considerably over this period[1], which led the media to portray Germany as a 'divided nation'.[2] Income inequality was relatively low before 1990, and even declined over much of the 20th century, but changed direction after the German reunification.

The rise in income inequality from 1990 onward is depicted in Figure 1 through various inequality indicators and the 'at-risk-of-poverty rate'. It can be seen that all measures of income inequality (before and after tax) increased markedly after 1990, as well as the 'at-risk-of-poverty rate'.[3] Felbermayr et al. (2014) furthermore document that the rise in wage inequality was faster in Germany than in the United States, the United Kingdom, and Canada between the mid-1990s and 2010. This rise in income and wage inequality has been accompanied, and to a certain extent caused, by a simultaneous increase in wealth inequality. Frick and Grabka (2009) calculate, using data from the Socio-Economic Panel (SOEP) for 2002 and 2007, that the Gini-coefficient for wealth increased from 0.77 to 0.80 during this period, particularly at the top 1 percent by more than 10 percentage points.

A growing number of studies have investigated the reasons for this rise in income and wealth inequality (see for instance Dustmann et al., 2009, 2014; Biewen and Juhasz, 2012; Felbermayr et al., 2014). This paper contributes to this literature by arguing that a *decline* in the effectiveness of technological innovation, together with the erosion of the social welfare state, have been important causes. Precisely because technological innovation has become *less and less effective* at raising labor productivity in Germany, policy makers and the corporate sector turned to measures that curb labor compensation to improve international competitiveness.

This paper shows that technological innovation has historically been a driving force for inclusive economic growth in Germany, and identify three reasons why this is no longer the case. These are(i) historical legacies, (ii) weaknesses in the education system, and (iii) entrepreneurial stagnation. Improving the impact of technological innovations on labor productivity growth will require a more diversified education system, a deepening of active labor market policies, better immigration policies, and a greater contestability of markets. Ensuring these recommendations in a coordinated fashion suggests the need for an appropriate industrial-innovation policy.

The call in this paper for more and better technological innovation and the message that technological innovation is a driver of inclusive growth is somewhat contrary to some of the recent literature and popular press (see e.g. Ford, 2015). These tend to blame too rapid technological innovation for income inequality and jobless growth, warning

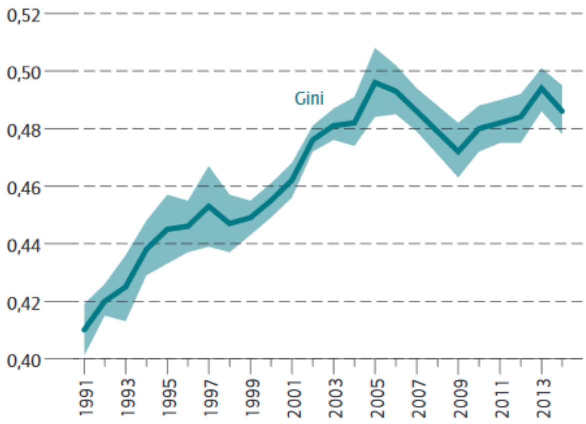
[1] High inequality negatively affects growth and sustainable economic development (Berg and Ostry, 2011; Ostry et al., 2014) and may lead to economic, political and social turmoil (Stiglitz, 2012).

[2] Der Spiegel, 12.03.2016: 'Die geteilte Nation'.

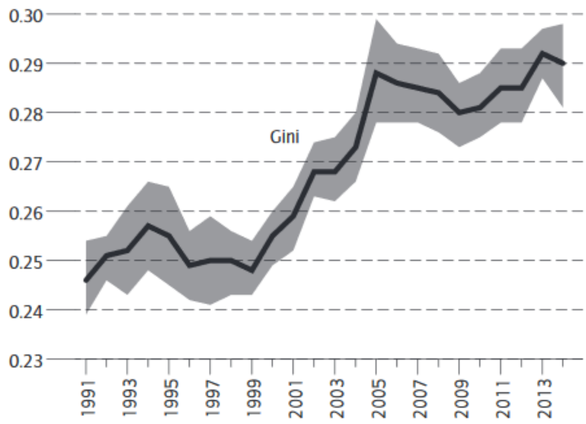
[3] Somaskanda (2015) reports, citing the *Paritätischer Gesamtverband*, that Germany is at its highest poverty levels since reunification with 12.5 million poor people, of which 3 million are estimated to be 'working poor'. This leads to the observation, or concern, that 'rich Germany has a poverty problem'.

Figure 1: Inequality measures and poverty rate in Germany, 1991 to 2015

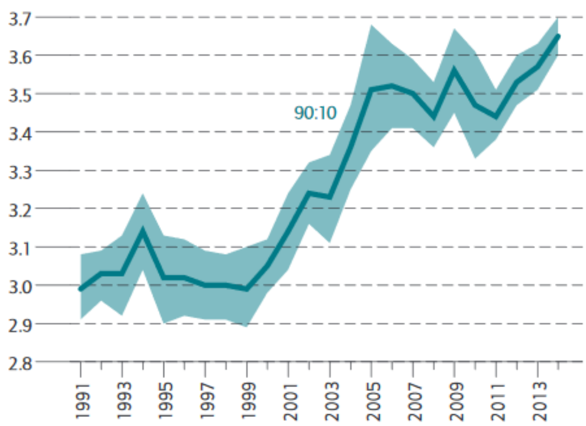
(a) Gini coefficient - market income



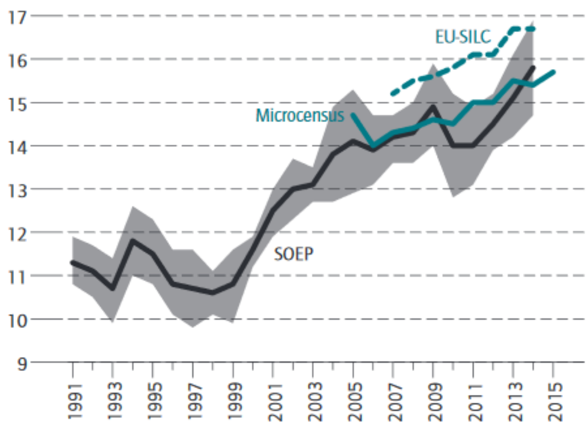
(b) Gini coefficient - disposable income



(c) 90:10 percentile ratio - disposable income



(d) At-risk-of-poverty rate



Data source: Figures taken from Grabka and Goebel (2017), based on data from SOEPv32 (calculations of DIW Berlin), Federal Statistics office (Microcensus, EU-SILC). *Notes*: At-risk-of-poverty rate is defined as '[p]ersons with less than 60 percent of median disposable income. Real incomes in prices of 2010. Population: Persons living in private households. Equivalized annual income surveyed the following year. Equivalized with the modified OECD-scale. Shaded areas indicate a 95-percent confidence band (Grabka and Goebel, 2017, p.55).

that technological innovation is skill-biased, disproportionately driving up the wages of the highly skilled workforce, and eliminating middle-skill intensive jobs, causing wage polarization (Brynjolfsson and McAfee, 2012). Frey and Osborne (2015) predict that up to 51 percent of current jobs in Germany may be lost due to technological innovation (e.g. automation) in the future, and Acemoglu and Restrepo (2017) warn, based on U.S. data, that each new robot can replace up to seven jobs. This study does not share this pessimism and moreover support the conclusion of studies such as by Autor (2015) and Pfeiffer (2016), that suggest that the prediction of robots taking over human jobs are unlikely to materialize. In particular, Dauth et al. (2017b, p.39) find that in Germany 'more robot exposed workers are even more likely to remain employed in their original workplace', despite the fact that there are more robots per worker in Germany than in the United States or any other European country.

The remainder of this paper is structured as follows. In Section 2 the core message is summarised and diagrammatically illustrated, with cross-references to the various sections, where the details of the specific arguments are elaborated. Section 3 shows that technological innovation has historically underpinned inclusive growth in Germany, however, as Section 4 documents, the effectiveness of technological innovation has declined in recent years. In Section 5 three broad reasons are discussed why technological innovation, despite high and rising expenditure on the promotion of innovation, is not stimulating labor productivity growth:(i) historical legacies, (ii) weaknesses in the education system, and (iii) entrepreneurial stagnation. In Section 6 evidence is provided to show that the decline in the effectiveness of technological innovation helps explain rising income inequality. In Section 7 the main findings are summarized and various recommendations for policy and further research discussed.

2 Linking technological innovation and inclusive economic growth: Diagrammatic illustration

For purposes of this study, growth is inclusive 'if and only if the incomes of poor people grow faster than those of the population as a whole, that is, inequality declines' (Anand et al., 2013, p.1). The first question to answer in this section is therefore: *how is inequality defined?*

Inequality is a complex term that implies a set of theoretical constructs, as well as various ways to measure and express this concept empirically. While inequality is often associated to material or economic aspects, such as inequality in wages, incomes or wealth, inequality goes far beyond. The notion of inequality must be extended to comprise non-material aspects such as equal access to opportunities, for example in education and employment, and the possibility of social mobility.

For present purposes however, to provide a tractable analysis given the lack of sufficient and consistent data on non-material equality in Germany, the remainder of this study will define and measure inequality by the distribution of incomes (wage and capital incomes) and wealth. As indicated in the introduction, all measures of income and wealth inequality have deteriorated in Germany over the past thirty years. This study furthermore focuses on income inequality, measured by the changes in the distribution of wage and rental (capital) incomes over time.

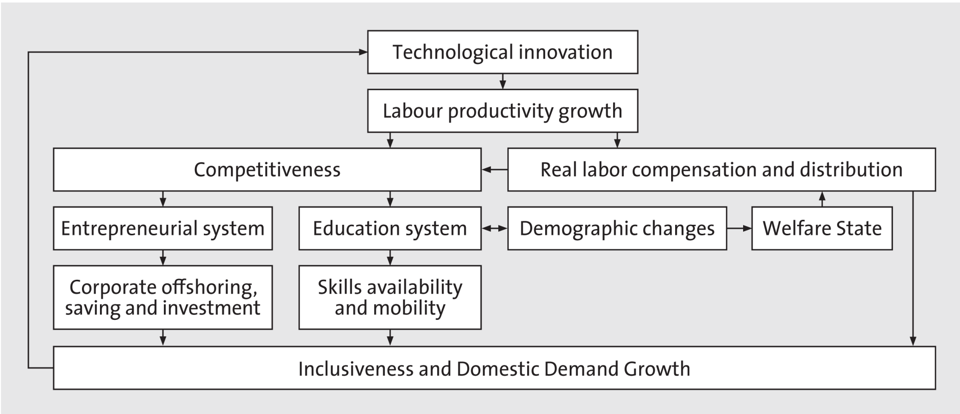
If inequality increases within a society, or remains at persistently high levels over time, it can have potential negative economic and social consequences that are worth counteracting. Inequality can lead to a set of negative externalities that might cause economic, political and social turmoil (Stiglitz, 2012). In contrast, nations with a more equal society are more likely to grow economically[4] and develop (Birdsall and Londoño, 1997).

[4] While too much inequality is highly problematic, some inequality is also unavoidable, and even desirable. Some level of inequality is considered necessary to provide incentives, and stimulate development. Forced complete equality can threaten personal freedom. Additionally, institutions suffer from efficiency losses due to a 'leaky bucket' of bureaucracy or administration in the distribution process (Keeley, 2014).

The second question, which is the central question addressed in this study, is: *what is the link between technological innovation and inequality in Germany?*

There are increasing concerns that too rapid technological innovation is responsible for rising inequality. This paper argues that this is not the case in Germany - in contrast, it is rather a lack of effective technological innovation that triggers responses by government and the corporate sector, contributing to rising inequality, in addition to demographic pressures. The argument can be explained with the help of the following diagram in Figure 2.

Figure 2: The channels from innovation to inclusiveness



Data source: The authors.

Technological innovation can raise labor productivity growth, which is a fundamental aspect of the endogenous growth theory. The extent of labor productivity growth, in turn, determines the competitiveness of the economy, as well as the real compensation of labor, and how it is distributed. Germany's key challenge lies in declining labor productivity growth. This study documents that labor productivity growth has been consistently declining, even in the face of rising spending on innovation. Labor productivity growth was five times *slower* in 2013 than in 1992. This decline in labor productivity growth is inconsistent with a scenario of rapid technological innovation, or with technology replacing human labor. As Yglesias (2015) points out, '[i]f robots were taking our jobs, the productivity of the workers who still have jobs would be going up rapidly. But it is not.' A recent study of robots in Germany also concludes that '[...] robots have not raised the displacement risk for incumbent manufacturing workers. Quite in contrast, more robot exposed workers are even more likely to remain employed' (Dauth et al., 2017b). In Germany, declining labor productivity growth was further worsened by the negative productivity shock from reunification.

The problem caused by the decline in labor productivity growth is that real compensation of labor will, over the long run, only grow in line with growth in labor productivity. In Germany real wage growth has indeed be slow and declining, and was even around zero and negative during the mid-2000s, since the stagnation in labor productivity growth set in. This slower growth in wages implies that domestic demand will also grow slowly.

A comprehensive literature exists that studies the impact of labor productivity growth on wage distribution, and that explains rising wage inequality as the outcome of skill-biased technological change (SBTC) (see e.g. Acemoglu and Autor, 2011). Goldin and Katz (2010) explain that the wage premium of workers who have the skills to use the new technology continues to rise if their supply cannot keep up with demand, due to the speed of innovation and technology diffusion. A more unequal distribution of incomes will result in an overall decline in domestic demand growth. While there is some evidence of a rising wage premium due to SBTC in Germany, this paper concludes that it has not been significant for income inequality, nor has it been the major threat to jobs and incomes. To be more specific, there is little evidence the technology is generally replacing human workers with machines and robots, and especially not at the high skilled level (Marin, 2014; Dauth et al., 2017b).

A decline in labor productivity will put the competitiveness of the economy under pressure, and will cause the corporate sector (the entrepreneurial system) to respond by, for instance, offshoring production to locations with lower wages or higher productivity[5]; furthermore by increasing corporate savings, and hence by investing less in fixed capital. This paper presents evidence that this has indeed occurred in Germany in recent years. Today large corporations hold substantial amounts of cash reserves instead of investing in capital or breakthrough innovations. The significant decline in corporate fixed capital investment, in turn, further decreases the effectiveness of technological innovation, because it delays the distribution and spread of technology through the economy, given that new technology is most often embodied in the capital that laborers use. The net result was that profits grew faster than labor wages, leading to a decline in the relative share of labor in national incomes, resulting in top incomes rising out of proportion.

The extent to which the corporate sector engages in the above mentioned adjustments towards better competitiveness, will partly depend on the success of the educational system to deliver workers with the type of skills in demand, and with skills that can 'travel' between different sectors. If the education system is too specialized and does not deliver the right kind of skills, the wage gap will grow faster via SBTC, but also via rising forms of insecure and low-wage employment. As a consequence, growth will be less inclusive and domestic demand will grow slower.

Fears of reduced competitiveness do not only elicit a response from the corporate sector, but also from the government. Fearing that the country's internationally competitiveness would be weakened, government also contributed towards the reduction of real labor compensation since the mid-1990s. The so-called Hartz reforms were the central policy response in this regard. As a result various benefits of the social welfare state were reduced or abolished. Self-employment and forms of irregular and part-time employment with low(er) wages increased, while labor unionization rates dropped. The rate of working and 'at-risk-of-poverty' doubled from 4.8 percent to 9.6 percent between 2005 and 2015. Thus, although unemployment declined in Germany after reaching a peak in 2005, income inequality did not (Biewen and Juhasz, 2012). The authors ascribe this outcome, at least partly, to the fact that the rise in employment was largely due to more self-employment, part-time, and marginal forms of employment.

Simultaneously to the above pressures on real labor compensation, certain skills become

[5] The offshoring of production refers to the allocation of parts of the supply chain, within the production process, to other countries.

scarcer due to demographic changes and the nature of the education system. As a result of the relative specialized nature of higher education in Germany, the mobility of skills between sectors was hampered. More aged workers and more pensioners further imply reduced productivity, which reduces consumption growth and leads to an upward pressure on the wage premium. The overall effect leads to reduced domestic demand growth, and more inequality in incomes and wealth (i.e. reduced inclusiveness of growth).

Whereas the stagnation in domestic demand may have led to policy responses to raise domestic demand, such as expanding government consumption and investment, and encouraging fixed investment by corporations, Germany could avoid these due to the benefits of the Euro exchange rate, which favors the country's exporting. The euro has been argued to induce the 'hyper-competitiveness' of the German economy, as witnessed by the fact that it generates the largest current account surplus worldwide. Hence, corporates and the government could partly ignore the decline in domestic consumption. The ability to shift production towards foreign demand through exporting and to offshore production, resulted in German firms reducing their demand for low-skilled labor while increasing their demand for high-skilled labor, driving the wage premium upward (Becker and Muendler, 2015). In this regard, Felbermayr et al. (2014) document that by 2003 exporting firms in Germany paid what can be labeled an 'exporter premium', resulting in higher wages of 11 percent on average. The authors also find that the export premium has only become a significant contributor towards wage inequality since 2003, ascribing this to an indirect effect of the Hartz labor market reforms and the decentralization of collective bargaining in the late 1990s, stating that 'wage flexibility has increased sharply in Germany due to the documented decline of collective bargaining agreements. As such, company characteristics [...] such as export status, have a stronger effect on paid wages' (Felbermayr et al., 2014, p.37).

The rise in income inequality documented through the channels above, was exacerbated by two features related to the poor innovation performance:(i) good management skills were in relative short supply, leading to a rise in CEO wages; (ii) the lack of management skills resulted in an increasing divergence in firm-level productivity growth, which, in turn, resulted in high productivity frontier firms vs. low productivity laggard firms. A lack of management skills further contributed to a more sluggish diffusion of technological innovation through the economy, making innovation less effective.

The conclusion of this study is that Germany needs more and better innovation that will increase labor productivity again. While Germany is highly competent in traditional and medium-technology industries, such as automobiles and machine tools, it has failed to acquire the innovation lead in semiconductors, computing, 3D-printing, nanotechnology, robotics or molecular biology - the drivers of what has been named the 'fourth industrial revolution' by the World Economic Forum. Only four German firms are among the top 30 innovative companies in the areas of 3D-printing, nanotechnology, and robotics (as measured in terms of patents). The top 20 patent applicants in nanotechnology do not include a single German firm since 1970. In all of these, German firms are lagging behind those from the United States, Japan, South Korea, and increasingly also China. Germany has been, until recently, a technology leader in solar photo-voltaic (PV) energy. By now, however, most of the solar PV production has 'moved out of Germany' to China: almost 50 percent of the 100,300 workers in Solar PV manufacturing in Germany lost their jobs in only one year (2013). Because these new technologies are now fundamentally affecting manufacturing, Germany's critically important manufacturing sector is facing the threat of ending up as 'a sub-sector of the IT sector in the US'.

For innovation in Germany to be boosted, this study argues, a fundamental change is required in the national innovation system. In Section 3 it is described how Germany has a tradition of establishing an excellent system of innovation: between 1850 and 1913, when Germany experienced its remarkable industrialization, the unique collaboration between industries, government and higher education institutions created the 'triple-helix' system, which remained largely intact after the Second World War. The earlier success of the system, however, may be starting to work against delivering the type and impact of innovation that is now needed. An appropriate industrial-innovation policy, supported by diversification of the higher education sector, is required instead. Such an industrial-innovation policy will require a change in the approach and organization of the public sector with respect to innovation policy, raising the question posed by Mazzucato (2015, p.125): '[h]ow should public organizations be structured so that they can accommodate the risk-taking and explorative capacity needed?'

This study does not answer this question, although the latter will eventually need to be answered as a precondition in order to achieve sustained and inclusive growth in Germany in the future. In the meantime, the social welfare state is central, as pictured also in the diagram. In particular, compensatory social welfare policies, including redistributive taxes and transfers and active labor market policies, remain the first line of defense against rising income and wealth inequalities and dealing with the challenges changing demographics bring about.

3 Technological innovation and inclusive growth in Germany: A tale of two periods

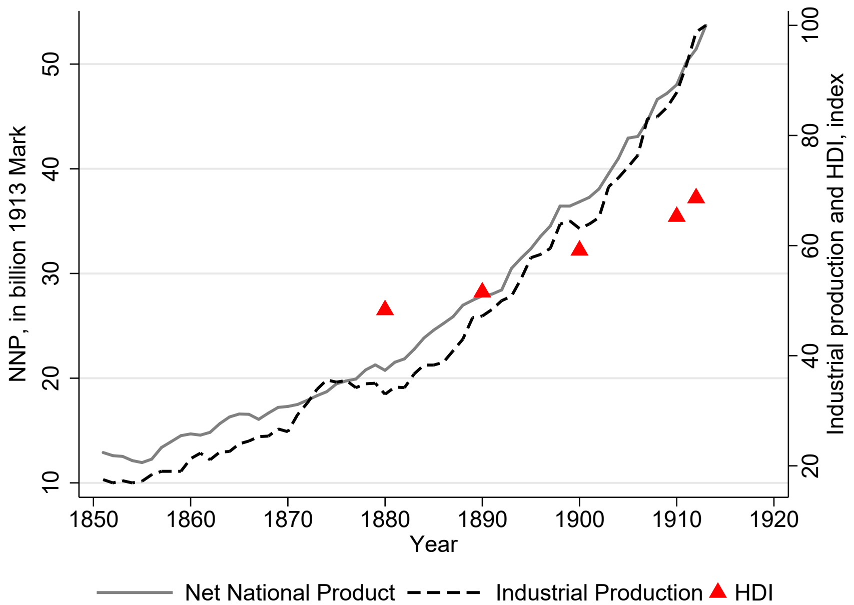
In this section Germany's experiences over the period 1850 to 1913 are compared with the post-World Wars period (1950 to present). This is useful for a number of reasons: first, the relationship between technology, growth, and social outcomes tends to be persistent and institutions can have long-term effects - outcomes therefore often have historical roots. Second, it allows to evaluate the impact of the national innovation system and to identify structural breaks. Third, a historical perspective makes strikingly clear that over a long span of history innovation-driven growth has been inclusive.

The historical overview emphasizes two points: first, that technological innovation has historically been an important source of inclusive growth in Germany, based on a series of remarkable breakthrough product innovations in the late 19th and early 20th century that laid the foundation for virtually the entire modern German economy. During this period the German social welfare state, the world's first, was established. And second that, in the period after the Second World War, technological innovation has became less effective, focusing on incremental process innovations, which was accompanied by an increase in inequality over the past two decades. In the remainder of this section the key features of these periods, in terms of the innovation-inequality linkages, are discussed.

3.1 The period of rapid innovation and inclusive growth, 1850 to 1913

Germany's system of technological innovation came into being between 1850 and 1913. This was the period of Germany's industrialization (Beise and Stahl, 1999)[6], and coincided with the 'first era of globalization' (Twarog, 1997) and the 'second industrial revolution'. In fact, the innovation system supported and drove rapid industrialization in the country, with Germany specializing in fields that were characteristic for the 'second industrial revolution', such as chemicals, automobiles and electricity. This development was accompanied by inclusive growth as shown by the Human Development Index (HDI) which rose from 48.3 (in the period 1871 to 1880) to 68.6 in 1912 (see Figure 3). As Twarog (1997) summarizes, real per capita income grew by 15 percent per decade between 1850 and 1913, industrial production achieved a growth rate of 37 percent per decade, and the population living in cities of more than 100,000 people increased from 4.8 percent in 1871 to 21.3 percent in 1910. In just about half a century the Germany economy had been significantly transformed. During this time, however, income inequality 'barely changed' (Williamson, 1995).

Figure 3: Economic take-off and industrialization in Germany, 1850 to 1913



Data source: Authors' own compilation based on 'compromise' data for the net national product (in billion 1913 marks) and industrial production data from Burhop and Wolff (2005, pp.651-653), and HDI data from Twarog (1997, p.322). *Notes*: The industrial production and the HDI are indexes with a range from 0 (lowest) to 100 (highest). The industrial production data is indexed to 100 for the year 1913.

[6] Although Germany's industrial revolution started around 1850, various types of manufacturing activities and 'pre-industrialization' pockets can be found before this time. As Ogilvie (1996) points out, the regions around Nuremberg were containing fairly advanced manufacturing hubs for the time, and parts of the Rhineland and Saxony were industrializing on small-scale by 1780.

Innovation played an important role in this inclusive growth. A large growth component over this period was the growth in total factor productivity (TFP), a frequently used indirect indicator of technological progress. Burhop and Wolff (2005, p.640) find that total factor productivity contributed 63.9 percent to total net national product (NNP) growth between 1851 and 1913. Without the myriad of (radical) technological innovations that the system produced during this period (see Table 1), German industrialization and development would not have been as successful.

Table 1: Radical innovations in Germany, 1871 to 1913

Entrepreneur-Engineer	**Radical Innovation**
Ernst Abbe (1840-1905)	Optic lenses
Albert Ballin (1857-1918)	Shipping lines (established the world's largest shipping company by 1900)
Andreas Bauer (1783-1860)	Steam powered printing press
Karl Benz (1844-1929)	4-stroke automobile engine
Melitta Bentz (1873-1950)	Coffee filter
Robert Bosch (1861-1942)	Spark plug
Gottlieb Daimler (1834-1900)	Internal combustion engine, motor cycle
Rudolf Diesel (1858-1913)	Diesel engine
Alfred Einhorn (1856-1917)	Novocaine
Paul Ehrlich (1854-1915)	Chemotherapy
Adolf Fick (1852-1937)	Contact lenses
Carl Gassner (1855-1942)	Dry cell battery
Hans Geiger (1882-1945)	Geiger counter
Heinrich Hertz (1857-1894)	Antenna
Fritz Hofmann (1871-1927)	Synthetic rubber
Felix Hoffmann (1868-1946)	Heroin and aspirin
Christian Hülsmeyer (1881-1957)	Radar (telemobiloscope)
Alfred Krupp (1812-1887)	No-weld railway tires, steel (by 1900 his company was the largest in Europe)
Heinrich Lanz (1838-1905)	Oil-fueled tractor
Julius Pohlig (1842-1916)	Cable car
Wilhelm Röntgen (1845-1923)	X-rays
Werner von Siemens (1816-1892)	Needle telegraph (today Siemens AG is the largest manufacturer in Europe)
Carl Zeiß (1816-1888)	Lens manufacturing

Data source: Authors' own compilation.

What made these radical technological innovations possible? This is a pertinent question, as by all accounts Germany was still an 'industrial backwater' around 1850. Bairoch (1982, p.284) documents that Germany was still lagging behind the United Kingdom, the United States, China, India, France, and Russia in terms of manufacturing output by 1860. One century later, however, Germany had not only caught-up and transformed, but had also become the world's leading innovator. Most economic historians agree that Germany's performance was enabled by the rise of its education and scientific sectors, and in particular by the collaboration between educational and research institutions, and private entrepreneurs and the government.

In the subsequent discussion the study focuses respectively on(i) the education and science establishment; (ii) the entrepreneurs and the business community; and (iii) the government, describing how their collaboration created the so-called ‘triple-helix’ model of innovation and development (Mroczkowski, 2014).

As far as the education and scientific research establishment is concerned, Watson (2010) traces significant institutional contributions to Frederick the Great’s establishment of the *Berlin Academy of Arts and Science* in the 18th century, as well as to a ‘revolution’ in learning and reading. As the author documents, by the year 1800 around 270 reading societies existed in Germany, with literacy rates in Prussia and Saxony amounting to the highest in the world.[7] In subsequent decades, between 1790 and 1840, German scholars, such as Wilhelm von Humboldt, re-created German universities as research institutions - heralding the modern research university - that were different from previous and other universities in its focus on new knowledge generation and innovation. This has been called the ‘institutionalization of discovery’ (ibid., p.226) and the ‘industrialization of invention’ (Meyer-Thurow, 1982, p.363).[8]

Science and engineering were preeminent in the best of these universities. Moreover, the 19th century also saw the rise of polytechnical and technical universities (*Technische Hochschulen*), where engineering and applied sciences were paramount. These institutions were widely accessible, and driven by the educated and rising middle classes of that period (Watson, 2010). The first steps were made to create a public research laboratory system in 1887, on the instigation of entrepreneur-engineer Werner von Siemens, namely the *Physikalisch-Technische Reichsanstalt* (Beise and Stahl, 1999). Further organizations of this kind included the *Kaiser Wilhelm Institutes*, established in 1911 on instigation of the chemical industries, to become the *Max Planck Institutes* after the Second World War. This ‘industrial research system’, influenced as much by entrepreneurs and businessmen as by the government and scientists, was one of the first of this kind worldwide (Grupp et al., 2005).

The scientific breakthroughs at universities and polytechnical institutions were quickly taken up and applied for commercial purposes by German entrepreneurs. One of the first examples were the contributions of scientists such as Rudolf Clausius, Julius Mayer and Hermann von Helmholtz to the understanding of the generation and conservation of energy. Their inventions stimulated engineer-entrepreneurs such as Werner von Siemens to establish the firm of *Siemens und Halske* in 1847, which manufactured the world’s first pointer telegraph, starting in effect the modern telecommunication industry. In 1851, Siemens invented the dynamo-electrical machine which would contribute to the eventual prominence of power engineering in Germany (Watson, 2010). Similarly, contributions in chemistry and organic chemistry led to the invention of synthetic color dyes, which - helped by the country’s large coal reserves - led Germany to become the world’s leading manufacturer of color dyes (Meyer-Thurow, 1982).

[7] By 1800, Germany’s adult literacy rate was 35 percent and it was publishing 116 million printed books per year, only lagging behind France and the United Kingdom (Buringh and van Zanden, 2009).

[8] As Watson (2010, p.835) points out, ‘the concept of the modern PhD is a German idea’, and as stressed by Mroczkowski (2014, p.412), ‘the modern research university was actually a German institutional innovation’.

The color-dyes industry developed into a global leading pharmaceutical industry with firms such as the *Badische Anilin & Soda-Fabrik* (*BASF*), *Bayer*, and *Höchst*, introducing famous inventions such as the aspirin. The chemical and pharmaceutical industries led the way to the establishment of private industrial research laboratories with the main purpose to invent and apply new inventions commercially (Meyer-Thurow, 1982). In 1891, for instance, the firm of *Bayer* established its own industrial research laboratory under the direction of Carl Duisberg; this laboratory was described as being superior to 'every university laboratory then in existence', although it relied on the universities to supply it with PhD chemists (ibid., p.370).

The list of radical inventions by engineer-entrepreneurs during the late 19th and early 20th century is remarkable (see also Table 1). The legacy of these innovations have endured into present-day Germany: many of the largest German industrial firms in the post 1950 period trace their roots back to this time, such as *Siemens AG*, *Bosch AG*, *Bayer*, *Mannesmann*, *AEG*, *Thyssen*, and many others.

The system that allowed them to become innovative, leading global firms has endured and was adapted over time to maintain their dominance in manufacturing, and hence in the machinery, tools, automotive, and electrical engineering industries. As it is shown later in this study, however, their shift has been towards more incremental, rather than the radical innovations that they pioneered during the 'second industrial revolution'. In the period after 1950, and particularly after 1980, Germany lost its preeminence as a global leader in generating radical innovations, by failing to contribute to the sectors that defined the 'fourth industrial revolution'. Many of the innovations which were driving this new industrial revolution, such as in ICT, originated from outside Germany, in particular from countries such as the United States, Japan, and South Korea.

The examples given in the text and in Table 1 reflect the close cooperation between higher education and industry that was established during the period 1871 to 1913. This 'organizational' innovation was complemented by further organizational changes in the German industry, such as the establishment of cartels ('Interessengemeinschaft') that fixed prices and market shares, and which, according to Watson (2010), helped to fund the R&D activities undertaken by the growing industrial companies. The extent of privately funded R&D activities increased substantially and led to the establishment of various private research laboratories. One of these research labs, of *Bayer*, held around 8,000 patents by 1913 (Meyer-Thurow, 1982).

The third partner in the emerging innovation system after 1871 was the government. Not only did the national and state governments (i.e. the 'Länder') support universal education, but they also played what many considered the igniting role in Germany's industrialization through the promotion of the country's railway system (Fohlin, 1998). The railways created a large demand for steel, engines and machinery, but also for coal and coal-based energy (of which the country had plenty), and helped, in turn, to reduce transport costs, and hence improve the competitiveness of all industries and trade (Kopsidis and Bromley, 2016). By 1913 the largest employers in Germany were state-owned enterprises such as the *Prussian-Hessian Railway* (employing more than 500,000 workers) and the *Deutsche Reichspost* (employing more than 300,000 workers) (Labuske and Streb, 2008). Since a degree was a requirement for many government job, the higher education system experienced a huge boost, and confirmed its importance as a central pillar of the development of the economy and the civil society.

Mechanical engineering and specifically machinery manufacturing received an important impetus from the establishment of the railways, and at the same time, from the emerging innovation system. As a result, Germany was able to expand into international markets. Labuske and Streb (2008) find a significant impact of innovation (as measured by R&D expenditure) on the development and export growth of the machinery industry between 1870 and 1913. By the latter date, the exports of machinery were the single largest category of exports from Germany, and the country was the world's largest exporter of machinery. The beginning of Germany's manufacturing export model is thus to be traced back to this era.

The machinery industry was also highly innovative, with half of the most innovative firms of that time located in this sector (Labuske and Streb, 2008). Many of them are still prominent in Germany, for instance the *Heinrich Lanz AG*, producing agricultural machinery (taken over in the 1950s by *John Deere*), *Demag* (*Deutsche Maschinenbau-Aktiengesellschaft*) producing industrial cranes, *Rheinmetall AG*, producing automotive parts and weapons, and the *Bosch AG*, the largest producer of automobile parts. In 1890 the *Deutsch-Österreichische Mannesmannröhren Werke AG* was established to produce steel pipes. This company would develop into the industrial conglomerate *Mannesmann AG* that was taken over in 2000 by *Vodafone* for EUR 190 billion, the largest amount ever paid in an acquisition in Europe until that time.

More generally, the creation of the German Empire in 1871 centralized government and further increased economic freedom and entrepreneurship that had already started in the late 18th century, through the diminishing control of various industrial and trade guilds that were stifling competition and innovation (Ogilvie, 1996; Kopsidis and Bromley, 2016).[9]

Although some state governments granted patents from around 1812 onward, it was only in 1877 that the first Germany-wide (unified) patent legislation was enacted by the new centralized government. This was important in terms of creating incentives for research, and also of creating a tradable market of innovations to facilitate technological transfer[10] and improve the allocation and distribution of technology (Meyer-Thurow, 1982; Burhop and Wolff, 2013).

It should be noted that woeful events also affected the government's capacity to foster innovation and growth. France repatriation payments (around 5 billion Francs) after the Franco-Prussian War led to a huge inflow of money into the newly established German Empire in the years after 1871. The government, repaying loans to entrepreneurs and

[9] Ogilvie (1996, pp.286-287) describes the depressing impact of the guilds on innovation by explaining how 'the Remscheid scythe smith's guild successfully resisted the introduction of water-driven scythe hammers in the 18th century'. The guilds were an outcome of the Thirty Years' War which 'forced German Princes to grant and enforce privileges to powerful institutions and groups [...] in exchange for fiscal, military and political support'. They 'prevented the emergence of industries in the period between 1600 and 1800' (ibid., p.297).

[10] As noted by Burhop and Wolff (2013) the trade in innovations, as measured by patent assignments, increased by 500 percent between 1889 and 1913.

businesses that had supported it to finance the war, reinvested these funds on a massive scale to commercialize innovations and invest in the expansions of the railways. As Watson (2010, p.374) notes 'as many new iron works, blast furnaces, and machine-manufacturing factories were built during the three years after 1871, as had come into being during the previous seventy'.

After the creation of the German Empire, corporate legislation was introduced to allow joint stock companies for the first time. This had a decisive influence on the financing of innovation and industrialization, but only towards the end of the 19th century, when big joint stock credit banks such as *Deutsche Bank*, *Dresdner Bank*, and others were founded (Burhop and Wolff, 2005). As Fohlin (1998) shows, it was not the big credit banks or security-issues that funded industrial expansion during the initial stages of Germany's industrialization, but largely own funding, credit-cooperatives, and (outside of Prussia) funding by private bankers that funded entrepreneurial ventures, and the states that funded the expansion of the railways (Edwards and Ogilvie, 1996). The banking system as a whole developed in tandem with the industrial sector during the late half of the 19th century.

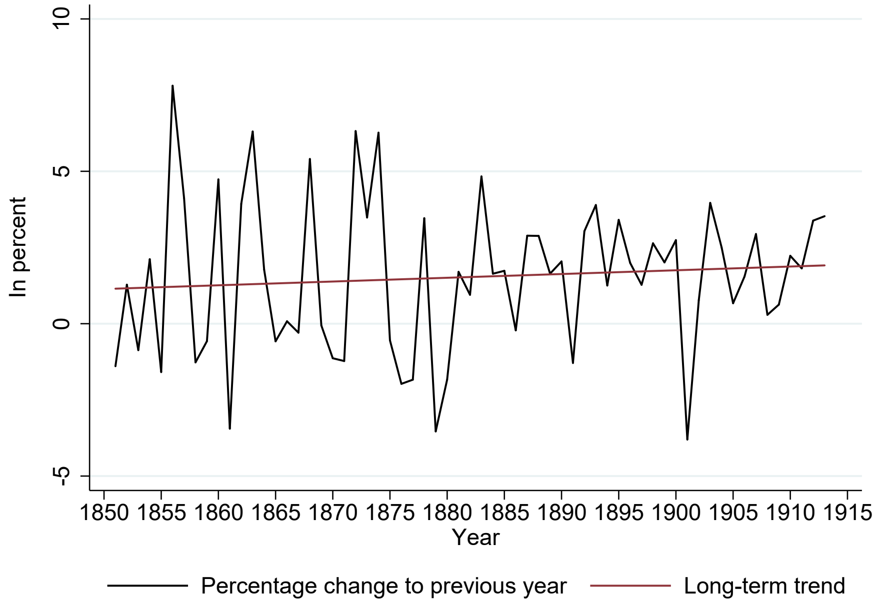
Finally, an important 'social innovation' during the German Empire was the establishment of the world's first welfare state (the German 'Sozialstaat'). This was deemed necessary for social stability, and moreover a political *stratagem* to ward off the rising socialist movement. The provision of these measures, which included health care and maternity insurance (introduced in 1883), insurance against work injury (1884) and old-age pension (1889) contributed to social inclusiveness. Williamson (1995) concludes that income inequality hardly changed in Germany during the period 1850 to 1913 despite the rise in top incomes, resulting in part from the fact that wages of low-skilled workers increased faster than in other industrial countries.

As indicated in Figure 3, using the HDI, incomes, literacy, and life expectation all improved significantly, showing that growing industrial production and a higher net national product were accompanied by an increasing HDI. Moreover, as Figure 4 shows, economic growth accelerated during this period - which is in stark contrast to the post-1950 period when growth decelerated.[11]

The lesson of this period was that technological innovations, supported by appropriate social protection, could be consistent with fast economic growth that was moreover inclusive - it did not lead to growing income inequality, and instead strongly contributed to human development, as measured for instance by the HDI, for the population in general.

[11] Although income inequality remained stable and the HDI improved during this period, the country still faced many social ills, including the use of child labor and urban poverty.

Figure 4: Per capita GDP growth in Germany, 1850 to 1913



Data source: Maddison Project.

3.2 The period of the 'Wirtschaftswunder', reunification and declining innovativeness, and rising inequality: 1950 to 2015

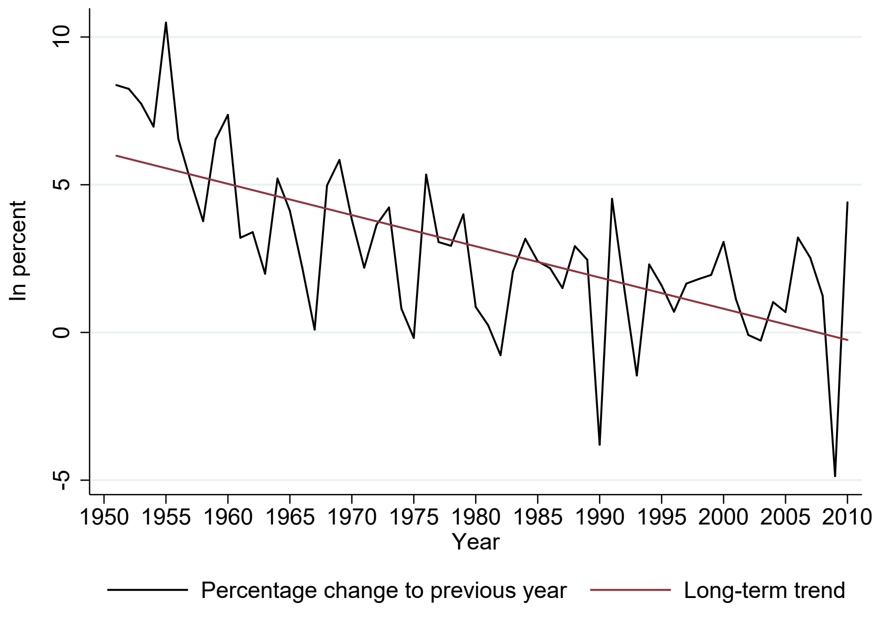
Between 1914 and the creation of the Federal Republic of Germany with its Constitution in 1949, the economy and its institutions were devastated by the two World Wars. Despite these, many of the pillars of the German Empire, including numerous 19th-century corporate giants and scientific and educational institutions, survived. Under the pressure from the Allied Forces occupying Germany after the Second World War, the *Kaiser Wilhelm Institutes* were renamed *Max Planck Institutes*. Moreover, the Allied Forces limited their mandate to basic research (Comin et al., 2016). To fill the gap in the former 'triple-helix' landscape, the *Fraunhofer Society* (*FhG*) was established in 1949. The *FhG* nowadays consists of a number of research laboratories that conduct applied research and industrial innovation for improving the competitiveness of industry (Beise and Stahl, 1999). Despite its prominence, only a relative small proportion of total R&D in Germany is allocated to the *FhG* (about 2.5 percent of all R&D in 2010).

Grupp et al. (2005) depict the historical innovation patterns in Germany from 1850 until 2000. They use total scientific expenditure as a percentage of total government expenditure as an indicator for innovation. Scientific expenditure includes R&D, training and teaching costs, and the costs of maintenance and diffusion of knowledge. The authors find that innovation expenditure increased during this period from around 1 percent in 1850 to a maximum of 6.5 percent in the 1970s, before declining to approximately 5 percent at the time of German reunification. R&D expenditure only amounted to 2.4 percent in 2004 (see also Figure 9 in Section 4.2). When comparing this trend with data on TFP growth for the post-war period (there is no TFP for the pre-war period), it can be seen that TFP growth peaked in the 1970s after which it declined.

Accompanying this decline, Germany has also experienced a decline in manufacturing employment and in the share of manufacturing in GDP. The extent of this de-industrialization process, however, has not been as significant in Germany as, for instance, in the United States, where more than 5 million jobs in manufacturing were lost between 2000 and 2014 (Dauth et al., 2017a).

Economic growth accelerated in terms of per capita GDP over the period 1850 to 1913. Between 1850 and 1869 average annual per capita GDP growth amounted to 1.6 percent. Between 1870 and 1899 it increased to an annual average of 2.5 percent, and in the period 1900 to 1913 accelerated even further to 2.8 percent (see Figure 4). In contrast, the period 1950 to 2010 experienced a deceleration of per capita economic growth. Initially though, between 1950 and the mid-1970s, average annual GDP per capita growth amounted to 5.0 percent on average. During this period the German economy was described by the term 'Wirtschaftswunder' (economic miracle). Growth was driven by the reconstruction of the country under the *Marshall Plan* and the introduction of social-market policies, including the model of 'Mitbestimmung' (co-management) in which workers obtained representation in the board of company directors (Comin et al., 2016). Growth, however, subsequently declined to an average of 2.0 percent between 1975 and 1990, and further to 1.0 percent between 1990 and 2010 (see Figure 5). During this latter period Germany was even called the 'Sick Man of Europe'.

Figure 5: Per capita GDP growth in Germany, 1950 to 2010



Data source: Maddison Project.

Audretsch and Lehmann (2016) point out that even before the unification German 'competitiveness began to sag', and that while everybody had expected a 'peace dividend' after the unification and end of the Cold War, this never materialized, because the reunification process was accompanied by a negative shock to labor productivity. This was a result of the re-integration of workers from the former East Germany, whose productivity were 40 to 70 percent of that of West German workers. This negative productivity shock occurred just as the country was 'exposed to new global competition' at the end of the

Cold War (ibid., p.4).

What have been the reasons for the secular decline in productivity in Germany since the 1970s? Most scholars point to the nature of the innovation system. According to Breznitz (2014), the German innovation system 'got stuck' at producing primarily incremental innovations in existing (and old) industries, rather than radically innovating and creating new industries and markets. Meyer-Thurow (1982) states that a major goal of R&D expenditure by individual companies was to prevent new firms of entering the market, and hence keeping competition out, rather than to create new markets. Erixon and Weigel (2016, p.59) describe the strategies of large German corporations as being essentially 'defensive', and that they 'favor the allocation of resources according to a rentier formula; and it crowds out innovations'. As an example, Meyer-Thurow (1982, pp.380-381) can be quoted, who conducted a case study of the pharmaceutical giant *Bayer AG* and concludes that the company's innovation system was,

> '[e]xtremely effective at maintaining and extending the company's superiority whenever it had established itself in the market [...]. But when Bayer tried to break into markets established by other companies or break new technical and scientific ground, industrial research proved less effective [...] industrial research was not a master key to entrepreneurial growth.'

Not only was incremental innovation the choice of strategy of the large corporate giants, but also of the *Mittelstand*[12], although for different reasons. The model of incremental innovation is part of the strategy of the *Mittelstand* to remain internationally competitive on the basis of quality, not costs. Today more than 70 percent of Germany's exports are from *Mittelstand* firms. German firms therefore continuously innovated to improve their existing products and services, but not to introduce novel products *per se*. This focus on quality has been described as a 'razor-thin focus on just a single product' (Girotra and Netessine, 2013). As Fear et al. (2015, p.12) explain,

> 'By and large, German companies are not pioneering leaders in basic innovations [...] rather they demonstrate technological excellence by applying basic innovations to solve customer-specific needs, and in the meticulous and customer-driven perfection of traditional products.'

By combining incremental innovation to produce specific products of exceptional quality and a focus on customer needs, in the context of a growing globalization of the world economy in the 20th century, the international export focus provided these *Mittelstand* firms with the possibility to make use of economies of scale. Over time, many of these firms

[12] The term *Mittelstand* refers to the small- and medium-sized enterprises that form the bulk of manufacturing enterprises in the country. They have a number of characteristics in common, which are referred to as 'enlightened family capitalism', such as family (private) ownership, long-term orientation, social responsibility, and an excellent focus on customer care (Fear et al., 2015, p.13). Most *Mittelstand* firms have historically clustered around the traditional late 19th and early 20th century giants of the German economy such as the automotive, machine engineering, electricity, and chemical industries. Many of these firms were also founded during this era, or even before.

became world leaders in their field, being described as Germany's 'hidden champions' (Simon, 2009). In 2015, the top 20 'hidden champions' had a turnover of over EUR 7 billion and employed more than 72,000 workers (see Table 3 in the Appendix). Fear et al. (2015) argue that the success of *Mittelstand* firms is not so much driven by their innovative abilities, as by doing 'good business': their focus on customer needs and quality, reliable products, and services.

Thus, while Germany today is a leader in traditional and medium technology industries such as automobiles, printing press and machine tools, it is not an innovation leader in semiconductors, computing, 3D-printing, nanotechnology, robotics or molecular biology - the drivers of what has been termed the 'fourth industrial revolution' or 'Industrie 4.0'[13] (Mroczkowski, 2014). Data from the World Intellectual Property Organization (WIPO) show that only four German firms are among the top 30 innovative companies in the areas of 3D-printing, nanotechnology and robotics, as measured in terms of patent applications. Three of these are in 3D-printing, namely *Siemens*, *MTU Aero Engines* and *EOS*; and one in robotics, *Bosch* (WIPO, 2015). Increasingly, German firms lag behind those from the United States, Japan, South Korea, and also China. The WIPO (2015) notes that 25 percent of all patent applications in 3D-printing and robotics, and 15 percent in nanotechnology have been made by Chinese firms since 2005. Moreover, the top 20 patent applicants in nanotechnology do not include a single German firm since 1970.

This section concludes that the weakening of Germany's innovativeness, from a world leader in breakthrough innovations to a country where incremental process innovations dominate, makes inclusive growth more difficult to achieve, particularly given slow growth in domestic demand and the imperative to remain internationally competitive. Hence, policy measures have been taken to reduce the real cost of labor in order to improve the competitiveness of the economy and to reduce pressure on fiscal resources. Whereas in the past technological innovation has promoted inclusive growth, it is becoming less effective. The following section documents the decline in German innovativeness in more detail.

4 Documenting the decline in German innovativeness

This section documents and substantiates the conclusion that the innovativeness of the German economy has declined over the past half century. This conclusion may appear counter-intuitive given that Germany's investment in stimulating technological innovation is large and growing. For instance, in 2014 the country spent more than EUR 80 billion on R&D, an increase of 66 percent since 2000. Various pieces of evidence are presented, using different measures of 'innovation', to show a consistent picture of Germany as a country that is generating less and less effective innovations, despite channeling significant amounts of investment into this sector.

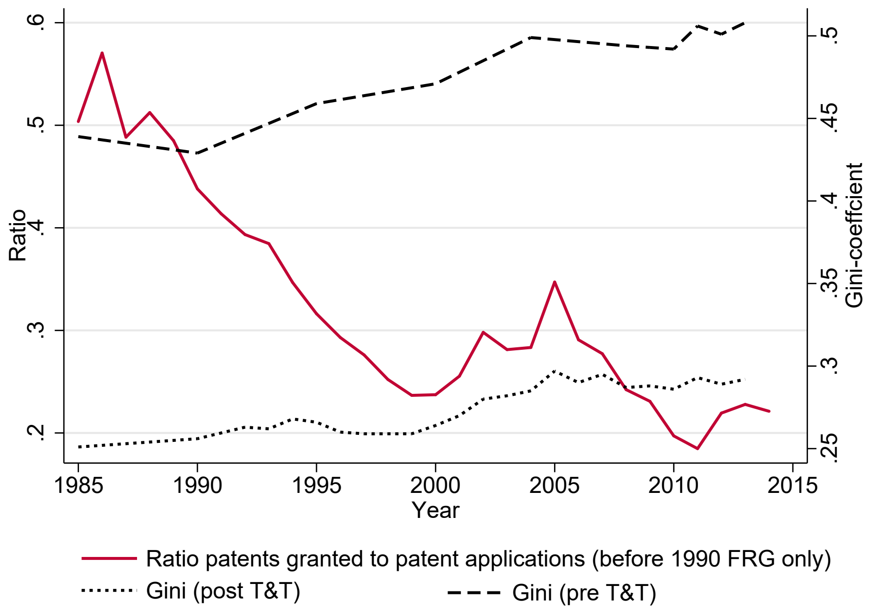
[13] The term 'Industrie 4.0' is ascribed to Henning Kagermann, head of the German Academy of Science and Engineering (Acatech) (The Economist, 2015).

4.1 Exhibit 1: A growing gap between applied and granted patents

This first piece of evidence is derived from patent data, an often used 'output' indicator of innovation. An important distinction is between patent applications and patents granted. The difference lies in the ratio of successful (granted) patents to patent applications, which is shown in Figure 6. In this respect, the figure indicates that the recent trend in Germany has been a reduction in the ratio of patents granted relative to patent applications.

In absolute terms the number of patent applications increased from around 43,100 in the mid-1980s (FRG only) to almost 66,900 in 2014, but the number of successful (granted) patents decreased from around 21,700 in the mid-1980s to only 14,800 in 2014. In other words, Germany has experienced a decline in the number of 'successful' innovations[14], which coincided with the period during which income inequality was increasing.

Figure 6: Ratio patent applications to patents granted and the Gini-coefficient in Germany, 1985 to 2014



Data source: WIPO (Patents) and OECD (Gini-coefficient). *Notes*: From the mid-1980s to the German reunification in 1990, only patent data from the FRG.

To the extent that the decline in successful (granted) patent applications reflects a decline in innovativeness, the broad reasons are discussed in the next section. It can be however noted that patents are far from being a perfect measure of innovativeness, and that some caution is warranted in making strong conclusions. First, because patent offices may be simply getting stricter, and second, because the growth in the number of patent applications might not be driven by quality. Instead they could reflect a legacy of the *Arbeitnehmererfindergesetz* (German Employee Invention Act), through which firms tend to apply for patents on employees' ideas, irrespective of whether they merit the effort or

[14] Germany also experienced a decline in the quality of its patents granted at the USPTO relative to the United States between 1980 and 2011 (Kwon et al., 2017).

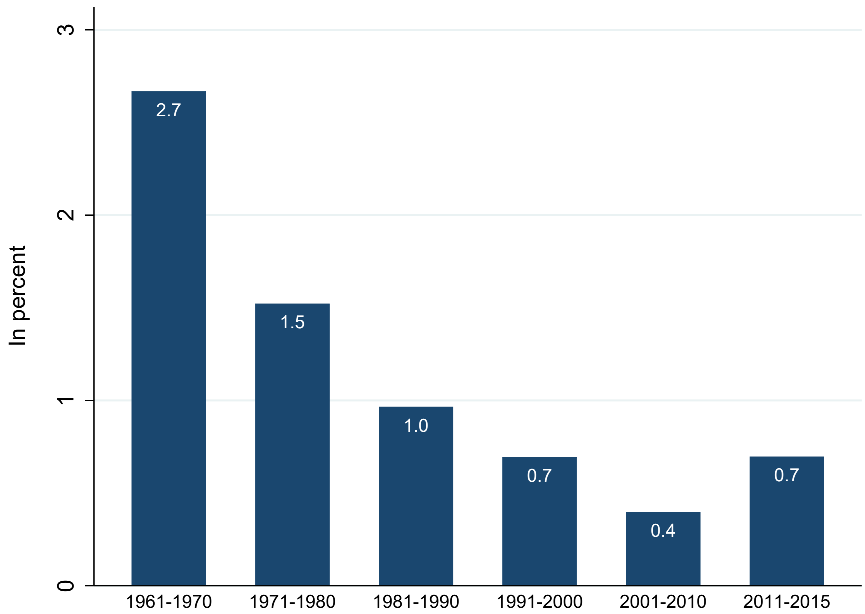
not.

4.2 Exhibit 2: Declining rates of growth in productivity

The second piece of evidence derives from data on labor productivity and total factor productivity. TFP growth has been declining in Germany since the 1970s, to a growth rate of only 0.5 percent *per annum* over the past ten years (OECD, 2016). As the OECD (2016, p.6) notes, TFP growth is on a long-term decline in Germany since the 1970s. Over the period 1996 to 2005 TFP growth in Germany averaged 0.4 percent, which puts it on the 34th position out of 37 OECD countries. Only Portugal, Italy and Spain did worse.

Figure 7 shows that German TFP grew annually by over 2.5 percent on average between 1961 and 1970. This growth declined over the subsequent decades, with the lowest annual growth rate experienced from 2001 to 2010, amounting to only 0.4 percent. Recently annual TFP growth has seen a moderate increase, rising to an average of 0.7 percent between 2011 and 2014, the same rate as in the decade from 1991 to 2000.

Figure 7: Average annual TFP growth in Germany, 1960 to 2015

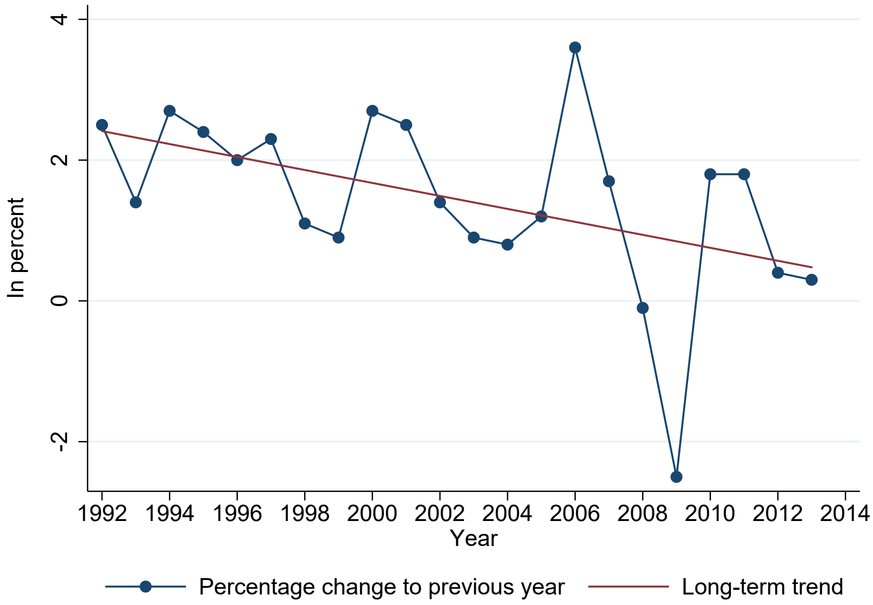


Data source: European Commission AMECO database online.

The 1960s were thus, at least measured by TFP, Germany's period of 'peak innovation', although there was no comparable list of breakthrough innovations as in the period from 1850 to 1913. The decline from the late 1970s onward, and especially since the 1990s, may be explained by a lack of radical innovations in the field of ICT (defining the 'third industrial revolution'), a slower diffusion of technology, and a slower capacity to learn and adapt new technologies, as the OECD (2016) posits - which may also reflect the relatively slower growth in high(er) skills in Germany over this period. Baumgarten (2013, p.5) finds that the 'German establishments invested more in technology during the 1980s than during recent years, showing that while 34 percent of firms invested in ICT in 1996, only 29 percent did so in 2010.' Thus, the decline in labor productivity occurred in spite of the rise the share of GDP spent on R&D. Innovation expenditure has become less effective.

Figure 8 further shows that the percentage change in real labor productivity per hour worked has been on a long-term decline since the 1990s. Labor productivity growth rates were five times lower in 2013 than in 1992.

Figure 8: Percentage change in real labor productivity per hour worked in Germany, 1992 to 2013



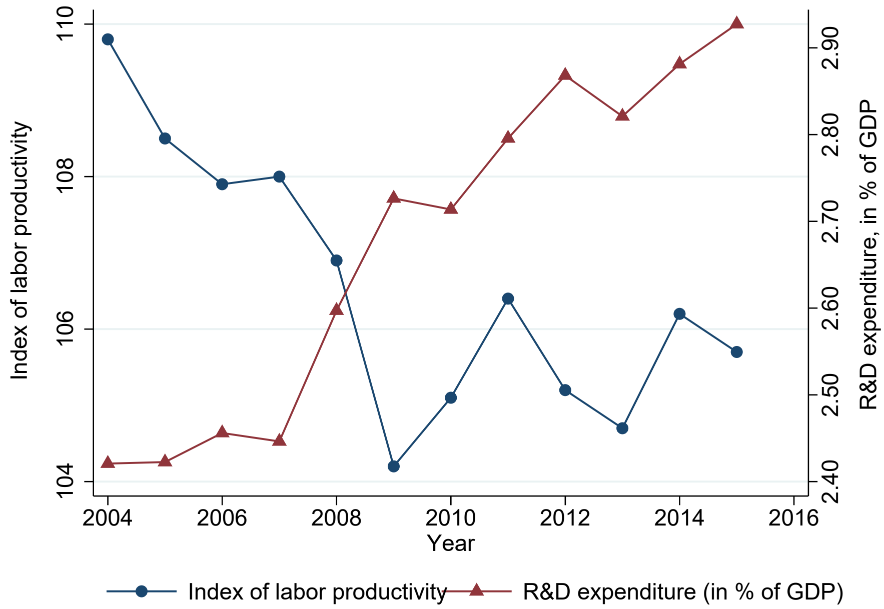
Data source: European Commission AMECO database online.

Figure 9 contrasts the index of labor productivity, showing that it has overall declined since 2004 (relative to the EU 28 countries), dipping after the Great Recession in 2008/2009, with R&D intensity, defined as the gross domestic expenditure on R&D, which increased considerably over the same period, especially since the mid-2000s, peaking at almost 3 percent in 2014.[15] The figure makes clear that R&D expenditure (innovation), since 2004 at least, has not contributed to raising labor productivity relative to other European countries.[16]

[15] These declines in productivity are highly unlikely, as some have argued, to be due to mismeasurement of the value-added effects of ICT technologies. Syverson (2017) contrasts these arguments, concluding that '[f]or the mismeasurement hypothesis to explain the productivity slowdown [...] current GDP measures must be missing hundreds of billions of dollars in incremental output'.

[16] Bloom et al. (2017, p.46) similarly find that research productivity declined in the United States over the period 1930 to 2000, stating that '[j]ust to sustain constant growth in GDP per person, the US must double the amount of research effort searching for new ideas every 13 years'.

Figure 9: Labor productivity per person employed and R&D expenditure in Germany, 2004 to 2015



Data source: Eurostat (Index of labor productivity) and OECD (R&D expenditure). *Notes*: Nominal labor productivity per person employed and hour worked (EU28 average=100 in each year).

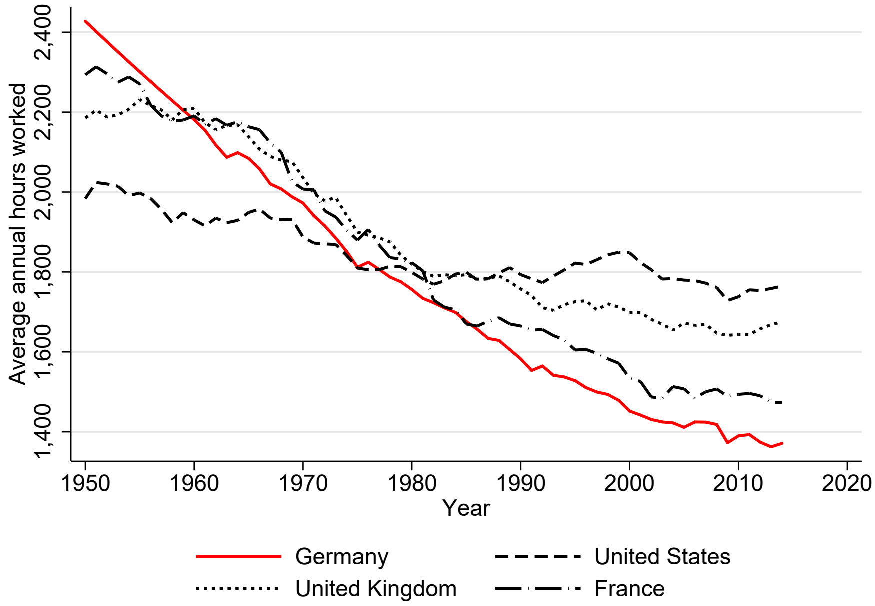
4.3 Exhibit 3: Labor hours worked, productivity and labor compensation

Since 1950 the annual hours worked by the average German worker declined from just over 2,400 hours to less than 1,400 by 2015. This decline has historical roots, having started already during the age of the German Empire.[17] In fact, Germany has experienced the fastest fall in annual average hours worked per employee compared to the United Kingdom, France, and the United States (see Figure 10). This sharp decline can be explained by the growing power of unions, by higher incomes (raising the value of leisure), and also by the low (and even declining) levels of inequality in Germany during the 20th century. The latter is an interesting point to make, given the conclusion by Huberman and Minns (2007), that hours of work will decline more rapidly in more equal societies, because of the lower opportunity costs of working more.

The decline in hours worked by the average worker in Germany is also based on increasing productivity over time, which was made possible by technological innovation and capital investment. This is why, even though average annual hours worked considerably declined over the past decades, employment and wages have grown. Wages, however, have grown increasingly slower over time, and furthermore less than labor productivity. This is inconsistent with a situation in which robots replace humans in the workplace. In fact, labor productivity growth has been slowing down. Hence, as Yglesias (2015) points out, '[i]f robots were taking our jobs, the productivity of the workers who still have jobs would

[17] In 1870 the average worker worked for almost 68 hours per week in Germany. By 1913, this amount had fallen to 57 hours, and by 2000 to only 41 hours (Huberman and Minns, 2007).

Figure 10: Average annual working hours, 1950 to 2014



Data source: Penn World Table 9.0.

be going up rapidly. But it is not'. As Figure 10 and the previous section make clear, labor productivity is not increasing fast enough to lend credence to the idea that robots are taking over. Notably,Dauth et al. (2017b, p.1) find that there is 'no evidence that robots cause total job losses' in Germany, in spite of the fact that the number of robots per workforce in Germany exceeds that of the United States and other European countries.[18]

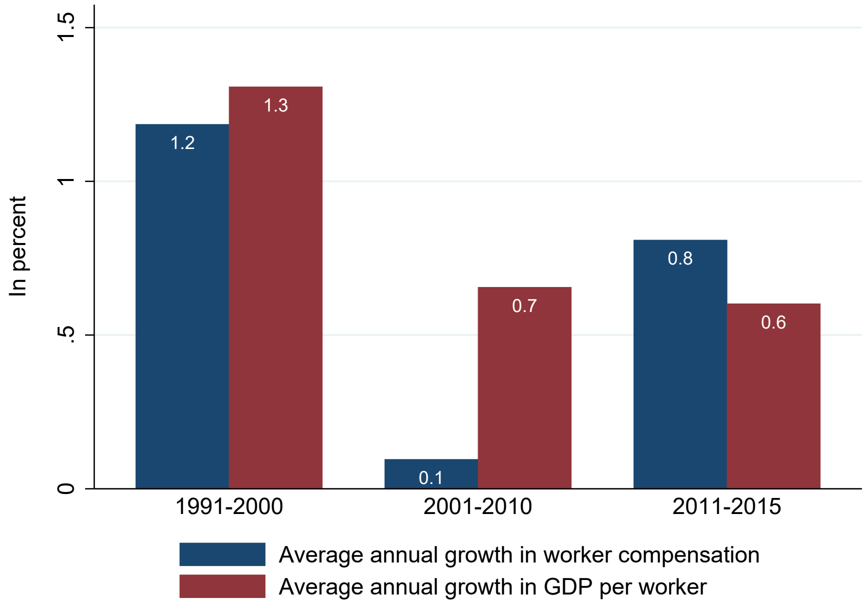
A final piece of evidence in this regard can be shown by comparing average annual growth in worker compensation with growth in GDP per worker (see Figure 11). Since 1991, GDP growth per worker has generally exceeded the growth in worker compensation - which means that a proportionately larger share was directed towards capital, consistent with the finding of higher income inequality over this period - except for the most recent period 2011 to 2015, when workers received proportionately more than their GDP share.[19]

The period 2011 to 2015 was also the period most intensely affected by the 'fourth industrial revolution' technologies (Industrie 4.0), such as robotics. Clearly, these technologies are not consistent with higher income inequality in the data (yet). This finding is in contrast to what would be expected if technological growth was 'too fast' for workers to adjust to, or if robots were indeed taking over people's jobs.

[18] The authors do find however that robots cause reduced employment in manufacturing: not through job losses for incumbent workers, but by restricting jobs for new labor market entrants. The robots, in contrast, even help incumbent workers to maintain their jobs (Dauth et al., 2017b).

[19] Based on OECD data, average wage growth was particularly low from the mid-1990s onward, and even 0 or negative during the 2000s. Only since 2010 has average wage growth started to rise again.

Figure 11: Average annual growth in worker compensation and GDP per worker in Germany, 1991 to 2015



Data source: European Commission AMECO database online.

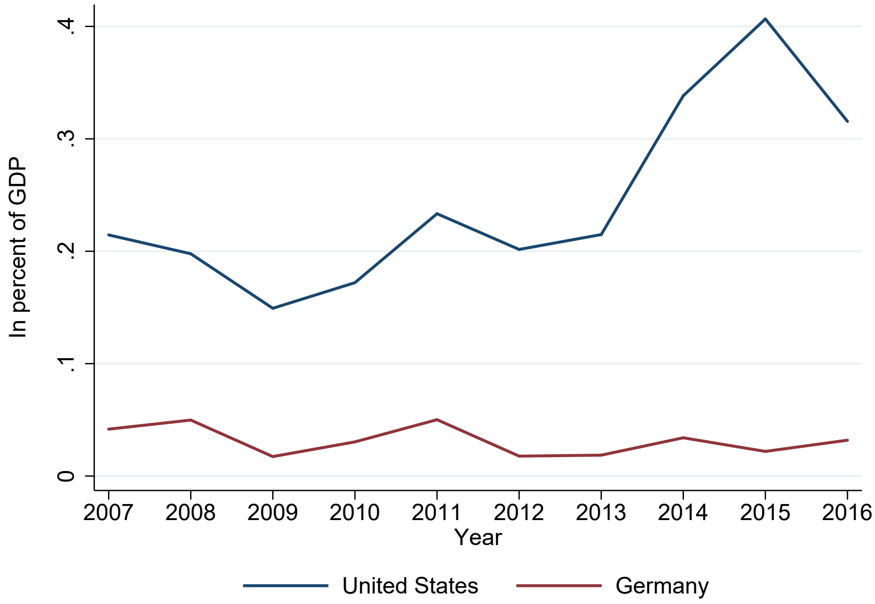
4.4 Exhibit 4: The relative scarcity of venture capital investment

Venture capital (VC) investment is sometimes used as an indicator of innovation, since it is generally employed to finance high-tech start-ups, particularly in the ICT industry. Fohlin (2016) describes how the VC market expanded in the United States in the late 1970s, in tandem with the ICT revolution. The location of VC investments also gives an indication of the location of innovative firms producing radical innovations. Florida and King (2016) estimate the total value of VC investment worldwide to USD 42 billion in 2012. Of this amount, only 13.5 percent was invested in Europe; and within Europe, Germany's share was relatively small, behind the United Kingdom, France, Denmark, and Russia. The authors report, for instance, that among the top 10 European cities for VC investment, there were only three from Germany (Berlin, Stuttgart, Munich), and that among the top 20 global cities for VC investment there was no German city at all.

Germany does not stand out in term of VC - on the contrary, it is in fact lagging behind, compared to the United States, China, and other emerging market regions. Consider, for instance, Figure 12, where VC investment is compared between the United States and Germany, in percent of GDP, between 2007 and 2016. The figure indicates that there has been a surge in VC investment in the United States since 2013, reaching more than 0.4 percent of the US GDP by the year 2015, which amounted to almost 20 times the proportion of VC investment in Germany.

In 2014, the VC investment in only two US city-regions (San Francisco and New York) was already 10 times the total VC investment in the whole of Germany. Other city-

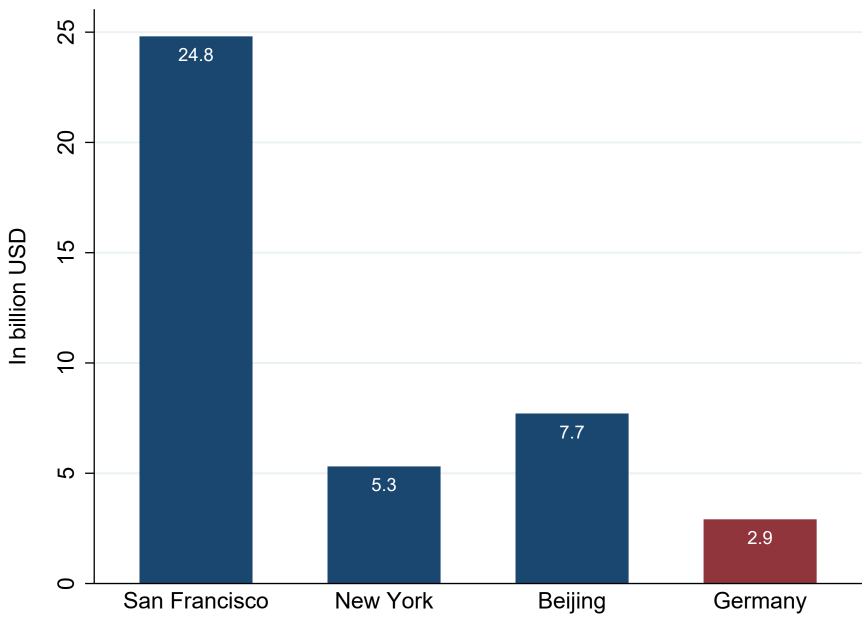
Figure 12: Venture capital investment in the United States and Germany, 2007 to 2016



Data source: Authors' own compilation based on data from Statista.

regions, such as Beijing, have also experienced more than double the VC investments compared to the entire country of Germany, as Figure 13 indicates. Moreover, according to EVCA data, the volume of investments by non-member companies in VC in Germany has declined from EUR 864 million in 2007 to EUR 607 million in 2014.

Figure 13: Venture capital investments in selected world cities and regions, 2014



Data source: Authors' own compilation based on data from Florida and King (2016).

Comin et al. (2016) consider the relative lack of VC in Germany a symptom of an 'innovation crisis', which the *Ifo Institute for Economic Research* in Munich had already identified two decades ago. Audretsch and Lehmann (2016, p.5) refer to *Der Spiegel* and *The Wall Street Journal*, describing Germany's computer chip, biotechnology and energy industries as 'disasters' by the 1990s. Comin et al. (2016, p.417) further describe how the 'Neuer Markt' (new market) for high-risk start-up finance collapsed, and how a host of government policies since 1989, intended to stimulate new emerging technologies such as biotechnology, was deemed to have largely 'disappointed' by 1998. The ROBO Global Robotics and Automation Index contains data on financial performance of 1,000 companies in the industry, of which only 4 percent are from Germany. The bulk of firms is from the United States (42 percent) and from Japan (30 percent).

5 The causes of decline in German innovativeness

Promoting itself as the 'Land der Ideen' (Land of Ideas), Germany invests heavily in stimulating technological innovation. Despite this investment and effort, the impact of technological innovation on labor productivity growth continues to decline. The previous section offered four pieces of evidence that individually and together strongly support the idea of a decline in the effectiveness of innovation. The question arises why the effectiveness of innovation has been declining in Germany - particularly, why has productivity been declining despite the rise in R&D spending? Only by understanding the causes of this decline can policy interventions be designed that have the potential to revive the contribution of technological innovation to inclusive growth.

Three main reasons are discussed in this section: first, the historical legacy and institutional context, as Germany lost a large portion of its intelligentsia during and after the Second World War; second, weaknesses in the education system; and third, entrepreneurial stagnation.

5.1 Historical legacy and institutional context

Fohlin (2016, pp.18-19) identifies the Second World War as representing a structural break in Germany's innovativeness, with a subsequent decline due to a combination of factors, including the destruction resulting from the war, the effects of the Cold War, the division of the country until 1990, and the subsequent costs of reunification. As a result of this particular combination, the author concludes that 'Germany could not pour large portions of its national resources into risky investments in research and development of new technologies'.

Germany also experienced a significant *brain drain*, when highly skilled labor fled the country during and after the Nazi period (Fohlin, 2016). The detrimental and long-run impacts of the human capital loss on Germany's skills are discussed in Moser et al. (2014) and Waldinger (2016). Moser et al. (2014, p.3222) document that '[b]y 1944, more than 133,000 German Jewish émigrés found refuge in the United States' and show that in the field of chemistry, for instance, their contributions made a significant impact on US patenting. Waldinger (2016) estimates that the dismissal of Jewish scientists, including eleven Nobel Laureates such as Albert Einstein, Max Born, Fritz Haber and Otto Meyerhof, from public institutions by the Nazis after 1933, had a long-term negative impact on scientific output. Furthermore, after the Second World War, the Allied Forces required research institutes to focus only on basic research, to the detriment of application and commercialization. As various historians point out: what disadvantaged Germany, advantaged the United States.

A further institutional feature that may have contributed to the decline in innovation, is the decline in unionization in Germany over the past three decades. In Section 6 the study later shows that unionization reached a peak in 1991, and subsequently declined. This may have contributed to the slower and poorer diffusion of technologies. In this regard Addison et al. (2013) find evidence that unionization has been beneficial for innovation in the past, because participation of workers in management helped with the facilitation of new technology adoption and diffusion. Over the more recent past, however, the power of unions has diminished.

5.2 Lack of diversity and innovativeness in the education system

The decline in innovation can also be found within the country's education system.[20] Two main problems are identified: first, the education system may be too specialized and intertwined with the current industrial structure; and second, the system may be 'un-entrepreneurial' and too bureaucratic.

One specialization of the German education system is rooted in the important role of manufacturing within its economy. Manufacturing value-added contributed 23 percent to GDP, and manufactures exports 84 percent to merchandise exports in 2016; 28 percent of its labor force was employed in industry, consisting of manufacturing, mining and construction 2015.[21] Iversen and Cusack (2000) point out that the reallocation of workers from manufacturing to services seems to have been easier in the United States, and argue that in Germany it is more difficult to transfer skills to another sector, because of the more specialist type of skills. Many skills in Germany are firm specific, especially in the typical *Mittelstand* manufacturing firms.[22] The challenge in Germany is thus the transferability of skills. The authors warn (ibid., p.346) that '[a] country like Germany with a training system that emphasizes specific skills will be politically more sensitive to occupational shifts than a country like the US where the educational system emphasizes

[20] The weaknesses of a generally much-praised education system have been reflected in the relatively poor and, at times, even declining rankings of Germany in global skills rankings. In terms of the Global Talent Index, for instance, Germany is ranked 16th in the 'Creative Class Ranking', 28th in the 'Talent Ranking', and only 38th in its 'Educational Attainment' (Florida et al., 2015). In the Global Index of Cognitive Skills and Educational Attainment Germany ranked 12th out of 39 countries in terms of 'Cognitive Skills', measured by Grade 8 PISA (Programme for International Student Assessment) Scores and Grade 4 PIRLS (Progress in International Reading Literacy Study) and TIMMS (Trends in International Mathematics and Science Study) achievements in sciences and mathematics, in 2014. The country's score in the 'Index of Cognitive Skills' declined from 0.56 to 0.48 between 2012 and 2014.

[21] Data source: World Development Indicators.

[22] 'Most skills acquired, in either manufacturing or in agriculture, travel very poorly to service occupations' (Iversen and Cusack, 2000, p.327).

general skills'.

As indicated in Table 2, Germany's tertiary education enrollments are relatively more concentrated or specialized than those of fellow OECD countries such as France, Italy, the United Kingdom, and the United States. In 2014, around 21 percent of all tertiary education enrollments were in engineering, manufacturing and construction programs, almost three times as much as in the United States, and twice as much as in France or the United Kingdom. In contrast, Germany has the lowest percentage of tertiary students enrolled in education programs in health and welfare, and in social sciences, in comparison to those countries. In the former, it has proportionately almost three times less students than the United States. In services study programs Germany also has relatively few students, at 2.15 percent compared to 7.01 percent in the United States. It is not *per se* a problem having many engineering students, it is rather the students missing in other fields that limit the ability of the labor market to adjust.

Table 2: Comparison of tertiary education enrollment by field, 2014

Percentage of students in tertiary education enrolled in 2014 in:	**DEU**	**FRA**	**ITA**	**GBR**	**USA**
Engineering, Manufacturing and Construction	21.00	11.93	17.03	9.20	7.65
Information and Communication Technologies	6.18	2.71	1.36	4.09	3.76
Business, Administration and Law	22.42	27.78	20.97	17.72	17.03
Natural Sciences, Mathematics and Statistics	10.20	6.51	6.71	14.59	6.03
Services	2.15	3.16	2.34	1.54	7.01
Arts and Humanities	13.48	13.33	15.24	16.12	17.47
Health and Welfare	6.94	15.91	15.53	17.00	18.24
Social Sciences, Journalism and Information	7.09	9.12	12.39	8.87	10.47
Agriculture, Forestry, Fisheries and Veterinary	1.58	1.14	2.63	1.04	0.64
Unspecified Fields	0.11	5.38	0.72	2.38	4.10

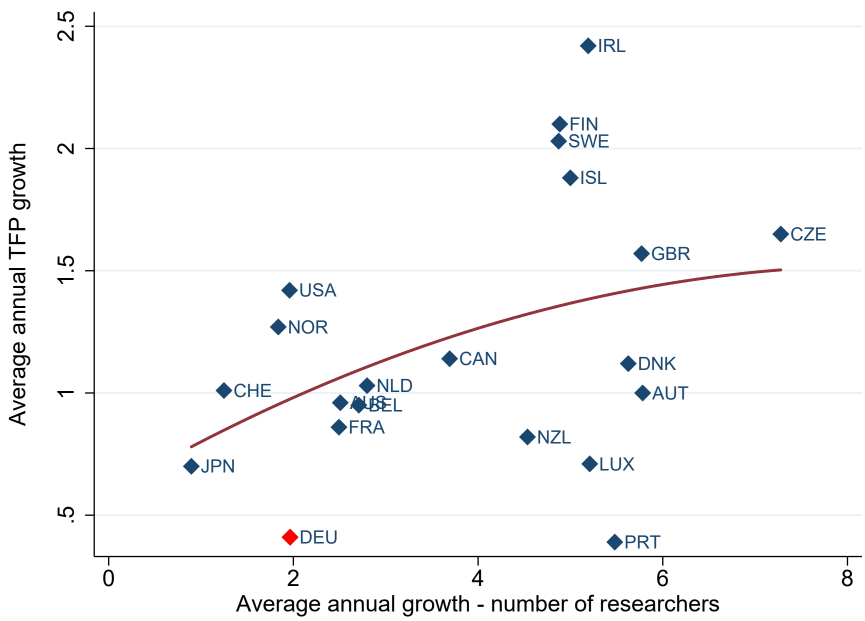
Data source: Authors' own compilation based on the UNESCO Education Database.

The overall conclusion from this table is that, in comparison to other high-income OECD countries where manufacturing has traditionally played an important role, Germany's tertiary student population is more heavily specialized in engineering and manufacturing until today. It is less diverse in comparison to the United States, where most students are in fields such as health and welfare, arts and humanities, business and law, and social sciences. Germany, however, also has proportionally more students in ICT technology programs than in any of these countries, which presents a potential positive attribute in terms of future labor market demands. It may result in better labor market matching if ICT jobs are less likely to be automated. It has been also argued, however, that it is precisely jobs in ICT, such as in programming and coding that can most easily be performed by computers rather than humans.

Due to the tendency to produce relatively more specific skills that are not easily transferable, the German government has increasingly *de facto* opted to encourage workers to exit the labor market through pension insurances (an expensive manner to deal with the challenge), as well as self-employment (labor market deregulation). The result of both was an increase in wage dispersion - and thus income inequality. In addition, it raised the uncertainty of employment, lowered the quality of jobs while increasing wage poverty, raised income inequality, and put the fiscal position of the state under pressure - the social welfare system relies heavily on transfers (Seeleib-Kaiser, 2001). This, overall, offers a possible explanation for the current 'malaise' and feelings of a divided society referred to in the introduction.

In addition to be relatively specialized, it is also suggested that the German education system is not able to keep up the 'production' and 'delivery' of the highly skilled workers that are needed in the R&D sector. Figure 14 plots the relationship between growth in the number of R&D researchers and TFP growth in selected OECD countries between 1996 and 2005. The figure shows that Germany had one of the lowest levels of growth in the number of R&D researchers - and, at the same time, one of the lowest TFP growth levels. Indeed, it is notable that the R&D intensity in manufacturing is lower than in Japan, the United States, France and South Korea, despite the importance of manufacturing for jobs and exports in Germany.[23]

Figure 14: Growth in R&D researchers and TFP growth in selected OECD countries, 1996 to 2005



Data source: Authors' own compilation based on data from Welfens (2015, p.480, average TFP growth data derived from the European Commission AMECO database online) and the World Bank Development Indicators online (Number of researchers). *Notes*: Growth in R&D researcher are from 1996 to 2005, with the following deviations: AUS, CHE (1996-2004); FIN, NOR, NZL, SWE (1997-2005); AUT (1998-2005); LUX (2000-2005).

Why has the education system not been more dynamic in the light of these weaknesses? The conclusion suggests that higher education has been relatively stagnant due to a lack of incentives to be innovative itself. Fohlin (2016, pp.19-20) points out that '[...] academics became government employees with neither the pressure of private incentives, nor the competition from private universities to spur research productivity'. Education

[23] As documented by Veugelers (2013), German manufacturers spend on average 8 percent of value added on R&D, compared to 12 percent in Japan, 11 percent in the United States, and 10 percent in France.

policy is fragmented across the 16 'Länder', the dual vocational system is difficult to enter, and is limited to 378 formal occupations; overall the education system is too much tailored to industrial needs (Malmer and Tholen, 2015). According to Mroczkowski (2014, pp.415-416), '[t]he country that invented the 'triple-helix', today is criticized for insufficient entrepreneurship and innovation, and for coddling university academics who are described as conservative, inward looking, and resistant to change'.

5.3 Entrepreneurial stagnation

A third broad reason for the decline in the effectiveness of innovation is what can broadly be described as entrepreneurial stagnation.[24] This does not refer to a general lack of entrepreneurship, nor of business firms in the economy. It means that entrepreneurship has not been as effective in producing and commercializing radical breakthrough innovations in recent times, as it was during earlier periods. The two main reasons for this phenomenon are(i) the 'defensive' corporate strategies and approaches of the large corporations and the *Mittelstand*; and (ii) a growing gap between high- and low-productive firms, reflecting discrepancies in management capabilities.

First, there is growing recognition that the essentially settled 19th century industries are dominant and entrenched, and have the potential to 'shift resources towards themselves' (Fohlin, 2016, p.19). As a result the focus has been on incremental innovations, resulting in a decline of the quality of technological breakthrough innovations.

Second, concerns have been rising that, more recently, a growing gap between leading and lagging firms has emerged in terms of innovation, with a resulting spread in firm level productivity. This occurs when the lagging firms cannot absorb the technology from leading firms, and moreover when lagging firms start to find it increasingly hard to innovate or benefit from innovations (Andrews et al., 2016). One of the outcomes of this rising productivity gap is greater wage and income inequality (Bloom, 2017).

The increase in the proportion of lagging firms is also reflected in a declining number of firms that invest in innovation[25], in the declining start-up rate of new firms since 1990[26], and in the small share of firms (only 1 percent)[27] that indicate that they are aiming to grow (Henrekson and Sanandaji, 2017).

Figure 15 depicts the growing gap in productivity between leading and lagging firms since

[24] Naudé (2016) argues that Europe is more generally in an 'entrepreneurship crisis', which is also echoed by Henrekson and Sanandaji (2017).

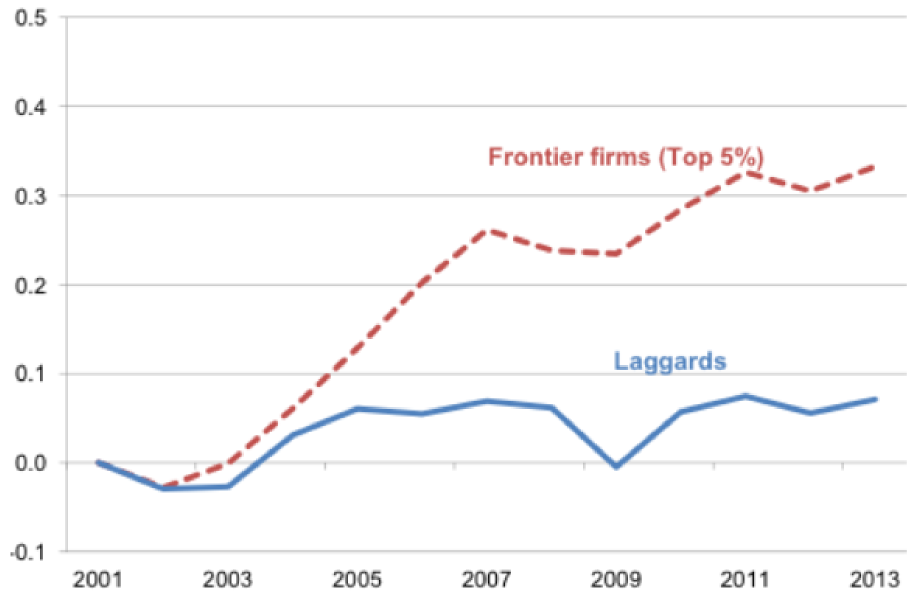
[25] According to data from the Mannheim Enterprise Panel, the Gini-coefficient for the proportion of firms with more than five employees that invest in innovation, increased from 0.88 in 1994 to 0.95 by 2013. This extreme level of inequality in terms of innovation implies that most firms in Germany invest nothing in innovation.

[26] Data from the Mannheim Enterprise Panel show that the index of start-up activity (measuring the proportion of new firm entry) in Germany fell from 120 to 60 between 1990 and 2013, a 50 percent decline.

[27] In comparison 3.6 percent of US firms indicate that they plan to grow, 3.9 percent in China, and 5.7 percent in Switzerland (Henrekson and Sanandaji, 2017).

the 1990s. This figure shows that '[b]etween 2001 and 2013, labor productivity at the global frontier increased at an average annual rate of 2.8 percent in the manufacturing sector, compared to productivity gains of just 0.6 percent for laggards'.

Figure 15: Widening labor productivity gap - labor productivity increase of frontier vs laggard manufacturing firms (value-added per worker, in percent) in the OECD, 2001 to 2013



Data source: Andrews et al. (2016) based on the recent update of the OECD-Orbis productivity database (Gal, 2013). *Notes*: The global frontier is measured by the average of log labor productivity for the top 5% of companies with the highest productivity levels within each 2-digit industry. Laggards capture the average log productivity of all the other firms. Unweighted averages across 2-digit industries are shown for manufacturing firms, normalized to 0 in the starting year. The time period is 2001 to 2013. The vertical axis represents log-differences from the starting year: The frontier in manufacturing has a value of about 0.3 in the final year, which corresponds to approximately 30% higher in productivity in 2013 compared to 2001. See details in Section 3.3 of Andrews et al. (2016).

The European Commission (2017) shows that existing evidence suggests that the impact of research and innovation (R&I) investment on productivity growth[28] has been declining in general in Europe, and not just in Germany. It ascribes this as due to 'obstacles to the diffusion of innovation from productivity-leading companies' (ibid., p.4). Hence, a lack of technology diffusion may be contributing to both the decline in productivity and the rise in income inequality. Between-firm pay inequality might therefore present one reason for growing income inequality in Germany. As Erixon and Weigel (2016, p.235) put it, 'a factor of rising inequality is that people work for the wrong firms'.

This lack of technology diffusion among firms, and the resulting polarization in labor productivity between leading and lagging firms, might be due to, among other factors, the relatively poor management practices in German firms, especially in *Mittelstand* firms[29].

[28] The European Commission (2017, p.3) reports that a 10 percent increase in R&I investment has been associated with an improvement in productivity of between 1.1 and 1.4 percent in the past, but that this relationship seems to be breaking down.

[29] Cooper et al. (2017) suggest another (related) reason, namely that the greater labor market flexibility introduced by the Hartz reforms which has helped the country maintain high employment rates has done so at the price of delining firm productivity. The reason for this is that the specific practice of 'short-time work' has hindered the reallocation of workers from less to more productive firms.

Broszeit et al. (2016) find, using the German Management and Organizational Practices (GMOP) data set, that(i) German firm level productivity lags behind that of US firms; (ii) a relatively wide productivity dispersal between firms exists; and (iii) a possible explanation for this finding lies in the poor management quality (on average) in German firms. Specifically, a poorer management quality means that firms have less absorptive capacity to learn from firms at the technological frontier. The authors conclude that this shortcoming is particularly a problem for the *Mittelstand*, since '[g]iven the comparatively low level of management scores for these types of establishments, there is substantial potential for catching up' (ibid., p.28).

What are possible reasons for the comparative lack of management quality in Germany? According to Fohlin (2016, p.21), this may reflect the lack of business school education in that 'the post-war German education system provided essentially no counterpart to the United States' business school education'. It may also reflect a lack of quality and quantity of entrepreneurship.

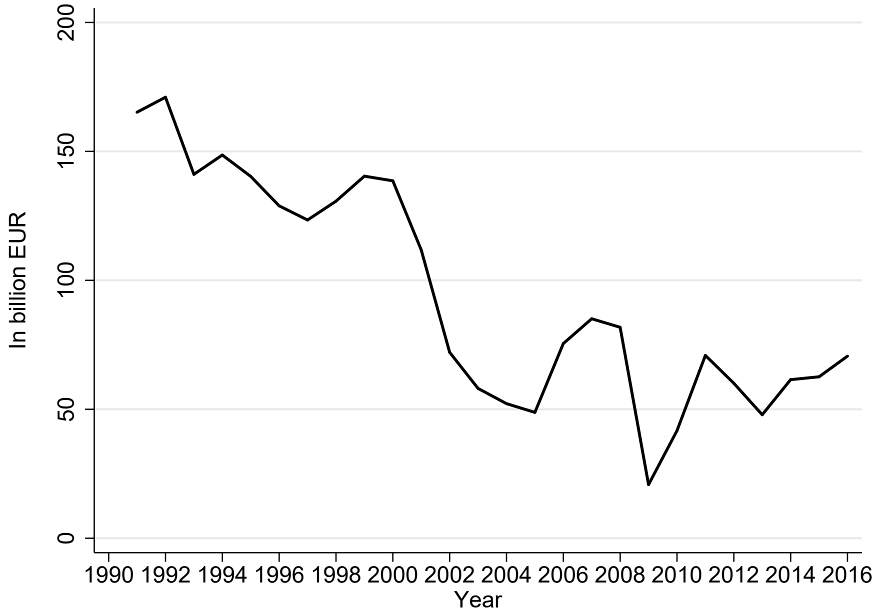
Other potential reasons are the dominance of large firms in comparative 'old' industries (e.g. machinery, automobiles, and energy) and the lack of venture capital (European Commission, 2017). Andrews et al. (2016) further identify a 'decline in the contestability of markets' as one of the reasons for the slower diffusion of technology. The authors recommend competition policy to address this shortcoming. Watzinger et al. (2017, p.4) argue in their study that competition policy is beneficial for innovation, citing the example of *Bell Labs* in the United States, and concluding that 'antitrust enforcement can have an impact on the long-run rate of technological change [...] the anti-trust lawsuit led to a quicker diffusion of the transistor technology, one of the few general purpose technologies of the post-World War II period'. Finally, as Erixon and Weigel (2016, p.27) note, fixed capital investment in the economy has declined 'pretty dramatically', and given that technology diffuses through the economy embodied in capital investment, this presents one reason for the slower diffusion of technology. In Figure 16 the precipitous decline in net fixed capital investment in Germany since 1991 is depicted.

In conclusion, entrepreneurial stagnation in Germany is characterized by the defensive strategies of large incumbent firms and poor management practices. These result in a decline in fixed capital investments and in the ability of lagging firms to learn from and catch up to leading firms. Inadequate competition allows lagging firms to survive, instead of pushing them out of the market, forcing larger firms to make capital investments to compete. As a result, the diffusion of technology has become sluggish, and with it labor productivity growth, too.

6 Declining technological innovativeness and rising income inequality

From the previous sections it can be concluded that the decline in technological innovativeness has caused labor productivity growth to stagnate, presenting a potential reason for the rise in income inequality. The link, however, is not direct nor

Figure 16: Net fixed capital investment (at 2010 prices) in Germany, 1991 to 2016



Data source: European Commission AMECO database online. *Notes*: Net fixed capital investment in billions of EUR.

automatic. In this section the study argues that slow productivity growth combined with demographic change has caused policymakers and the corporate sector to reduce real labor compensation, and thus erode the social welfare state. It is further noted that, unlike the United States, income inequality in Germany has not been caused by globalization or the financialization of the economy.

6.1 Demographic changes, demand stagnation and labor markets

Germany is characterized by low fertility rates and an aging population.[30] The average age of the German population increased from 38.3 years in 1991 to 41.8 years in 2009 (Fritsch et al., 2015), with more than 31 percent of households receiving pensions (Drosdowski et al., 2015). This demographic shift has and will have both direct and indirect effects on income inequality.

As a direct effect, aging can lead to more income inequality, because there are more pensioners (who have, on average, lower incomes)[31] and a reduced workforce (with

[30] This is generally the case for Western Europe. As the European Commission (2013) notes, by 2030 the EU-27 population will amount to approximately 522 million, of which 23 percent will be older than 65. UN-DESA (2015) estimates that 217 million people in Europe will be older than 60 by 2030. In Germany, an old and stagnating population means that the labor force will begin to shrink by 2025 to the extent that, all else equal, there will be between 3 to 6 million fewer labor market participants in 2050 compared to 2012 (Faik, 2012).

[31] Households on pension receive on average 18 percent less than the average household (Drosdowski et al., 2015).

higher wages due to scarcity). Whether this in fact occurs, and the extent of the impact, remains however questionable, and can only be settled empirically. A number of researchers have attempted to investigate this question in recent years. According to Drosdowski et al. (2015), 'most empirical findings so far show that income inequality increases with demographic aging'. Klemm and Weigert (2014) ascribe 10 percent of the rise in income inequality since the 1990s to aging. Drosdowski et al. (2015) study these questions using a macro-econometric input-output model that predicts more income inequality in Germany as the population ages, and in fact predicts accelerating income inequality after 2025 due to labor shortages. Faik (2012) similarly finds that demographic factors have been a significant determinant of income inequality, and that moreover the current trend in aging predicts 'a remarkable increase of German inequality until 2060' (ibid., p.1).

Households having children later in life and less stable marriages have accompanied this demographic trend; furthermore a significant increase in the number of single-parent households can be observed. According to the European Commission (2013), these changes in household structure explain 13 percent of income inequality in a country such as Sweden. In the case of Germany, Biewen and Juhasz (2012, p.629) find that the decline in household size and the increase in single parent households have had a 'moderate' impact on income inequality.

Evidence further shows that 'assortative mating' is having an effect in Germany. This term refers to the phenomenon where couples with relatively similar educational and skills levels marry. This phenomenon has been theoretically modeled and found empirically to drive higher income inequality over time (Fernández and Rogerson, 2001; Greenwood et al., 2014). Greenwood et al. (2014) find, using US Census Bureau data from 1960 to 2005, that 'assortative mating' has increased significantly; and moreover that it is a significant driver of income inequality, as predicted by models such as Fernández and Rogerson (2001). They find that in the United States the Gini-coefficient would amount to 0.34 instead of 0.43, if marriages were based on random matching instead of 'assortative matching' by 2005. Grave and Schmidt (2012) show, using German Microcensus data from 1976 to 2005, that 'assortative mating' has also significantly increased income inequality in Germany over the past three decades, contributing to wage polarization. Huber and Winkler (2016, p.3) find similar evidence for Germany, using data from the GSOEP covering the period 1993 to 2008. Their results show that 70 percent of workers 'have the same educational level and 15 percent work in the same 2-digit industry as the partner'.

The demographic determinants of income inequality in Germany have been pertinent to the country's debate on immigration. Most scholars concur that the recent influx may only have a short- to medium-term impact on meeting the requirements for skilled labor in the German economy (Drosdowski et al., 2015). It may, however, also lead to higher income inequality. The European Commission (2013) observes that migrants to Europe do not often bring the needed skills and are not always effectively integrated into labor markets. Hence, they are 'over-represented in low-skilled occupations and self-employment'.

Blau and Kahn (2012) point out that migrants may increase the supply of low-skilled labor, thereby reducing wages for all low-skilled workers, so that wage inequality rises. Card (2009) argues, using empirical evidence from the United States, that migrants tend to be concentrated in the 'tails of the skill distribution', i.e. they tend to be either low-skilled workers or highly skilled, so that an increase in a country's immigrant population may be accompanied by an increase in income inequality. Edo and Toubal (2015) therefore argue for selective immigration policies towards attractive highly skilled workers, coupled with flexible labor market arrangements. They find evidence from French data, between 1990 and 2010, that such a policy could reduce the relative wages of the highly skilled - i.e. reduce the skills premium, and hence lower income inequality.

Demographic changes can also, through the impact of reduced spending and higher savings, contribute to rising income inequality, if the government and corporate sector's response is to seek reductions in real labor compensation to maintain export competitiveness.

6.2 Erosion of the social welfare state

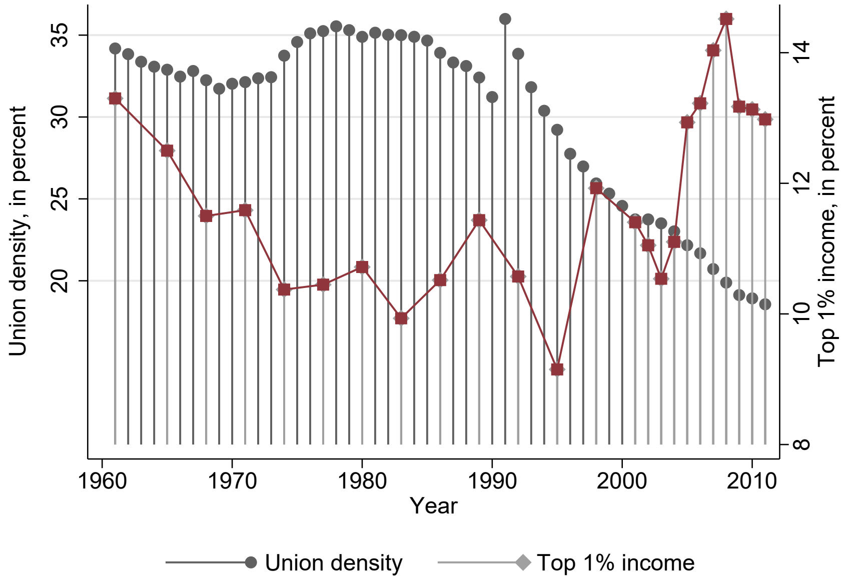
The erosion of the social welfare state can be traced back at least to the period following the oil crisis of the 1970s. Seeleib-Kaiser (2001) discusses the SPD's 'Ökonomisch-politischer Orienterungsrahmen für die Jahre 1975 bis 1985' (economic-political orientation framework for the years 1975 to 1985), which set out the claim that the social welfare state, established after the Second World War and underpinning the 'Wirtschaftswunder', was actually now threatening the international competitiveness of German firms. The unification process of the 1990s delayed many proposed welfare-state reducing policies (ibid.). Between 2002 to 2005 then, a series of fundamental reforms were implemented, the so-called Hartz IV reforms (Felbermayr et al., 2014). These reforms included various labor market reforms and further contributed to the decentralization of collective bargaining power since the late 1990s. As a consequence of these reforms, 'wage flexibility has increased sharply in Germany due to the documented decline of collective bargaining agreements' (ibid., p.37). As the The Economist (2017) points out, because workers in Germany value employment security to a large extent, they are willing to accept lower wage growth in return for employment security.

The decline in collective bargaining that followed the Hartz IV reforms is reflected in the decline in union density. Figure 17 shows that union density has significantly declined since its peak in the late 1970s, and moreover that it has been accompanied by a significant rise in income inequality, as measured by the share of income earned by the top 1 percent.

The falling union density is also inversely related to the 'in-work-at-risk-of-poverty rate', as Figure 18 shows. This suggests that one reason for the increase in income inequality can be located in the increase in the income share of the top 1 percent, and the simultaneous increase in the prevalence of the working poor, as low-skilled workers accept lower wages. In fact, the rate of working and being poor has almost doubled from 4.8 to 9.6 percent in Germany between 2005 and 2015 (OECD, 2016).

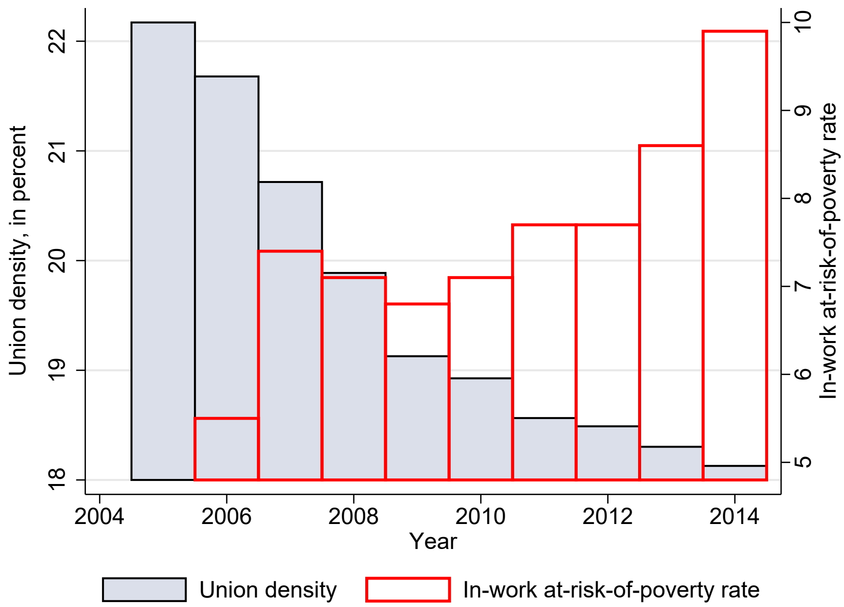
Between 1996 and 2010 the share of workers covered by industry-level wage agreements

Figure 17: Union density and top 1 percent income in Germany, 1960 to 2011



Data source: OECD (Union density) and World Wealth & Income Database (Top 1 share).

Figure 18: Union density and in-work at-risk-of-poverty rate in Germany, 2005 to 2015



Data source: OECD (union density) and Eurostat (in-work at-risk-of-poverty rate).

declined from 77 to 53 percent, and workers covered by any form of collective agreement from 82 to 62 percent (Felbermayr et al., 2014). According to Baumgarten (2013, p.5) this decentralization of wage bargaining has been one reason for the rise in wage inequality, because it decreased primarily the relative wages of 'workers in the lower part of the earnings distribution'. Felbermayr et al. (2014) point out that particularly wages in the 20th percentile have declined significantly, driving the widening of the skills premium.

Using data for the period 1996 to 2010, the authors decompose wage inequality and find that 50 percent of the increase in wage inequality can be explained by the decline in collective wage bargaining.

Figure 19 furthermore shows that since around 2000 the growth in profit rates has substantially exceeded the growth rate in labor compensation, meaning that the functional distribution of income will, *ceteris paribus*, worsen. It also shows the dramatic impact of the global financial crisis on profits, and the very fast recovery of profits afterwards.

Figure 19: Growth in gross profits and labor compensation in Germany, 1991 to 2015

Data source: European Commission AMECO database online.

In addition to the Hartz reforms which resulted in a reduction of social security benefits, a reduction in the top marginal tax rate from 53 percent in 1999 to 42 percent in 2007, was introduced (Biewen and Juhasz, 2012). The Hartz reforms were followed by an increase in self-employment in Germany, rising from 8 percent in 1991 to 11 percent of the labor force in 2009. The proportion of the self-employed in the service sector increased from 36 percent in 1991 to 53 percent in 2009. This was an important mechanism for reducing unemployment and for accelerating the structural shift in the German labor market, away from manufacturing towards more (skill-intensive) services (Fritsch et al., 2015).

More self-employment in a country is generally associated with higher income inequality. This is because the distribution of earnings among the self-employed tends to be quite diverse, with a few high-income earners and many low-income earners (OECD, 2011). Frick and Grabka (2009) indeed find that the self-employed in Germany are on average wealthier than wage-earners, with the average wealth of a self-employed person with more than ten employees amounting to approximately EUR 1,1 million in 2009; a sum that is approximately ten times higher than the average wealth of a wage earner.

6.3 Inequality is different in Germany than in the United States

Finally, before summarizing and putting forward some policy recommendations for inclusive growth in Germany, it can be pointed out that the patterns and determinants of income inequality are different in Germany with respect to the United States. The issue of rising inequality is very topical in the United States, and has been the subject of a growing literature, wherein the globalization and financialization of the US economy have been two of the major drivers of inequality. It can be asked whether or not these determinants may also be relevant for Germany. This sub-section shows that this is not the case. This has two implications: first, caution is advised in terms of avoiding financialization in Germany in future; and second, the predictions and analysis of the replacement of human jobs by robots, such as by Acemoglu and Restrepo (2017), are based on the US data and experience, and therefore perhaps not as relevant for Germany. Indeed a recent study from Germany does not show evidence that robots are causing total job losses in the country (Dauth et al., 2017b).

Since the mid-1970s the United States have experienced significant increases in income inequality, but also increases in unemployment and job polarization, especially in the manufacturing sector. Today the US manufacturing sector contributes only around 12 percent to employment, compared to roughly 23 percent in Germany. The reasons for this de-industrialization and the accompanying rise in wage inequality are largely due to globalization and the financialization of the economy. The impact of globalization occurred through the offshoring of manufacturing, which 'exported' jobs to China and other Asian countries (Baily and Bosworth, 2014). The financialization of the economy occurred as a result of financial deregulation, which drew away the 'best and brightest' from production into financial services, where relative wages started to outpace those in other industries since the late 1970s (Philippon and Reshef, 2012), and which contributed to the demise of labor unions and collective bargaining, and the rise of the shareholder economy (Lazonick, 2013; Lazonick and Mazzucato, 2013). Lazonick (2013) describes the term 'financialization' as the making of economic decisions that are not based on production considerations, but on (financial) share price information. In the United States resources have been massively diverted from physical production (manufacturing) towards the financial sector. This has generated higher income inequality, as it shifted income increasingly away from labor to capital sources.

The question can therefore be asked: are globalization and financialization also responsible for higher inequality in Germany? This study argues that this is not the case. On the contrary, globalization has had a positive influence on jobs and equality. As documented by Dauth et al. (2017a), employment in manufacturing declined much less in export-oriented industries - in fact, employment has remained remarkably constant since the 1990s in these industries. Germany manages a large trade surplus[32] on its current account, in contrast to the United States, which manages a large trade deficit. During the 1990s, furthermore, large German firms internationalized successfully by moving parts of their value chain to Eastern and Central European countries, thereby remaining globally competitive (Veugelers, 2013; Marin, 2016). Dauth et al. (2017a) also

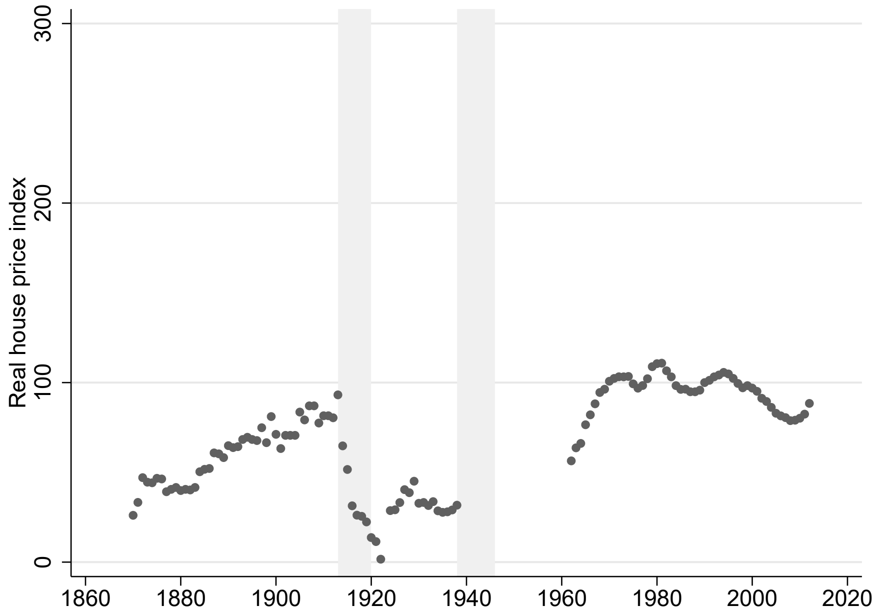
[32] Germany, in fact, has the largest trade surplus of any country, reaching a record of USD 300 billion in 2016 (Dubner, 2017).

find that the expansion of the service sector employment in Germany did not primarily occur because of workers re-allocating out of manufacturing, but rather because of new jobs being created for new labor market entrants and former unemployed workers. They conclude that (ibid., p.3),

> '[u]nlike in the case of the US, globalization therefore did not speed up the manufacturing decline in Germany, but it even retained those jobs in the economy.'

Financialization is also not a major contributor to income inequality in Germany. At present, the scale of financialization is not as extensive in Germany as in the United States and the United Kingdom. Since 2001 there has been a corporate de-leveraging in Germany following the abolition of government guarantees for *Landesbanken*[33], and a further de-leveraging after the 2008 financial crisis (Veugelers, 2013). The share of profits and property incomes in the gross national income (GNI) has remained stable, between 22 to 24 percent; and only 6 percent of the top 1 percent's income is derived from the financial sector (Niehues, 2015). Other authors point to the rather limited rise in the CEO compensation in Germany, due to the unique *Mittelstand*, wherein supervisory boards play an important part in corporate governance. The financialization of an economy often goes hand in hand with a property boom, which can be also ruled out in the case of Germany. As Figure 20 shows, real house prices have even been declining during certain periods.

Figure 20: Real house price index in Germany, 1870 to 2011



Data source: Figure and data taken from Knoll et al. (2017).

Although the financialization of the economy has not been a cause of rising income inequality in Germany so far, it has the potential of becoming more pronounced as a

[33] The Landesbanken are a group of state-owned banks of a type unique to Germany. They are regionally organized and their business is predominantly wholesale banking.

cause in the future. Caution is necessary, since there are indeed signs that financial capital sources of income are becoming more important (Dell, 2005; Frick and Grabka, 2009; OECD, 2011).

7 Summary, recommendations and concluding remarks

7.1 Summary

Technological innovation has been central to Germany's economic success. During the period 1850 to 1913 the country's economic rise, from an industrial 'backwater' to an industrial powerhouse, was made possible by a remarkable and historically unparalleled series of radical innovations. These included technologies such as the internal combustion engine, aspirin, radar, the diesel engine, and others. The provision of supporting social welfare, which was first introduced during this period, including unemployment and pension insurance, health and employment protection, helped to ensure that the growth sparked by these innovations was to a larger degree socially inclusive: income inequality did not increase and indicators of human development improved consistently. The technological breakthrough innovations of the late 19th and early 20th century moreover led to the rise of a number of firms that would become global household names. Firms such as *Siemens*, *Bosch*, *ThyssenKrupp*, *Bayer*, and *BASF*, were among those founded during this period. These firms and others would later provide a basis for the *Mittelstand*-led 'Wirtschaftswunder' of the 1950s and 1960s.

The 'Wirtschaftswunder', however, could not be sustained. Average annual growth per capita started to decline in the 1970s. In the post-war era, Germany's industries were largely focused on incremental innovations, rather than on radical innovations. In fact, the country lost its leading edge as a generator of radical innovations during the 'third industrial revolution', and was overtaken as a leading innovation country by the United States, and later by Japan and South Korea. The manner in which the country responded to the potential loss of its international competitiveness that this implied, had significant implications for income and wealth inequalities.

Inequality started out at low levels after the Second World War[34], and even declined in the first decades that followed, but began to rise again, particularly during the 1990s. At the same time, Germany lagged behind the United States, Japan, and South Korea in terms of radical innovations in key new industries such as semiconductors, nanotechnology and robotics. It was moreover also a period during which the social welfare state began to erode, partly as a response to reduced impact of technological innovation on labor productivity growth. The outcome was rising income and wealth inequalities.

This study therefore argues that it is not 'too much' technological innovation that is

[34] The two World Wars of the 20th century have had a leveling effect on economic equality by destroying wealth, infrastructure, and social and political structures (Piketty, 2013).

causing rising income inequality in Germany, through skill-biased technological change, but the contrary - a declining impact of technological innovation on labor productivity growth. Fearing that this declining impact would undermine the international competitiveness of the economy, real labor compensation was progressively curbed since the mid-1990s. This occurred *inter alia* through the government's erosion of the social welfare state, as well as offshoring and reduced fixed capital investment by the corporate sector. The outcome was rising income and wealth inequalities. Between the mid-1990s and 2010 the rise in wage inequality was faster in Germany than in the United States, the United Kingdom, and Canada. This study identified three reasons why technological innovation has become less and less effective:(i) historical legacies, (ii) weaknesses in the education system, and (iii) entrepreneurial stagnation.

7.2 Recommendations

First, it is recommended revamping the German technological innovation system, although this might be difficult to implement: the recent historical evidence suggests that the innovation system has become rather entrenched. It may be difficult for the government and industry to significantly alter the nature of the country's innovation system over the short- to medium-term. Innovation policies, for instance policies to spur R&D and commercialize intellectual property in important new industries, are not expected to lead to quick results. This does not mean, however, that there is nothing the government can undertake to invigorate the innovation system to deliver more breakthrough innovations, particularly in the areas underpinning 'Industrie 4.0'. This study can recommend, following Mazzucato (2015), that a 'mission-driven' industrial policy, aiming to 'stimulate development of markets and activities for those things which at present are not done at all' could be useful in this regard. Much of the current *de facto* 'industrial-policy' initiatives, such the 'Energiewende' (energy transition)[35] are focused on incumbents instead of focusing on 'things that are not done at all' or wherein the country is lagging.[36]

Moreover, such a shift in industrial policy will also require a change in the approach of public sector organizations with respect to innovation policy. One important point to bear in mind is that, as Coad and Rao (2008) pointed out, 'an innovation strategy is even more uncertain than playing a lottery, because it is a game of chance in which neither the probability nor the prize can be known for sure in advance'. Hence, the public

[35] In 'Industrieland Deutschland' (industrial country Germany) the major industries such as automobiles, machines, chemicals and electro-technology are all energy-intensive industries. The cost of energy is an important determinant of their competitiveness. The current approach to energy is contained in the 'Energiewende' of 2010, which aims to steer the country to certain targets of energy consumption, greenhouse gas emissions, and the use of renewable energy by 2050. Policy support for renewable energies started in 1991 with the 'Stromeinspeisungsgesetz' (Law on the Sale of Electricity to the Grid); in 2000 the 'Erneubare Energien Gesetz' (Renewable Energies Act) was introduced, and more recently the decision was taken to phase out the use of nuclear energy by 2022 (Rutten, 2014).

[36] In recent years there have been increasing calls made for so-called 'inclusive innovation policies' (e.g. Planes-Satorra and Paunov, 2017, p.17), referring to policies that 'aim to remove barriers to the participation of individuals, social groups, firms, sectors and regions that are underrepresented in innovation activities'. More research is needed to clarify whether and how such inclusive innovation could also lead to more effective innovation, i.e. innovation that raises labor productivity in Germany.

sector must be prepared to occasionally fail, and to act entrepreneurially. For Mazzucato (2015, p.125) this raises the question, '[h]ow should public organizations be structured so that they can accommodate the risk-taking and explorative capacity needed'? Answering this question falls outside the scope of the present study, although it will be increasingly required as a precondition for achieving sustained and inclusive growth in Germany in the future.

A second recommendation is to focus on the social welfare system as the most important tool for inclusive economic growth in the short-run. Social protection, fiscal redistribution, and active labor market policies (ALMP)[37] will provide the most appropriate measures to limit income and wealth inequalities from further widening in the upcoming years. These could include the creation of more government jobs, more redistributive taxation[38], and a stronger collective labor and union movement. Fears that stronger unionization will be detrimental to innovation in Germany's case are, so far, without evidence. On the contrary, Addison et al. (2013, p.6) do not find any proof that unionization has delayed innovation in the past, and even find some evidence that unionization benefited innovation. This positive impact of unionization on innovation may be due to the participation of workers in managing the 'adoption and spread of new technologies'.

It can further be suggested considering new and innovative forms of social protection schemes. These could include, for example, a form of Universal Basic Income (UBI)[39] or a negative income tax, although there are many justifiable objections for such schemes. At present, the many objections, reinforced by the practical difficulties, make them unlikely to be implemented in the near future. A global wealth tax could further support redistribution and thereby lower inequalities, and may be moreover used to finance innovative social protection schemes. A global wealth tax, however, is equally unlikely to be implemented. The search for other policy measures will certainly continue, as for example in a recent proposal by the European Union and Bill Gates that robots should be taxed.[40] Such social protection measures may also help stimulate innovation in Germany, as a more equal distribution of economic growth will boost domestic demand.

[37] These policies amount to about 1 percent of GDP at present, compared to 2 percent in Denmark, where they have been found to be effective. Zöllner et al. (2016) evaluate a range of entrepreneurship promotion programs (including bridging allowances and start-up subsidies) within Germany's ALMP and find that they had 'high success rates as well as high cost efficiency'. This recommendation resonates with the evaluation of the German social welfare system by Snower et al. (2009, p.155) who identify as crucial problem 'a lack of adaptability and versatility [of the labor force] in the presence of the reorganization of production and work in response to technology-driven globalization processes' which requires state support to allow these laborers to 'turn themselves into winners through their own efforts'.

[38] The concern is whether higher tax rates would discourage entrepreneurs (who are typically among the highest income earners), which, in turn, could lead to less job creation. A welfare maximizing top tax rate should thus balance the potential reduction in job creation with the increased ability to provide transfer payments. Brüggemann (2016) provides model estimates, using US data, which shows that a welfare-maximizing top marginal tax rate would be 82.5 percent.

[39] A UBI is a payment to every adult citizen, irrespective of labor market status or income. A number of UBI schemes (or 'Bedingungsloses Grundeinkommen') have also been proposed for Germany (Haywood, 2014).

[40] A difficulty, however, lies in the definition of a 'robot'. For this and other reasons the EU recently rejected a proposal to consider a tax on robots. Guerreiro et al. (2017) show that if the cost of automation falls to the extent that full automation occurs, it is in fact not optimal to tax robots.

It is widely accepted that social protection and fiscal redistribution need to be reformed - not only because of the challenges of potential technological unemployment (whether real or not), but also because of demographic changes and the resulting pressure on public finances.

Third, a reform of the education system remains fundamentally necessary, not only to deliver the scientists and entrepreneurs that can catalyze future innovation-led growth, but moreover to allow skills to be more transferable and less specialized than at present. As the labor intensity of Germany's manufacturing sector continues to decline, it will become more necessary for the workforce to be better adapted (with diversified skills) to reallocate to the service sector. Herein lifelong learning[41], as well as managerial and entrepreneurial competencies, are essential components. A possible reason for the lack of relative managerial competencies in Germany may be the dominance of the economy by a number of large incumbent firms, most of them with historical roots in the pre-war area and the lack of contestability in markets. Thus, as a complementary policy it can be recommended to increase competition in the economy, and stimulating fixed capital investment by these large incumbent firms.

Finally, it is also essential to align immigration policies with the country's growing shortage of educated workers. Attracting appropriately skilled immigrants, better integrating the existing stock of immigrants[42], integrating working parents in the economy, and postponing retirement through more flexible work practices, are further policies that can be recommended.

An overview of the policy recommendations outlined in this section, including a set of examples, are summarized in Figure 21.

7.3 Concluding comments: What if the 'fourth industrial revolution' is different?

Technological innovation has historically contributed to inclusive economic growth in Germany. But will this also be the case in the near future, given that many are claiming that the technologies which characterize 'Industrie 4.0' are different? The concern is that they will replace human labor instead of complementing it, as compared to previous technologies (Ford, 2015). Germany may be particularly vulnerable for two reasons: first, about 23 percent of its labor force is employed in industry, which presents the

[41] Gries et al. (2017) present a theoretical model of population aging and skill-biased technological change to show that 'well-designed education policies can substitute for simple social transfers', and that this is especially the case for lifelong learning which helps aging workers to find and keep employment.

[42] After the United States, Germany has become the most significant international destination for migrants. According to Daley and Kulish (2013, p.A1), however, 'Germany's experience with integrating foreign workers in the past [...] has proved difficult [...]. A recent study found that more than half of the Greeks and Spaniards who came to Germany left within a year'. The Bertelsmann Stiftung (2014, p.31) notes 'a worrisome trend with regard to acceptance of diversity'. Their indicator of 'acceptance of diversity' has declined consistently in Germany since the mid-1990s. The report recognizes that more needs to be done with integration, stating that '[i]ntegration is needed - not only of immigrants, but of anyone who is different'.

Figure 21: Overview policy recommendations and examples for Germany

Policy recommendation	Examples
Stimulate the industrial-innovation system to raise productivity growth	- Promote R&D in new and lagging sectors. - Expand active labor market policies. - Improve contestability of markets. - Implement industrial policies and venture capital funding for raising real investment. - Improve labor market mobility.
Strengthen the social welfare system	- Develop innovative social protection schemes. - Ensure a progressive tax-transfer system. - Strengthen the power of unions.
Diversify the education system	- Promote diversification of skills. - Enhance lifelong learning. - Expand managerial and entrepreneurial competences.
Align immigration policies, integrate working parents, postpone retirement	- Attract appropriately skilled immigrants. - Better integrate the existing stock of immigrants. - Promote technologies that will help postpone retirement.

Data source: The authors.

sector that will be most affected by the 'fourth industrial revolution'; and second, since the Second World War the United States and other countries have overtaken Germany in terms of producing the radical (product) innovations that are driving the new industrial revolutions. If disruptive technologies, wherein Germany does not have a leading innovative position, replace much of these jobs over the next two decades, it could well result in further increasing income and wealth inequalities.

The vulnerability of Germany is compounded by the fact that the reallocation of the working force from manufacturing to other sectors, such as services, may be difficult because of the more limited transferability of skills in the economy. The German education system is excellent in forming skilled workers for specialized areas based on the structure of its economy. Whereas this has been a recipe for past successes, it may become a liability in the future. Unlike the United States and the United Kingdom, Germany has a less diversified education system with proportionally more tertiary education students in engineering and science than in services, social sciences, and other sectors. The German education system has also become slow to adapt, is perceived as bureaucratic, and lacks entrepreneurial dynamics. Hence, it may have difficulties in providing for the 're-skilling' of the labor force and in attracting the high-skilled workers needed. The outcome may well be that the skills premium in the labor market will continue to rise, as certain skills become scarcer, also as more and more people exit the labor market due to retirement age. Thus, income inequality may also rise in future via this channel.

These concerns do not need to become reality. There are two reasons to be optimistic: first, there is no consensus that the 'fourth industrial revolution' will indeed lead to the huge job replacement and technological unemployment rates that some predict, and that have made headlines. Many leading scientists suggest that the impacts will not be as radical, that tasks rather than jobs will be affected, and moreover, that new markets and new business models will result in many new jobs being created (see e.g. Autor, 2015; Pfeiffer, 2016). As Autor (2015, p.26) concludes, the distinction between tasks and jobs is important; and although automation will affect tasks, it may not affect jobs to the same extent, and even raise the demand for jobs that contain different combinations of tasks including problem-solving skills: '[w]hile some of the tasks in many middle-skill jobs are susceptible to automation, many middle-skill jobs will continue to demand a mixture of tasks from across the skills spectrum'. For Germany, unlike several other countries, the rise of the 'fourth industrial revolution' in newly emerging countries potentially offers many opportunities as a supplier of inputs, materials, services, and technologies. It may even result in less need or incentives for German companies to outsource or offshore their manufacturing or assembling to countries with low-cost labor. The potential of the 'fourth industrial revolution' could indeed be that Germany in particular, and Europe more broadly, will experience a 're-shoring' of manufacturing. This, in turn, could lead to fewer jobs being exported, and hence result in more inclusive economic growth.

Second, German policy makers, industry associations and academics are well aware of the potential threats and opportunities, and a number of prominent policy initiatives in recent years are explicit and well-crafted attempts to ensure that manufacturing remains competitive, continues to provide jobs, and improves its innovativeness. Among these are active labor market policies, which consist, for example, of policies to encourage entrepreneurship. A recent evaluation of these measures find them to be overall successful (Zöllner et al., 2016). The long-term competitiveness of Germany's manufacturing sector will depend more than ever on the extent to which the required skills (termed '21st century skills') will be available in the economy. The effectiveness of higher education and its collaboration with business and government in the 'triple-helix' model will become more important, both for the incremental innovations that are needed to absorb and utilize the new technologies originating elsewhere, as for the more radical innovations that will be required to take on a leading global role as producer. Germany fortunately has much experience with the 'triple-helix model' which served it well during its industrialization in the 19th century. It can serve it well again, for its (re)industrialization in the 21st century.

In conclusion, this study stresses the need for further research, focusing on future opportunities and on assessing the impact of new technologies rigorously, as well as on the elaboration of new policy instruments to steer innovation, such as the EU's new directives on pre-commercial innovation procurement and innovation partnerships.[43] The argument that the 'fourth industrial revolution' may be significantly different from previous industrial revolutions, with less scope for compensatory employment creation, should - despite the optimism - still be taken seriously; just as the social, political and ethical implications of artificial intelligence have to be given more attention by policy makers and scientists. Germany cannot afford to be complacent about any trend that affects employment in its manufacturing sector. The remote but real threat is that, given Germany's lagging position in radical new ICT innovation, its manufacturing industry will ultimately become 'a sub-sector of the IT sector in the US' (Malmer and Tholen, 2015, p.53).[44]

[43] See, for instance, the 'EU policy initiatives on Innovation Procurement'.

[44] The United States' Smart Manufacturing Leadership Coalition (SMLC) aims, with strong US

Acknowledgements

We want to thank Armando García Schmidt, Andreas Esche, Dominic Ponattu and their colleagues at the Bertelsmann Stiftung for discussions and comments on an earlier draft. We further benefited from comments and suggestions from Werner Bönte, Uwe Cantner, Giacomo Domini, Thomas Gries, Dominique Guellec, Georg Licht, Emmanuel Muller, Markus Nagler, Caroline Paunov, Frank Piller, Jürgen Rüttgers and Björn Weigel. We further want to thank Marie-Louise Knopf, who contributed to our work with inputs from her master thesis while at UNU-MERIT. The usual disclaimer applies.

government financial backing, to (re)capture the United States' global dominance in manufacturing.

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A Appendix

Table 3: The top 20 hidden champions in Germany, 2015

Company	**Sector (product)**	**Turnover in mio EUR (latest)**	**Employment (latest)**
Herrenknecht	Machinery (tunneling)	1,300	4,955
Otto Bock	Health care (mobility)	1,000	7,614
Lürssen	Shipbuilding	829	1,635
Delo	Chemicals	80	500
Windmöller & Holscher	Machinery (flexible packaging)	500	2,000
Grimme	Agricultural machinery	438	2,200
Haver & Boecker	Machinery	470	2,870
Duravit	Ceramics	380	5,700
Kaeser Kompressoren	Machine tools	650	5,000
Peri	Construction tools	873	5,300
Schunk	Machine tools	360	2,700
Dorma	Construction materials	856	6,500
Sick	Industrial sensors	1,000	6,597
Mennekes	Industrial plugs	100	800
Abeking & Rasmussen	Shipbuilding	na	393
KWS Saat	Biotechnology	1,003	4,843
Renolit	Chemicals	410	4,500
Sennheiser	Audio equipment	385	2,100
Max Weishaupt	Energy	540	3,000
Big Dutchman	Agricultural machinery	905	2,853
Total		**7,780**	**72,060**

Data source: Authors' own compilation.