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ABSTRACT

The Rise and Fall of German Innovation

In this paper, we describe the historical co-evolution of innovation and economic growth in Germany since 1871. The country's rise as an industrial power in the late 19th century, through its innovation and entrepreneurial performance, is contrasted with the post-World War II period. This latter period, although it contained the German economic miracle, was nevertheless a period during which innovation went into relative decline. We document this decline and offer four broad, interrelated explanations: (i) an innovation system locked into incremental innovation, (ii) a slowdown in the diffusion of technology, (iii) weaknesses in the education system, and (iv) entrepreneurial stagnation. Implications for policy are noted. Our paper contributes to the growing literature attempting to understand the decline in business dynamism that characterises many advanced economies.

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

Keywords: entrepreneurship, inequality, innovation, productivity, technology

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1 Introduction

The evidence that innovation in advanced economies is in relative decline is accumulating. It may be surprising to claim that we live in a world where innovation is slowing down, given the notable acceleration in digital technologies and connectivity over the past decade (*e.g.*, Friedman, 2016) and the popular narrative of a "4th Industrial Revolution" (*e.g.*, Schwab, 2016). This decline can however be observed in decreasing total productivity growth rates, increased concentration in patenting, and declining R&D expenditure shares - see *e.g.*, Arora et al. (2019), Bhattacharya & Packalen (2020), Bloom et al. (2020), Brynjolfsson et al. (2017), Gordon (2015) and Jones (2009). Erixon & Weigel (2016) and Ridley (2020) even refer to an 'innovation famine' and Elert et al. (2017, p.1) describe the European Union as suffering from an 'innovation deficit'. Further, the slowdown in innovation is also considered an important reason for a decline in business dynamism that is equally being observed in many advanced nations[1].

In this paper, we contribute to the literature on declining innovation in advanced economies by studying innovation in Germany, the largest economy in the European Union, over the period 1871 to the present. We document changes in innovation and identify the likely suspects behind both the rise in innovation in the late 19th century and its fall since the 1970s. On the one hand, Germany is not a special case as most advanced economies have been experiencing a slowdown in innovation due to an entrenchment of institutions and the dilution of incentives for science and disruptive entrepreneurship. On the other hand, Germany's experience shows that the pathways and patterns by which institutions and incentives change are country-specific. While the rise of German innovation was based on a unique historical confluence of policies and circumstances, it still holds a contemporary lesson for the West, namely that a range of complementary measures and initiatives, akin to the 'big push' of the late 19th and early 20th century, may be needed to propel new scientific breakthroughs on which continued gains in productivity and value-added can be based; albeit the 'low-hanging fruits' could be exhausted by now (Weinstein, 2012).

In this light, our paper also contributes to the literature on the long-run relationship between innovation and economic growth[2], in which respect it is close in spirit to the recent work

[1]The decline in business dynamism in advanced economies has been extensively documented by, amongst others, Akcigit & Ates (2019), Bijnens & Konings (2018), Bravo-Biosca (2016), Cowen (2010, 2016, 2017), Criscuolo et al. (2014), Decker et al. (2016, 2017), Gordon (2012, 2016) and Naudé (2020).

[2]This literature is far from settled. As Andrews et al. (2020, p.3) point out, referring to the conflicting observations between declining business dynamism and technological progress, "[w]hile economists have long posited a relationship between innovation, entrepreneurship, productivity growth, and economic output [...],

of Akcigit et al. (2017) on the United States and Prados de la Escosura & Rosés (2020) on Spain. The experience of Germany is particularly interesting and relevant for the current concerns about a slowdown in innovation since the country is one of the world's top three producers of scientific research (Dusdal et al., 2020). At the same time, it is also a country where the long-term decline in innovation is rarely acknowledged. The reason for this is that consequences of a decline in innovation have been offset by the country's success in export-led growth, the outcome of the creation of a 'bazaar economy' (Sinn, 2006). This might however come to an end: with the sustainability of Germany's 'bazaar economy' increasingly under pressure and with the likely acceleration of de-globalisation in the wake of the COVID-19 pandemic (Razin, 2020), the challenge of revitalising innovation may become paramount. From our diagnosis of the problem, we offer a number of suggestions in this regard.

The rest of the paper proceeds as follows. In Section 2 we describe the historical co-evolution of economic growth and innovation in Germany since 1871 to the present. In Section 3 we document the innovation slowdown. In Section 4 we investigate the causes for this decline in innovation. Here we provide four interrelated reasons, namely (i) a propensity for incremental innovations, (ii) the slower diffusion of technology, (iii) weaknesses in the education system, and (iv) entrepreneurial stagnation. In Section 5 we conclude with policy implications.

2 Three periods of innovation and growth

Between the formation of Germany as a modern state in 1871 and the present day, three distinct periods of innovation and growth can be discerned. The first period was from 1871 until World War I in 1914. The second period were the wars and inter-war years from 1914 until around 1949; and the third period was the post-war period from 1950 until the present. In this section we provide a snapshot of how innovation and economic growth evolved during these three periods.

the conflicting observations above led us to question just how much we actually know about the role of innovation and entrepreneurship in driving productivity and economic growth".

2.1 From new country to World War I, 1871-1914

In the period between the formation of the modern German state in 1871 and the outbreak of World War I in 1914 the country industrialised (Beise & Stahl, 1999)[3], which coincided with the 'first era of globalisation' (Twarog, 1997). By all accounts, Germany was still an 'industrial backwater' around the mid-19th century. Bairoch (1982) documents that Germany was 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 one of the world's leading innovators. How did this happen? Most economic historians agree that Germany's industrialisation and subsequent socio-economic development were significantly determined by the rise of its education and scientific research establishment, and its successful collaboration with private entrepreneurs and the government. In the subsequent discussion, we will focus respectively on the education and science establishment, the entrepreneurs and the business community, and the government, describing how their collaboration created the so-called 'triple-helix' model of innovation and development (Mroczkowski, 2014).

Watson (2010) traces one of the first significant institutional contributions in education and scientific research to Frederick the Great's establishment of the *Berlin Academy of Arts and Science* in the 18th century, and an accompanying revolution in learning and reading as well as research. By the year 1800, around 270 reading societies existed in Germany and the literacy rates in Prussia and Saxony were among the highest in the world. In subsequent decades, until 1840, German scholars, such as Wilhelm von Humboldt, re-created German universities as research institutions - heralding the idea of the modern research university - that were different from previous universities in their focus on new knowledge generation and innovation, in what has been called the "institutionalisation of discovery" (Watson, 2010, p.226)[4] and the "industrialisation of invention" (Meyer-Thurow, 1982, p.363).

Science and engineering were pre-eminent in the best of these universities. The 19th century also saw the rise of poly-technical and technical universities (*Technische Hochschulen*), where engineering and applied sciences would be paramount. These institutions were widely acces-

[3]Although Germany's industrial revolution started around the time the country unified, various types of manufacturing activities and 'pre-industrialisation' pockets existed before. 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 industrialising on a small-scale by 1780.

[4]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".

sible, and attended by the educated and rising middle classes of that period (Watson, 2010). The first steps to create a public research laboratory system were made in 1887, on the instigation of engineer-entrepreneur Werner von Siemens, namely the *Physikalisch-Technische Reichsanstalt* (Beise & Stahl, 1999). Further organisations of this kind included the *Kaiser Wilhelm* Institutes established in 1911, later to become the *Max Planck* Institutes. This industrial research system, influenced as much by entrepreneurs and business owners as by the government and scientists, was one of the first of this kind worldwide (Grupp et al., 2005).

The scientific breakthroughs at these universities and poly-technical institutions would be quickly taken up and applied for commercial purposes by German entrepreneurs. One of the first instances was the contribution of scientists to the understanding of the generation and conservation of energy. Their inventions stimulated 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. Shortly after, 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 the country to become the world's leading manufacturer of colour-dyes (Meyer-Thurow, 1982), which developed into a global leading pharmaceutical industry with firms such as *BASF*, *Bayer* and *Höchst*. The chemical and pharmaceutical industries also paved the way in the establishment of private industrial research laboratories with the main purpose to invent and to apply new inventions commercially (Meyer-Thurow, 1982).

The list of breakthrough or radical innovations by engineer-entrepreneurs that resulted from this context during the late 19th and early 20th century is remarkable. Table 1 lists major innovations and their associated engineer-entrepreneurs. The legacy of these innovators lasts to present-day Germany in that numerous of the largest German industrial firms in the post-1950 period trace their roots back to this time. The examples further reflect the close cooperation between higher education and industry that was established during this period.

The third partner in the emerging innovation system was the government. Not only did the national and state governments support universal education, but they also played what many considered the igniting role in Germany's industrialisation 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), which helped reducing transport costs and hence improved the competitiveness of all

Table 1: Radical innovations in Germany, 1871-1913

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.

industries and trade (Kopsidis & Bromley, 2016)[5]. Mechanical engineering and specifically machinery manufacturing received a huge impetus from the establishment of the railways as well as from the emerging innovation system, which resulted in a comparative advantage in mechanics-related industries and Germany becoming one of the most complex economies in the world by the turn of the century (Domini, 2019). As a result, the country was able to expand into international markets. By the end of this period, the exports of machinery was the single largest category of exports and Germany the world's largest exporter of machinery. The beginning of Germany's manufacturing export model is thus to be traced back to this era (Audretsch et al., 2018).

[5]Spatially, the industry in Germany is still today concentrated around the historically coal-mining and smelting areas such as around the Ruhr (Kopsidis & Bromley, 2016).

The consequences of the confluences of a developmental state, the establishment of higher education and scientific systems, and organisational innovations were significant. As Twarog (1997) documents, real *per capita* income grew by 15% per decade between the mid-19th century and 1913, industrial production achieved a growth rate of 37% per decade, and the population living in cities of more than 100,000 people increased from less than 5% in 1871 to over 20% in 1910. In about half a century, the German economy had been significantly transformed. Moreover, total factor productivity (TFP), a measure of innovation (Hall, 2011), increased significantly over this period. Burhop & Wolff (2005) find that total factor productivity contributed 64% to the total net national product (NNP) growth between 1851 and 1913. Growth in GDP *per capita* accelerated after 1880, from a 1.3% per year average between 1860 and 1879, to a 1.9% per year average between 1880 and 1900[6].

An important 'social innovation' of the 1880s 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 achieve a higher level of social inclusiveness. The welfare state thus contributed to improve the effectiveness of innovation by facilitating the diffusion of technology and labour market adjustments. The rise of innovation and industrialisation in 19th century Germany's was therefore facilitated by an expanding social welfare system.

2.2 Years of war and political instability, 1914-1949

Since the establishment of the modern German state in 1871 to the present, there were only two decades during which average GDP *per capita* growth was negative: the 1910s and the 1940s, both decades during which the country was engulfed by a world war. The years in between the two wars saw great political instability, but despite this, there was bounce-back growth after the end of World War I - the country achieved GDP *per capita* growth averaging 4.1% during the 1920, which declined to a still high 3.6% during the 1930s.

World War II saw the economy and its institutions devastated. From the point of view of innovation, a long-term significant effect was the loss of talent through a brain drain, as highly skilled labour fled during and after the Nazi regime (Fohlin, 2016). The detrimental and long-run impacts of the human capital loss on Germany's skills are discussed in Moser et al.

[6]Calculations based on data from the Maddison Project Database (see Bolt & van Zanden, 2020).

(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 from public institutions by the *Nazis* after 1933, including eleven Nobel Laureates such as Albert Einstein, Max Born, Fritz Haber and Otto Meyerhof, had a long-term negative impact on scientific output. Furthermore, after World War II, the Allied Forces required research institutions to focus exclusively on basic research, to the detriment of application and commercialisation (Comin et al., 2016). As various historians point out: what disadvantaged Germany, advantaged the United States after the war.

Despite the ravages of the wars, many of the pillars of the first German state, including many 19th-century corporate giants that were the result of the remarkable innovations mentioned in Table 1 as well as scientific and educational institutions, survived. These corporate giants, such as *BMW*, *Bosch*, *Mercedes-Benz*, *Siemens*, *Volkswagen* and others, would continue to play a central role in Germany's post-war economic recovery and innovation landscape. The collaboration between the German government and the corporate sector also continued after the war, and to fill the gap in the former 'triple-helix' landscape[7], the *Fraunhofer Society* (*FhG*) was established in 1949. The *FhG* nowadays consists of a number of research laboratories that conduct applied research with a focus on industrial innovation for improving the industry's competitiveness (Beise & Stahl, 1999). It should be noted however that despite its rise to prominence in the post-war period, only a relative small proportion of total R&D in Germany is allocated to the *FhG* (about 2.5% of all R&D in 2010).

2.3 The post-war years and the economic miracle, 1950-present

In the immediate post-war period, roughly from 1950 to the mid-1970s, average annual GDP *per capita* growth amounted to 5% on average. During this period, the German economy was described by the term *Wirtschaftswunder* (*i.e.*, economic miracle). Growth was driven by three institutional factors: (i) the reconstruction of the country under the *Marshall Plan*, (ii) 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), and (iii) the success of small and medium enterprises (SMEs) from the so-called *Mittelstand* to grow their exports to global markets. Growth was structural,

[7]The 'triple-helix' model of innovation refers to interactions between academia, industry and governments, to foster economic and social development.

with a shift in employment and value-added taking place from agriculture towards services (Broadberry, 1997).

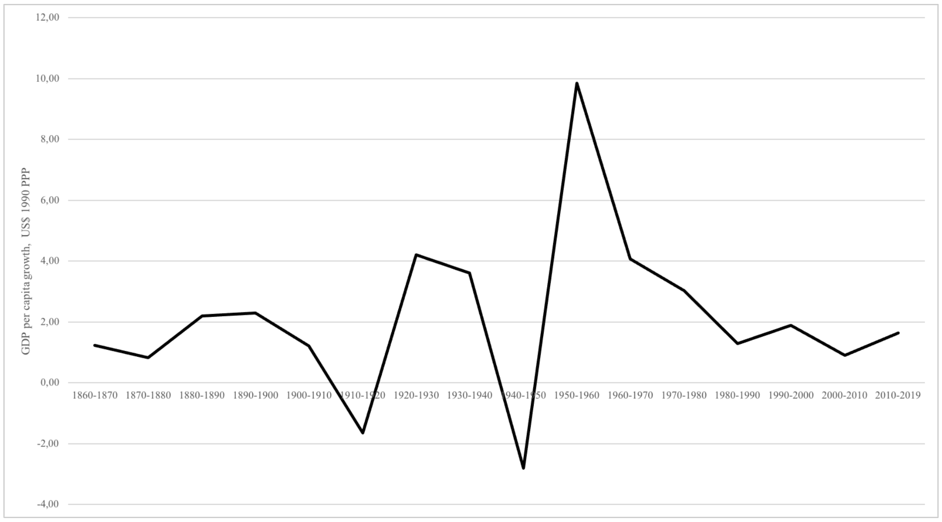
The rise of the *Mittelstand* is an important feature of the country's development, as its institutional and organisational embedding in the economy has far-reaching implications for innovation (Heider et al., 2020). The term *Mittelstand* refers to the small- and medium-sized enterprises that form the 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 (*i.e.*, private) ownership, long-term orientation, social responsibility, and an excellent focus on customer care (Fear et al., 2015). More than 60% of Germany's exports come from *Mittelstand* firms (Audretsch et al., 2018). Over time, many of these firms became world leaders in their field and have been described as Germany's 'hidden champions' (Simon, 2009). Fear et al. (2015) argue that the success of *Mittelstand* firms was not so much driven by their innovative abilities, as by doing 'good business': their focus on customer needs and quality, reliable products, and services.

Despite the economic miracle and the rise of the *Mittelstand*, economic growth in Germany started to decline to an average of 2% between 1975 and 1990, and further to 1% between 1990 and 2010. During the latter period Germany was even labeled the 'Sick Man of Europe' by the Economist. Audretsch & Lehmann (2016a, p.4) point out that even before the German reunification "competitiveness began to sag". While everybody had expected a peace dividend after the end of the Cold War and the German Reunification, this never materialised, as the process was accompanied by a negative labour productivity shock resulting from the re-integration of workers of former East Germany, whose productivity were 40% to 70% 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 (Audretsch & Lehmann, 2016a, p.4).

It is instructive to compare the economic growth of the three periods in order to put the decline in economic growth (and innovation) into perspective. Figure 1 shows the three periods of growth: the first period, until World War I, which saw accelerating GDP growth until this was brought to end by World War I; the second period, the war and inter-war period, with fairly high inter-war re-bound growth surrounded by two decades of declining GDP growth (the 1910s and 1940s); and finally, the post-1950 period which started with historically high growth rates (from a low base given the economic destruction of the war) that marked the economic miracle years, followed by a steady decline in average annual growth rates since the 1960s. The GDP per capital growth remained below 2% since the

1980s, and decelerated to less than 1% during the 2000s.

Figure 1: Per capita GDP growth in Germany per decade, 1860-2019



Data source: Bolt et al. (2014, p.67) and World Bank Development Indicators online.

The decline in economic dynamics is also apparent from long-run innovation trends. According to Grupp et al. (2005), who use total scientific expenditure[8] as a percentage of total government expenditure as an indicator for innovation, innovation expenditure increased from around 1% in 1850 to a maximum of 6.5% in the 1970s, before declining to approximately 5% at the time of German reunification.

3 Documenting the innovation slowdown

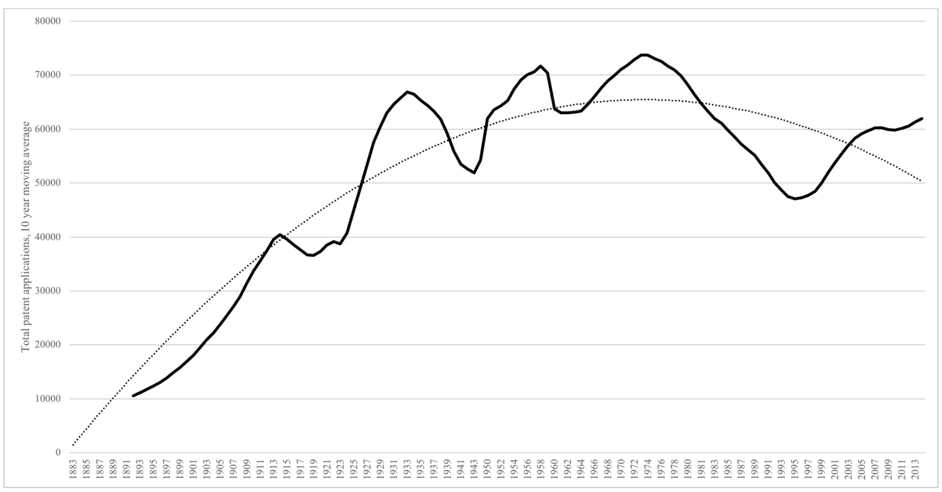
In this section, we sketch a consistent picture of Germany as a country where innovation is slowing down, using different measures of innovation; and where innovation is furthermore becoming less effective as a driver of growth. This is despite the fact that the government and corporate sector continue to channel significant amounts of investment into innovation. We are not the first to note or express concern about the slowdown in Germany's innovation. Boeing & Hünermund (2020) report evidence of a decline in German research productivity, Rammer & Schubert (2018) conclude that the number of German firms who engage in innovation fell sharply, and Lang (2009, p.1438) document the decline in the rate of return of R&D in German manufacturing, finding that the "rates of return of R&D are estimated

[8] Scientific expenditure includes R&D, training and teaching costs, and the costs of maintenance and diffusion of knowledge.

to have reached an all-time low spanning the last 45 years". We add to these findings, and contrast them with history.

We first use patent data, an often-used output indicator of innovation. Figure 2 depicts the long-run evolution in patent applications in Germany. Patenting reached a peak in the 1970s[9], after which it declined, with a recent resumption of growth in patents. This figure shows the difference in growth rate between the pre- and post-World War II periods. The suggestion from this figure is that innovation peaked in the 1970s, which is consistent with other measures of innovation, such as TFP growth.

Figure 2: Total patent applications in Germany, 1883-2014 (10-yr moving average)



Data source: WIPO.

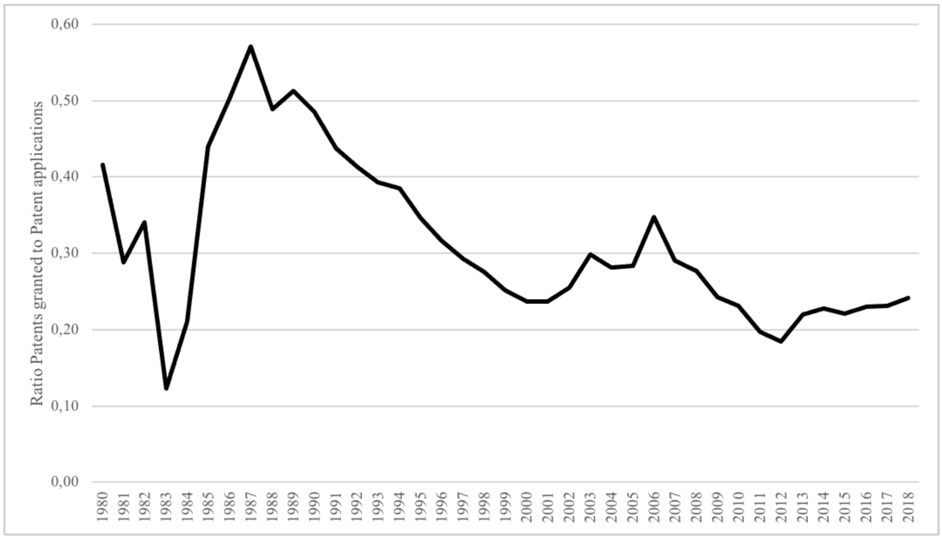
An important distinction lies between patent applications and patents granted. The difference can be seen in the ratio of successful (granted) patents to patent applications, which is shown in Figure 3. The figure illustrates a reduction in the ratio of patents granted relative to patent applications since the mid-1980s. In absolute terms the number of patent applications increased from around 44,382 in 1985 to 67,898 in 2018, but the number of successful (granted) patents decreased from 19,500 to 16,367 over the same time.

We discuss later in the paper to what extent the decline in successful patent applications reflects a decline in innovativeness. It can be however noted that patents are far from being a perfect measure of innovativeness[10], and that some caution is warranted in making

[9]The growth rate in innovation as measured by patenting in Figure 2 was particularly rapid between roughly 1923 and 1935 and gave rise to a first peak in innovation around the mid-1930s. This is interesting in light of the analysis of Field (2003, p.1399) which shows that for the United States "the years 1929–1941 were, in the aggregate, the most technologically progressive of any comparable period in US economic history".

[10]Jensen et al. (2007) discuss how measures such as patents reflect the outcome of formal scientific and

Figure 3: Ratio patent applications to patents granted in Germany, 1980-2018



Data source: WIPO. *Notes*: From 1980 to the German reunification in 1990, only patent data from the FRG.

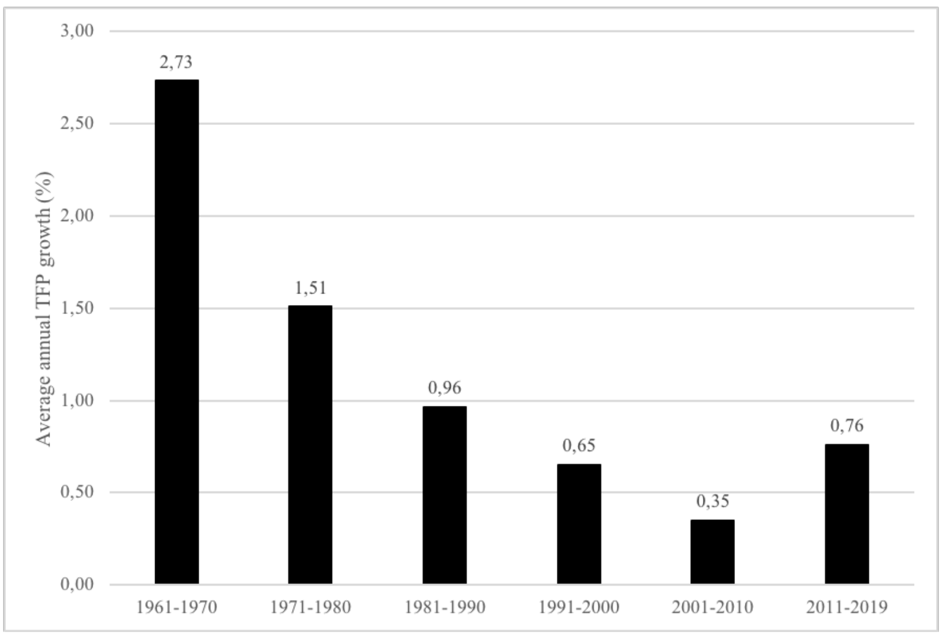
strong conclusions. On the one hand, because patent offices may be simply getting stricter; on the other hand, because the growth in the number of patent applications might not be driven by quality. Instead, this could reflect a legacy of the *Arbeitnehmererfindergesetz* (German Employee Invention Act) of 1957 through which firms tend to apply for patents on employees' ideas, irrespective of whether they merit the effort or not (Harhoff & Hoisl, 2007). As the *Arbeitnehmererfindergesetz* precedes the decline noted in Figure 2 by various years, some caution is again warranted. It may be more plausible that this reflects the strategic considerations of large firms, which do most of the patenting, with respect to negotiations, international expansion, or for blocking competitors (Blind et al., 2006).

There is further evidence that the quality of German patents is declining. Another common measure of patent quality is the average number of citations that a patent receives over a certain period of time. Using this measure and data from the United States Patents and Trademark Office (USPTO), Kwon et al. (2017) find that the quality of German versus US patents has been in continuous decline. In the 1980s, German patent citations were on average 14% lower, in the 1990s 30% lower, and in the 2000s even 41% lower compared to those in the United States. This decline was steeper than that of the United Kingdom and Japan, while emerging Asian countries have improved their position in the global patent quality ladder.

technological learning, taking place at the firm level. They argue that much firm innovation results through informal "doing, using and interacting" behavior (Jensen et al., 2007, p.680). Policy makers, however, tend not to take this into account when measuring innovation.

A second, indirect measure of innovation is total factor productivity (TFP) (Hall, 2011). As the OECD (2016) notes, TFP growth has been on a long-term decline in Germany since the 1970s. Figure 4 shows that German TFP annually grew by 2.73% on average between 1961 and 1970, and that growth declined over the subsequent decades, with the lowest annual growth rate experienced between 2001 and 2010. More recently, annual TFP growth has seen a moderate increase, but we can only speculate about the reasons. One possible reason is that following the 2009-2010 global financial crisis, the sharp decline in interest rates in the EU stimulated investment in new capital and technology to replace that made obsolete or destroyed by the crisis (Caballero & Farhi, 2018). Gries & Naudé (2020) point out that shocks are frequently associated with subsequent growth and innovation episodes.

Figure 4: Average annual TFP growth in Germany, 1960-2019



Data source: European Commission AMECO database online.

The 1960s and 1970s were thus, at least measured by TFP, Germany's period of 'peak innovation' in the post-war period. That there is no comparable list of breakthrough innovations as in the period from 1850 to 1913, reflects that much of innovation after the 1950s, in particular by the rising *Mittelstand*, were of an incremental rather than a breakthrough nature (Heider et al., 2020).

Thirdly, although 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 the so-called '4th Industrial Revolution' or 'Industrie 4.0' (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, nano-technology 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 recently China. The WIPO (2015) notes that 25% of all patent applications in 3D-printing and robotics and 15% 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. The ROBO Global Robotics and Automation Index contains data on financial performance of 1,000 industrial companies, of which only 4% are German. Most firms are from the United States (42%) and Japan (30%). This relative decline in innovation may however not be a cause of its declining productivity growth. Many of the advanced economies leading in these technologies (*e.g.*, the United States, Japan) are in spite of it also suffering from declining productivity growth. Rather, it is a symptom of deeper underlying causes, which will be discussed in the next section.

Finally, the decline in innovation in Germany can also be documented by showing that the proportion of firms that engage in innovation activities has been declining. According to data from the Mannheim Enterprise Panel, the Gini-coefficient for 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 implies that most firms in Germany invest nothing in innovation. Rammer & Schubert (2018) find that the R&D growth rate of businesses in Germany averaged 4% between 2001 and 2013, but that this was mainly the result of a few larger enterprises which increased their R&D budgets by almost 5% on average compared to less than 2% in the case of SMEs. While it is expected that larger firms spend more on R&D, it is important to know that the German government increased R&D subsidies to SMEs by 900 million EUR for 2009 and 2010, as part of the Central Innovation Programme for SMEs (*Zentrales Innovationsprogramm Mittelstand* - ZIM) (Brautzsch et al., 2015). Rammer & Schubert (2018, p.388) thus conclude that "the German economy runs a risk of becoming much more vulnerable to aggregate technology or demand side shocks that affect firms in one sector in a similar way. In this respect, the ongoing concentration process may reduce considerably the resilience of the German economy to external shocks in the longer run".

4 What caused the decline in innovation?

What caused the decline in innovation noted in the previous section? We discuss four main reasons: (i) a lack of radical innovations, (ii) a slower diffusion of technology, (iii) a slower capacity to learn and adapt new technologies, and (iv) a relatively weak entrepreneurial system, which also contributed to the aforementioned three factors.

4.1 Locked into incremental innovation

The first is the conspicuous lack of radical or breakthrough innovations, and the predominance of incremental innovations - the country has become virtually 'locked' into doing incremental innovations. Breznitz (2014) argues that the German innovation system 'got stuck' at producing primarily incremental innovations in existing (traditional) industries, rather than radically innovating and creating new industries and markets. We already noted the rise of the *Mittelstand* as part of the economic miracle in the 1960s. The *Mittelstand*, however, tends to engage largely in incremental innovations. Heider et al. (2020, p.1) point out that the "German *Mittelstand* firms are part of an institutional setting characterised by tightly knit relationships with internal and external stakeholders, which makes it more difficult for these firms to engage in business model innovation [...]. This type of innovation is [...] much more difficult in a coordinated market economy such as the German *Mittelstand*".

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. The model of incremental innovation is part of the strategy of the *Mittelstand* to remain internationally competitive on the basis of quality, not costs. 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 & 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 globalisation 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. Further, these firms are hugely benefiting from the adoption of the Euro as currency, which together with their service-focus have turned Germany into a hyper-competitive economy (Dubner, 2017).

A related, and perhaps more pernicious reason for the lack of radical innovations is the widespread adoption of 'defensive corporate strategies' by large firms (Erixon & Weigel, 2016). As an example, Meyer-Thurow (1982, pp.380-381) can be quoted, who conducted a case study of the pharmaceutical giant *Bayer AG* and who 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."

Meyer-Thurow (1982) states that a major goal of R&D expenditure by many German companies is to prevent new firms of entering the market, and hence to keep competition out rather than to create new markets[11]. In a related manner, Erixon & Weigel (2016, p.59) describe the strategies of large German corporations as being essentially defensive, "favouring the allocation of resources according to a rentier formula; and crowding out innovations".

Finally, the lack of radical innovations may also be a legacy of the the historical context, and specifically the impact of the wars. According to Fohlin (2016), World War II can be seen as a structural break in Germany's innovativeness, because of the destruction of the capital stock, 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, Fohlin (2016, pp.18-19) concludes that "Germany could not pour large portions of its national resources into risky investments in research and development of new technologies".

[11] Gutiérrez & Philippon (2019) find that the United States experienced a significant decline in free market entry over the past 20 years, largely due to lobbying and regulations that shelter large incumbents. Faccio & McConnell (2020) find evidence, using data from 75 countries since 1910 (including Germany), that political connections and lobbying are indeed responsible for many large incumbent firms avoiding being displaced by new entrants.

4.2 Slower diffusion of technology

A second reason for the decline in innovation, and in particular for the decline in indirect measures of innovation such as TFP and labour productivity, is a slower diffusion of technology. This has been implicated in the decline in business dynamism in the United States (Akcigit & Ates, 2019), and likely to be also a factor in Germany. In addition to a reduction in the number of breakthrough innovations and in 'Schumpeterian' entrepreneurship in Germany, the defensive corporate strategies[12] previously discussed led to a slower diffusion of technology through reduced fixed capital investment[13]. Erixon & Weigel (2016, p.30) noted that fixed capital investment in Germany has declined "pretty dramatically". Given that technology diffuses through the economy embodied in capital investment, this is an obvious mechanism that will slow down the diffusion of technology.

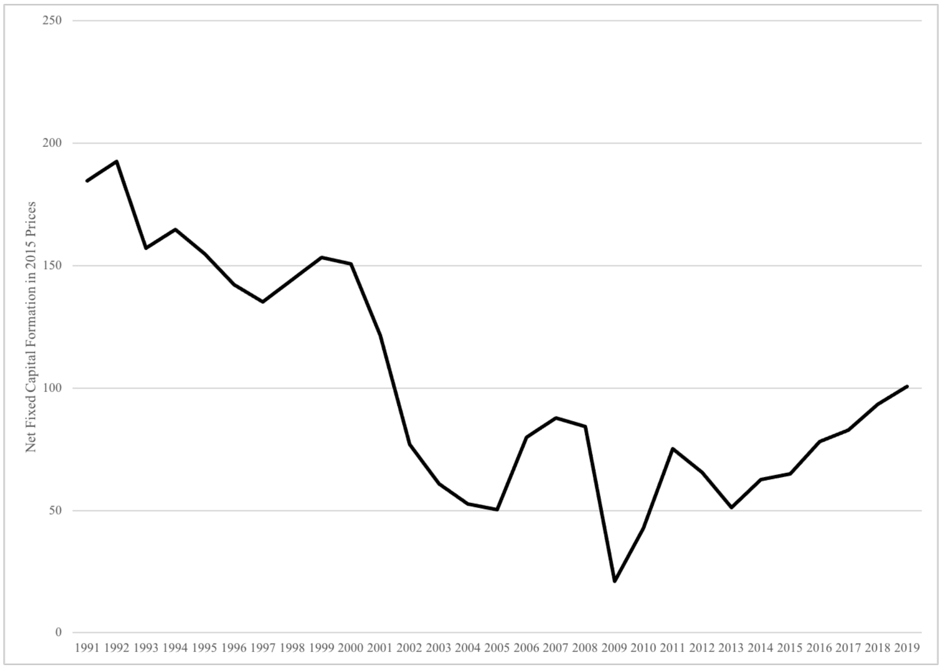
In Figure 5 the precipitous decline in net fixed capital investment in Germany between 1991 and 2009 is depicted. The figure also indicates that after 2009 (global financial crisis), net fixed capital investment started growing again. We speculate that this may reflect the stimulation of investment in new capital and technology to replace that made obsolete or destroyed by the global financial crisis of 2009-2010. It may also be the result of the slight reduction in inequality brought about by the global financial crisis, as documented by Gokmen & Morin (2019) and Milanovic (2020), which could have stimulated new entrepreneurship.

The slower diffusion of technology has also been associated with relatively poor management practices of German firms, especially of *Mittelstand* firms (Broszeit et al., 2019) and in firms of former East Germany (Burda & Severgnini, 2018). In this regard, Broszeit et al. (2019) found that (i) German firm level productivity lags behind that of US firms; that (ii) a relatively wide productivity dispersal between firms exists; and that (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. Broszeit et al. (2019, p.e688)

[12]For the United States, Arora et al. (2019) make the case that not only defensive corporate strategies led to a decline in innovation, but also a decline in corporate innovation due to the increasing shift of research from universities over the past few decades. In Germany, there are 142 research-universities but also 427 research institutes, constituting a dual-pillar system for R&D, and with a larger share of government R&D funding going to the institutes rather than the universities (Dusdal et al., 2020). These institutes, which include institutes such as *Frauhnhofer*, *Leibniz*, *Helmholtz* and *Max Planck*, tend to do better than universities at commercialising research (Savage, 2019). It is therefore less likely that a rising share of university R&D is contributing to the decline in innovation in Germany.

[13]The decline in investment also includes investments in ICT. In this regard, Baumgarten (2013, p.5) finds that the "German establishments invested more in technology during the 1980s than during recent years [...] while 34% of firms invested in ICT in 1996, only 29% did so in 2010".

Figure 5: Net fixed capital investment (at 2015 prices) in Germany, 1991-2019



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

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".

The slower diffusion of technology is likely also a result of a decline in collective bargaining regimes. Germany had a strongly unionised labour market with a peak in unionisation in the early 1990s, which subsequently declined (Naudé & Nagler, 2017b). This may have contributed to the decline in the effectiveness of innovation by slowing the diffusion of technologies. Addison et al. (2013) present evidence that unionisation has been beneficial for innovation in the past, because participation of workers in management helped with the facilitation of new technology adoption and diffusion.

Finally, the erosion of the German social welfare system could have delayed the diffusion and uptake of new technology through a slow-down in worker reallocation and labour market churning. These are however important mechanisms for learning and the diffusion of technology (Andrews et al., 2016; Decker et al., 2016). Strengthening the social welfare system could thus contribute to speeding up the diffusion of technology again. Also specific labour markets policies, such as the practice of 'short-time' work[14], may have contributed

[14]See Brenke et al. (2011) for a discussion and evaluation of the short-time work programmes, which they

to the same phenomenon. At least in normal (non-crisis) times[15], these policies may hinder the reallocation of workers from less to more productive firms (Cooper et al., 2017), leading again to decreased learning and technology diffusion.

4.3 Weaknesses in the education system

A third reason for the decline in innovation, and one that has been highlighted by the OECD (2016) for Germany, is the relatively slow growth in high(er) skills. This reflects growing weaknesses in the education system of a traditionally much-praised education system, that however often ranks relatively poorly in global skills rankings. In the *Global Talent Competitiveness Index*, for instance, Germany was ranked 15th in 2015-2017, declining to 16th in 2018-2020[16]. In Pearson's 2014 *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, Grade 4 PIRLS scores (Progress in International Reading Literacy Study) and TIMMS (Trends in International Mathematics and Science Study) achievements in sciences and mathematics. The country's score in this index further declined from 0.56 to 0.48 between 2012 and 2014.

These relatively poor outcomes may reflect that the education system is too specialised and intertwined with the current industrial structure; and that the education system itself may be un-entrepreneurial and too bureaucratic, and hence not adjust flexibly enough to the challenges that the economy is facing. The specialisation of the German education system is rooted in the important role of manufacturing within its economy. Manufacturing value-added contributed 23% to GDP and manufactures exports 84% to merchandise exports in 2016; 28% of its labour force was employed in industry, consisting of manufacturing, mining and construction in 2015[17]. Iversen & Cusack (2000) point out that the reallocation of workers from manufacturing to services has been easier in the United States, and argue that it is more difficult to transfer skills to other sectors in Germany, because of the more specialist type of skills. Many skills in Germany are firm specific, especially in the typical *Mittelstand* manufacturing firms[18]. The authors warn that "[a] country like Germany with a training

describe as context specific to Germany.

[15]In crisis times, for example during a pandemic, the flexibility afforded by short-time work practices will be less distorting, as all workers whether in high or low productivity firms are equally affected. Moreover the practice may help firms to retain skilled staff.

[16]See `https://gtcistudy.com`.

[17]Data source: World Development Indicators.

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

system that emphasises specific skills will be politically more sensitive to occupational shifts than a country like the US where the educational system emphasises general skills" (Iversen & Cusack, 2000, p.346).

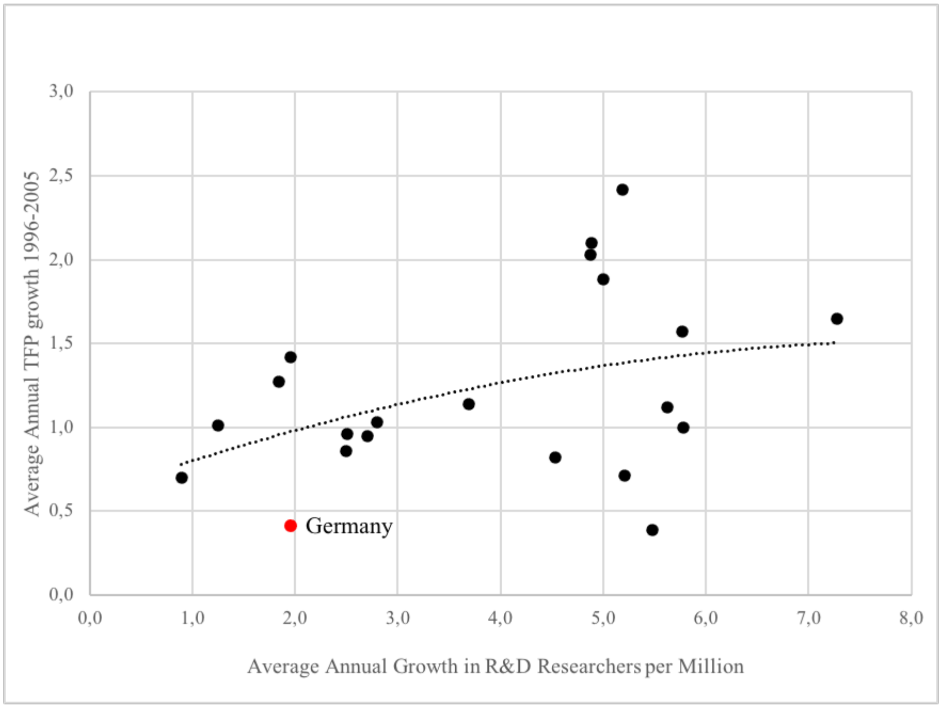
Germany's tertiary education enrolments are relatively more concentrated or specialised than those of fellow OECD countries such as France, Italy, the United Kingdom, and the United States. In 2014, around 21% of all tertiary education enrolments were in engineering, manufacturing and construction programmes, 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 programmes in health and welfare, and in social sciences, compared to those countries. In the former, it has proportionately almost three times less students than the United States. In services study programmes, Germany also has relatively few students at 2.2% compared to 7.0% 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 labour market to adjust.

In addition to being relatively specialised, the German education system may not be able to keep up 'the production and delivery' of the highly skilled workers (researchers) that are needed in the R&D sector. Figure 6 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, 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[19]. It is thus no surprise that Boeing & Hünermund (2020) report evidence of a decline in Germany's research productivity, and Lang (2009) reports evidence of a historical drop in rates of return to R&D.

Why has the education system not been more dynamic in the light of these weaknesses? 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 policy is fragmented across the 16 *Länder*, and the dual vocational system, although widely praised, is difficult to enter and limited to 378 formal occupations. Overall, the education system is too much tailored to industrial needs

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

Figure 6: 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 researchers are from 1996 to 2005.

(Malmer & Tholen, 2015). According to Mroczkowski (2014, pp.415-416), "[t]he country that invented the 'triple-helix', today is criticised for insufficient entrepreneurship and innovation, and for coddling university academics who are described as conservative, inward looking, and resistant to change".

4.4 Entrepreneurship stagnation

The fourth reason for the decline in innovation is a relatively weak(er) entrepreneurial system - and even entrepreneurial stagnation. Most scholars and German policy makers tend to be oblivious of this fact. Audretsch & Lehmann (2016b, p.302) have claimed that the country's economic performance is the result of "a vibrant entrepreneurship scene, which is the most dynamic in continental Europe". Germany, however, is not ranked among the top ten countries in the world or even in Europe in the *Global Entrepreneurship Index* (Acs et al., 2017). In the *Family Business Country Index* of the Mannheim-based ZEW Economic

Research Institute, Germany is ranked a poor 17th out of 21 advanced economies in 2020[20]. Only about half of the German population considers entrepreneurship to be a good career choice, which is lower than the OECD average and much lower than the 70% in the United States and the 80% in the Netherlands (Jones & Jin, 2017). From an innovation point of view, the stagnation in entrepreneurship is of concern as it means that it has not been as effective in producing and commercialising innovations in recent times as during earlier periods, and has become less 'Schumpeterian', *i.e.*, less disruptive and less likely to displace existing firms (Bessen et al., 2020; Henrekson & Sanandaji, 2017). This is a reason for the dearth of radical innovations as well as for the slower diffusion of technology.

The main feature of entrepreneurial stagnation in Germany is reflected in the dominant position of its large multinational firms and the entrenched nature of its *Mittelstand*, both features already noted earlier[21]. These features result in reduced competition, which has both static and dynamic negative effects, the latter in particular resulting in reduced disruptive innovation. For the United States, Bessen et al. (2020) found that reduced competition has indeed been accompanied by less risk of displacement of incumbent firms since 2000. The authors state that "[w]hile technology is often seen as disrupting industry leaders, it now appears to help suppress disruption" (Bessen et al., 2020, p.1). This is likely also the case in Germany, where the dominant position of the large multinational firms hark back to the last decades of the 19th century. These "settled 19th century industries" have been described as "dominant and entrenched" with the potential to "shift resources towards themselves" (Fohlin, 2016, p.19). They do not face significant competition[22], the threats of new entrants to disrupt their markets are low, and their defensive innovation strategies solidify their positions - all which contributes to a decline in the contestability in Germany's market, consistent with the OECD experience more generally (Andrews et al., 2016).

As a result of this corporate dominance, not only has the diffusion of technology been delayed, but the establishment and growth of new firms - most often the source of radical innovations - stifled. Evidence for this is reflected in that "in Germany's DAX 30 index of leading companies, only two were founded after the 1970s" (Erixon & Weigel, 2016, pp.10-11). More generally Germany has, like most notably the United States, experienced a long-run decline in the start-up rate of new firms since 1990 (Decker et al., 2016). Data from the Mannheim

[20] See `https://www.familienunternehmen.de`

[21] In the United States, another feature of entrepreneurial stagnation is the financialisation of the economy and the pernicious effects of financial innovation, see for instance Johnson & Kwak (2012). Germany, in contrast, has not experienced the same degree of financialisation as the United States (Niehues, 2015).

[22] This suggests a need for better competition policy. Watzinger et al. (2020) argue that competition policy is beneficial for the diffusion of technology, discussing the example of the *Bell Labs* in the United States.

Enterprise Panel show that the index of start-up activity, measuring the proportion of new firm entry, fell from 120 to 60 in Germany between 1990 and 2013, a 50% decline. The country has also experienced a decline in the share of firms which indicate that they plan to grow. In Germany, this percentage was around 1% in 2017, which compares unfavourably to 3.6% of US firms, 3.9% in China, and 5.7% in Switzerland (Henrekson & Sanandaji, 2017).

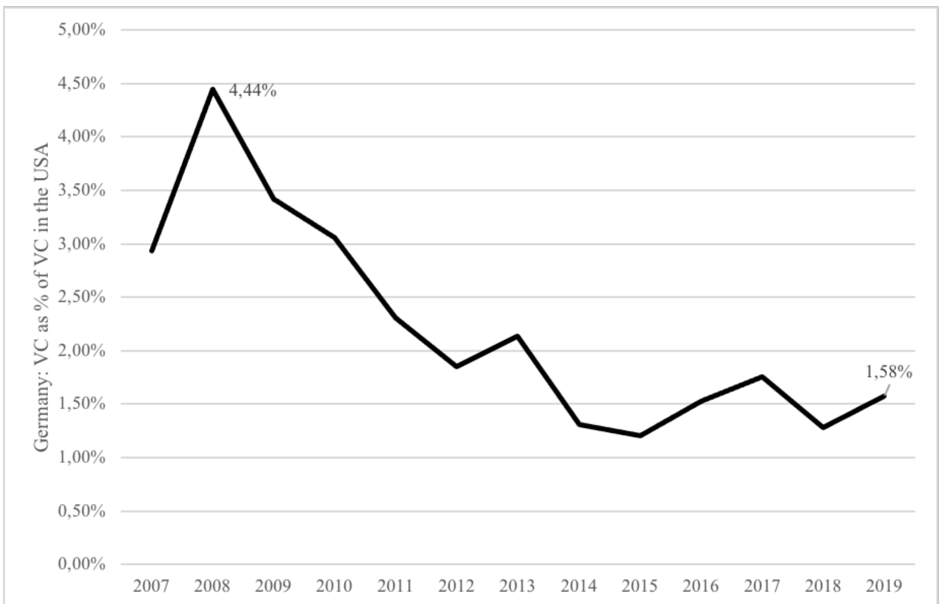
The stagnation in entrepreneurship is not only reflected in the declining start-up rate, but also in the nature of entrepreneurship, which has become less dynamic and less 'Schumpeterian'. In this respect, Henrekson & Sanandaji (2017) measure 'Schumpeterian' entrepreneurship by the *per capita* number of self-made billionaire entrepreneurs, the number of large firms that were founded by individual entrepreneurs after 1990, venture capital investments as percentage of GDP, and the number of unicorns, *i.e.*, the number of recent start-ups with a market capitalisation of at least USD 1 billion. Regarding these measures, the authors report that Germany had only 0.52 billionaires per million inhabitants compared to 1.37 in the United States and 0.55 in East Asia; only three large firms have been founded since 1990 compared to 60 in the United States and 22 in China; and it had only five unicorns compared to 115 in the United States and 47 in China.

Another measure of entrepreneurial stagnation in Germany is reflected in the growth and development of the venture capital (VC) industry. VC is a rough indicator of high-tech entrepreneurship, as it is most intensively used to finance high-tech start-ups and growth-oriented entrepreneurship (Adelet McGowan et al., 2017; Henrekson & Sanandaji, 2017). Florida & King (2016) estimate the total value of VC investment worldwide to USD 42 billion in 2012. Of this amount, only 13.5% was invested in Europe. And within Europe, Germany's share of VC was relatively small, behind the United Kingdom, France, Denmark and Russia. Florida & King (2016) also report that among the top 20 global cities for VC investment there was no German city at all. 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-regions, such as Beijing, have also experienced more than double the VC investments compared to the entire country of Germany.

Looking at more recent VC data from the OECD, we find that although the absolute value of VC did increase in Germany, from just over USD 1 billion in 2006 to just over USD 2,1 billion in 2019, the country's actual position weakened relatively to the growth of VC in the United States (the frontier country) as Figure 7 shows. The figure indicates that VC investment in the United States was around 63 times that invested in Germany in 2019 (around 16 times in *per capita* terms). Comin et al. (2016) consider the relative lack of VC in

Germany directly to be a symptom of an 'innovation crisis'. Audretsch & Lehmann (2016a, 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 an earlier attempt to stimulate VC entrepreneurship, the so-called *Neuer Markt*, collapsed, and how a host of government policies intended to stimulate new emerging technologies, such as biotechnology, was deemed to have largely "disappointed" by 1998. The stagnation had already set in.

Figure 7: Venture capital in Germany as % of US venture capital (USD, 2007-2019)



Data source: Authors' own compilation based on data from the OECD Stat.

5 Concluding remarks

In their book *The Seven Secrets of Germany*, Audretsch & Lehmann (2016a, p.7) argue that Germany's relatively good economic performance, especially since 2010, when the rest of Europe was struggling with the effects of the global financial crisis, was due to "a remarkable entrepreneurial society" which moreover is "an important role model for countries in Europe and elsewhere". We believe, as argued in this paper, that this view is unfortunately wrong.

In the past decade Germany has performed well in terms of employment growth, exports and macro-economic stability. This performance had more to do with the dependence on an exporting model - the 'bazaar' economy *à la* Sinn (2006) - facilitated by having the Euro as currency, rather than on innovation-driven entrepreneurial growth (Burda, 2016). Labour productivity growth has continuously declined, despite high employment and successful exports, reflecting that the economy has become less innovative. With the sustainability of Germany's export-led growth model under pressure since the 2008 global financial crisis, and with the likely acceleration of de-globalisation in the wake of the COVID-19 pandemic (Razin, 2020), the challenge of revitalising innovation is paramount.

How can this be done? Revitalising the German technological innovation system is likely to be a challenging task, as recent history suggests that the innovation system has become rather entrenched. It will be difficult for the government and industry to significantly alter the nature of the country's innovation system over the short- to medium-term, as it has shown itself to be quite resistant to change. Various successive post-war governments have essentially been unable to effect noticeable shifts in innovation outcomes (*e.g.*, patents). This has also been identified and discussed by Grupp et al. (2005, p.27-28) who conclude that,

> "[m]ost astonishingly the German innovation system was very stable although it witnessed several political system changes in the past century [...]. This persistence of the innovation system points to a resistant innovation culture in and around Germany which may not be influenced so much by external shocks and incentives."

That the innovation system has become entrenched is not to say that changes are not possible. Rammer & Schubert (2018, p.388), for example, have called for more robust public support of firm-level innovation efforts, pointing out that "Germany is among the countries with the lowest shares of state-funded enterprise R&D". They show that the share of this type of funding is more than twice as high in France, the United Kingdom and the United States compared to Germany. And Falck et al. (2019) have called for a redesign of the country's *Innovative Regional Growth Cores* (IRGC) programme after finding that this programme has been ineffective and resulted in crowding-out of private R&D. Moreover, to generate more breakthrough-type innovations in areas of the new industrial revolution, initiatives will need to be embedded in an appropriate industrial policy, which could however face political difficulties at the national level and constraints at the EU level.

It may also be effective to focus on addressing the country's entrepreneurial stagnation, which is characterised by the defensive strategies of large incumbent firms, a growing productivity gap between leading and lagging firms, and declining innovation activities by the *Mittelstand*.

Reasons for these features include relatively poor management practices and lack of effective competition (contested markets). These have shown resulted in a decline in fixed capital investments and in the inability of lagging firms to learn from, and catch up to, leading firms. As a result, the diffusion of technology has become sluggish, and the economy less innovative.

There is no shortage of concern about entrepreneurial stagnation in Europe and in the United States, and hence no shortage of prescriptions to remedy this. Many of these will also be relevant for Germany. Recent examples include Decker et al. (2014), Elert et al. (2017), Leceta et al. (2017), Naudé (2020) and Thierer (2016). Leceta et al. (2017) argue for actions that focus on 'people, places and policies' and put forward a list of no less than 55 policy recommendations from which one can conclude that a truly comprehensive - perhaps big push - effort is required to turn European countries into more conducive places for entrepreneurs. Similarly, Elert et al. (2017) propose reforms across nine broad areas in the EU to make countries more entrepreneurial, so that innovation can have a 'Schumpeterian' impact. These nine areas exhaustively cover what can be described, such as the institutions governing the entrepreneurial ecosystem, including laws, tax systems, social insurance, regulations, human capital and intellectual property.

A discussion and evaluation of these proposals fall outside the scope of the present paper, but it is worth a consideration and further investigation in the future. From our survey of the key features of the German institutional environment since the 1870s, we conclude that four areas should be highlighted for special attention: (i) education and managerial capabilities, (ii) venture capital, (iii) the contestability of markets, and (iv) the social welfare system. The latter may be particularly important, and at the same time unappreciated, tool to improve entrepreneurship and innovation. It should be kept in mind that Germany's industrialisation was greatly facilitated by introducing the world's first social welfare state. The country's continued economic success in a more risk-averse post-COVID-19 world, will likewise require an appropriate social welfare approach.

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