IZA Institute of Labor Economics

Initiated by Deutsche Post Foundation

DISCUSSION PAPER SERIES

IZA DP No. 15607

The Ossified Economy: The Case of Germany, 1870-2020

Wim Naudé
Paula Nagler

SEPTEMBER 2022

I Z A Institute
of Labor Economics

Initiated by Deutsche Post Foundation

DISCUSSION PAPER SERIES

IZA DP No. 15607

The Ossified Economy: The Case of Germany, 1870-2020

Wim Naudé
RWTH Aachen University, ASC Leiden University and IZA

Paula Nagler
Erasmus University Rotterdam and IZA

SEPTEMBER 2022

ISSN: 2365-9793

IZA – Institute of Labor Economics

Schaumburg-Lippe-Straße 5–9
53113 Bonn, Germany

Phone: +49-228-3894-0
Email: publications@iza.org

www.iza.org

ABSTRACT

The Ossified Economy: The Case of Germany, 1870-2020

We describe Germany's rise as an industrial power in the late 19th century through radical innovation and entrepreneurship, and contrast this with the post-World War II period. This latter period, although it contained the German economic miracle, was nevertheless a period during which innovation slowed down - a somewhat surprising conclusion, but consistent with the decline in business dynamism noted in a growing number of advanced economies. We document this decline using several innovation indicators, and offer four broad, interrelated explanations in a historical context: (i) the innovation system is locked into incremental innovation, (ii) the diffusion of technology is slowing down, (iii) the education system is subject to weaknesses, and (iv) entrepreneurship is stagnating. Implications for policy are noted. Our paper contributes to the literature on the decline in business dynamism and the "great stagnation", to the literature on the historical forces that determine innovation outcomes, and to the literature that seeks to identify what makes an entrepreneurial state.

JEL Classification: N13, N14, O31, O33
Keywords: innovation, Germany, entrepreneurship, technology

Corresponding author:
Wim Naudé
Technology and Innovation Management (TIM)
RWTH Aachen University
Kackertstraße 7
52072 Aachen
Germany
E-mail: wnaude@ucc.ie

1 Introduction

The evidence that innovation in advanced economies is in 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). That innovation in many advanced economies is declining is however no novel thesis - concerns have been voiced by, amongst others, Arora et al. (2019), Bhaskar (2021), Bhattacharya & Packalen (2020), Bloom et al. (2020), Brynjolfsson et al. (2017), Gordon (2015), Huebner (2005) and Jones (2009). Erixon & Weigel (2016) and Ridley (2020) refer to an "innovation famine," Elert et al. (2017, p.1) describe the European Union as suffering from an "innovation deficit" and according to Bhaskar (2021) we live in "an age of small thinking." Naudé (2022) labels this the "ossified economy" to contrast this to the claim that the West is characterised by an "entrepreneurial economy" (Audretsch & Thurik, 2004). The slowdown in innovation is considered an important reason for the decline in business dynamism that is 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 1870 to the present. Our concern is not with the level of innovation, but with changes in innovation, i.e., with innovation getting becoming more "difficult." The first part of the paper describes trends in innovation, using several indicators, and shows that these paint a consistent picture of a long-term slowdown in innovativeness. The second part of the paper offers some conjectures - which are critically assessed - on some of the causes of the slowdown. Thus, in this paper we document changes in innovation and identify the likely suspects behind both the rise in innovation in the late 19th century and its comparative slowdown since the 1970s.

Our paper contributes to the literature attempting to understand the decline in business dynamism that characterises advanced economies (e.g., Decker et al., 2017). It also contributes to the literature that tries to understand the historical determinants of innovation (e.g., Mokyr, 2010) and to the literature that seeks to identify what makes an entrepreneurial state (e.g., Mazzucato, 2013). It may also provide a counter-perspective to the view that the current era is the most consequential in history, the "most important century" (Karnofsky,

[1] The decline in business dynamism in advanced economies has been extensively documented by, amongst others, Akcigit & Ates (2019), Bhaskar (2021), Bijnens & Konings (2018), Bravo-Biosca (2016), Cowen (2010, 2016, 2017), Criscuolo et al. (2014), Decker et al. (2016, 2017), Gordon (2012, 2016) and Naudé (2022).

2021). Our paper further contributes to the long-term quantitative depiction of economic development in Germany, Europe's largest economy, for instance, complementing recent long-term studies on the evolution of inequality (e.g., Alfani et al., 2022; Bartels, 2019) and sustainability (e.g., Blum et al., 2017) in the country.

We consider Germany to be an interesting and relevant case study from which to learn more about the long-term patterns of and returns to innovation. On the one hand, the country is not a special case, because most advanced economies have been experiencing a slowdown in innovation. On the other hand, Germany's experience shows that while the pathways and patterns by which institutions and incentives affect innovation change are country-specific, it may hold more general lessons. Hence, while the rise of German innovation after the 1870s was based on a unique historical confluence of policies and circumstances, the contemporary lesson that it holds for the West is that a comprehensive range of complementary measures and initiatives, akin to a "big push", may be needed to propel new scientific breakthroughs - which may be necessary for further gains in productivity and value-added (Naudé, 2022). The "low-hanging fruits" of physics and innovation seem to have been largely exhausted by now (Gordon, 2012; Johnson, 2014; Weinstein, 2012), and Germany, as one of the countries that made some of the most fundamental contributions to physics, illustrates this point well.

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 works of Akcigit et al. (2017) on the United States, Prados de la Escosura & Rosés (2020) on Spain, and Yamashita (2021) on Japan. The experience of Germany is particularly interesting and relevant given concerns about a slowdown in innovation, since the country has traditionally been 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. Because of this, we have been careful to base our analysis on a wide range of perspectives, using various measures and considering these over as long a period as data availability allows. This approach, which is also an attempt to avoid criticisms of cherry-picking data, indicates that the broad range of measures on innovation are overall consistent.

While our paper is perhaps the most comprehensive, as far as we are aware, in arguing that Germany's innovation is in relative decline, we are not the first or only scholars to have

[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 [...], 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".

come to this conclusion. Scholars including Boeing & Hünermund (2020), Kwon et al. (2017), Mroczkowski (2014), Lang (2009), Rammer & Schubert (2016, 2018), Schoellhammer (2022) and Zabala-Iturriagagoitia et al. (2021) have raised similar concerns. What we contribute is a synthesis - putting together a long-run and multi-sided perspective, and identifying possible reasons for the innovation slowdown.

One reason why our thesis of declining German innovation is often at first met with incredulity, and thus not widely acknowledged, is that the adverse consequences which normally follow a slowdown in innovation may have been offset by the country's (past) economic success. This has, especially since the 1960s, being accomplished through export-led growth. This has been the ascribed, not uncontroversially, as the outcome of a "bazaar economy" (Sinn, 2006). But with the sustainability of Germany's bazaar economy increasingly under pressure,[3] the likely acceleration of de-globalisation in the wake of the COVID-19 pandemic (Razin, 2020), the spectre of de-population (Jones, 2020) and the country's problematic energy policies,[4] the revitalisation of innovation becomes urgent. The challenge is that innovation is getting more difficult, just as the country is facing unprecedented post-WWII headwinds to well-being and sustainability (Blum et al., 2017; Schoellhammer, 2022).

The rest of the paper proceeds as follows. In Section 2, we describe the historical co-evolution of economic growth and innovation in Germany from 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.

[3]In May 2022 Germany ran a one-billion euro trade deficit, the first such since 1991.

[4]Referring to rising energy prices in 2021-2022, Schoellhammer (2022) predicts that "the year 2023 will see electricity turning from a utility into a luxury good for many Germans."

2.1 From new country to World War I, 1871-1913

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)[5], 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. Half a 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)[6] 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 were paramount. These institutions were widely accessible,

[5] 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. Hornung (2014) describes how Huguenot immigrants fleeing France after 1685 boosted textile manufacturing in Prussia.

[6] 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".

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[7] (Grupp et al., 2005).

The scientific breakthroughs at these universities and poly-technical institutions were quickly taken up and applied for commercial purposes by German entrepreneurs[8]. 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 chemicals industry with firms such as *BASF*, *Bayer* and *Höchst*. The chemical 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 innovations - many radical[9] - by engineer-entrepreneurs that resulted from this context during the late 19th and early 20th century is remarkable. Table 1 lists a selection of major innovations and their associated engineer-entrepreneurs (we list entrepreneurs that have made a mark; many others have failed). The legacy of these innovators lasts to present-day Germany in that many 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.

[7]Interestingly, this period also saw an unique flourishing of engagement between scientists, science fiction writers and the public on spaceflight - laying the seeds for rocket-based spaceships in the 20th century. In 1891 for example, Hermann Ganswindt designed a spaceship based on reaction propulsion (Brandau, 2012).

[8]The simultaneous development of finance in Germany, in the form of joint-stock credit banks (Burhop, 2006) and the Berlin stock exchange (Lehmann-Hasemeyer & Streb, 2016), played a significant role in getting these innovations funded.

[9]We follow Hesse & Fornahl (2020, p.1166) in defining radical innovations as radical if "they introduce totally novel knowledge combinations [...] or if they are radical in terms of their impact".

Table 1: Selected Major 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.

To respond to possible criticism that Table 1 is selective and provides no basis for comparison with the most recent past, we prepared a count of inventions and discoveries in Germany over a broad range of fields - including fashion[10], tourism[11], appliances[12] and animals[13] - in the period 1870 to 1945, and contrasted this with the 1946 to 2020 period. We based this count on a comprehensive list published on Wikipedia. This is crowd-sourced and open to scrutiny, thus less subject to individual bias. The result is depicted graphically in Figure A1 in the appendix. This shows that in virtually all fields Germany was more innovative

[10] An example is the invention of the jeans, in 1871, by German-born Levi Strauss.

[11] The world's first purpose-built cruise-ship, the *Prinzessin Victoria Luise*, was a German innovation.

[12] Examples include the modern refrigerator invented by Carl von Linde in 1870 and the glue stick of Henkel (1969).

[13] These inventions include, for example, the founding of the modern zoo in Hamburg in 1907 by Carl Hangenbeck and the establishment in 1916 of the world's first guide-dog training school.

between 1870 and 1945. In fact, the total number of inventions and discoveries in the period 1946 to 2020 was only 27% of the inventions and discoveries of the period 1870 to 1945. Only in the fields of electronics[14], sports[15], toys[16], and computing did Germany do better or similar in the latter period.

The third partner in the emerging innovation system was the government. According to Parada (2018, p.640) "during Imperial Germany, the role of the state was overwhelming". National and state governments supported universal education, an moreover 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 industries and trade[17] (Kopsidis & Bromley, 2016). 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. 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 can thus to be traced back to this era (Audretsch et al., 2018).

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, and by 1907 labor productivity in Germany was between 4% and 7% higher in Germany than in the UK (Veenstra, 2015). Burhop & Wolff (2005) found 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

[14] An example of a notable post-1945 German invention in electronics is the SIM card in 1991 by Giesecke & Devrient.

[15] Amongst post-1945 inventions in sports, modern football boots, introduced by Adidas and Puma, can be mentioned.

[16] In 1902, Richard Steiff invented the Teddy Bear. In the post-1945 period, Playmobil, invented by Hans Beck, stands out.

[17] 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).

1880, from a 1.3% per year average between 1860 and 1879, to a 1.9% per year average between 1880 and 1900[18]. According to Pfister (2019, p.514) GDP capita (measured in 1990 international dollars) more than doubled between 1851 and 1913, from USD 1,697 in 1851 to USD 3,648 by 1913 - a 115% increase.

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. (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

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

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 established companies that were the result of the remarkable innovations mentioned in Table 1 as well as scientific and educational institutions, survived. These eventual corporate giants, such as *BMW*, *Bosch*, *Daimler-Benz*, *Siemens*, *Volkswagen* and others, would 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[19], 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, 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-

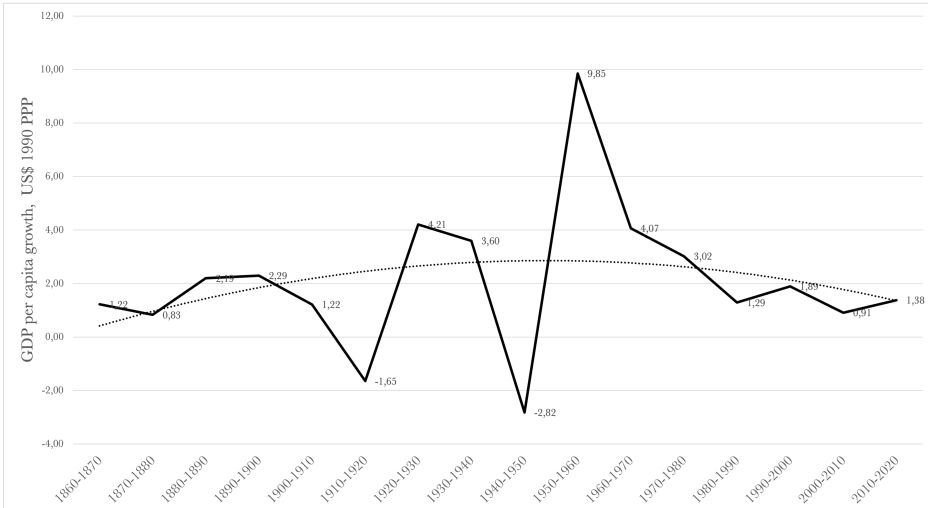
[19] The 'triple-helix' model of innovation refers to interactions between academia, industry and governments, to foster economic and social development.

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 to put the decline in economic growth (and innovation) in 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. It is important to emphasise that we are focusing in this analysis of per capita GDP growth on its changes, rather than levels. In other words, the direction of change in growth was positive (accelerating) before World War I, and negative (decelerating) after World War II - the slope of the trend-line in Figure 1 becomes negative in the 1950s.

Figure 1: Per capita GDP growth in Germany per decade, 1860-2020



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[20] 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 country-level measures of innovation. The measures of innovation that we use are patent data, the growth rate of total factor productivity, and R&D expenditure shares. These are all imperfect measures of innovation, but they are however the the three most used and accepted measures of innovation in the literature, and moreover for which reliable data is available (Edison et al., 2013; OECD, 2005) and moreover, as we show below, these measures trace a consistent trajectory. We also suggest that innovation has been becoming less effective as a driver of growth than before. This is despite the fact that the government and corporate sector continue to channel significant amounts of investment into innovation.

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

We need to reiterate that 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, Zabala-Iturriagagoitia et al. (2021), using a global Malmquist productivity index applied to the 2019 European Innovation Scoreboard, finds a significant decline in the productivity of Germany's national innovation system (and that of some other EU countries), 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 to have reached an all-time low spanning the last 45 years". We add to these findings, and contrast them with history.

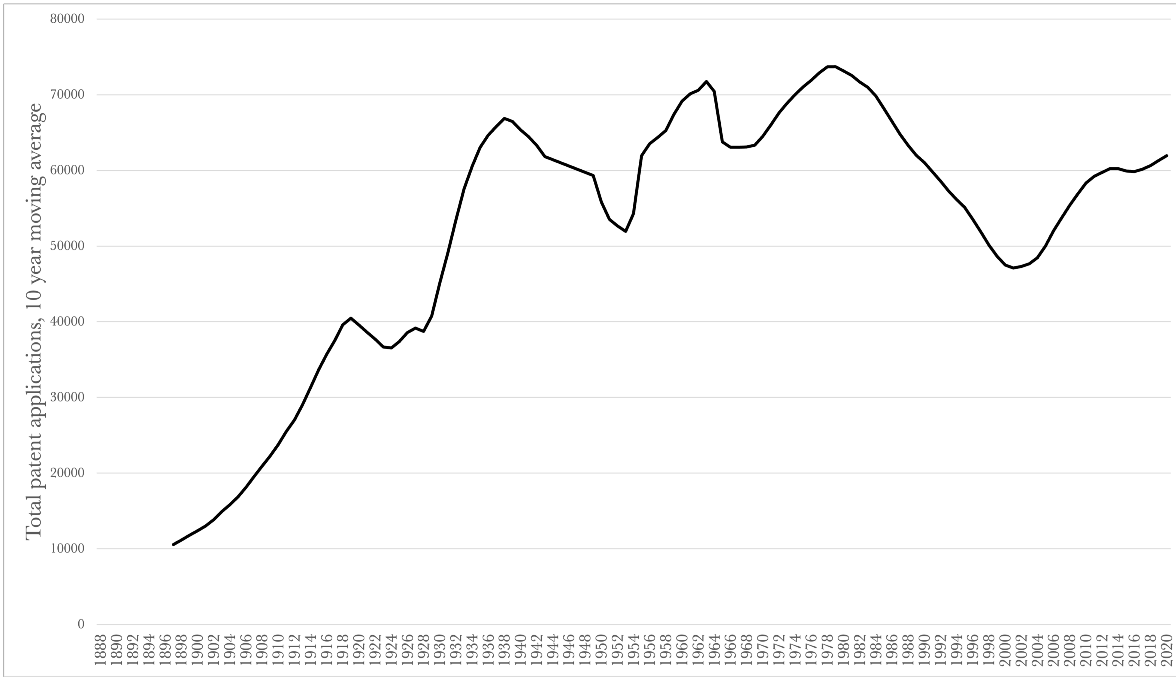
We first use patent data, a generally accepted "output" indicator of innovation (though not without its shortcomings). Figure 2 depicts the long-run evolution in patent applications in Germany. It clearly shows that patenting reached a peak in the 1970s[21], after which it declined, with a recent (since 2002) resumption of growth in patenting. Those critical of our thesis will no doubt point to this most recent positive change as evidence that innovation is not declining anymore; the problem with such a conclusion is that it may be premature - in 2020, the 10-year moving average of patenting was at pre-war (1934 level), and after 2014, its growth rate had already slowed down. The suggestion from Figure 2 moreover is that innovation peaked in the 1970s, which is consistent with other measures of innovation, such as TFP growth (see Figure 4).

An important distinction lies between patent applications and patents granted. The difference can be seen in the percentage of successful (granted) patents to patent applications, which is shown in Figure 3. The figure illustrates a reduction in the percentage of patents granted relative to patent applications since the mid-1980s. While total patent applications started an upward trend around 2002 (see Figure 2), an upward trend in the percentage of patents granted started later, around 2012. It is too early to judge whether this upward trend will continue, as the long-term downward trend since the 1980s has been interrupted by temporary increases.

We discuss later in the paper to what extent the long-term decline in successful patent applications may reflect a decline in innovativeness. It should be again stressed that patents

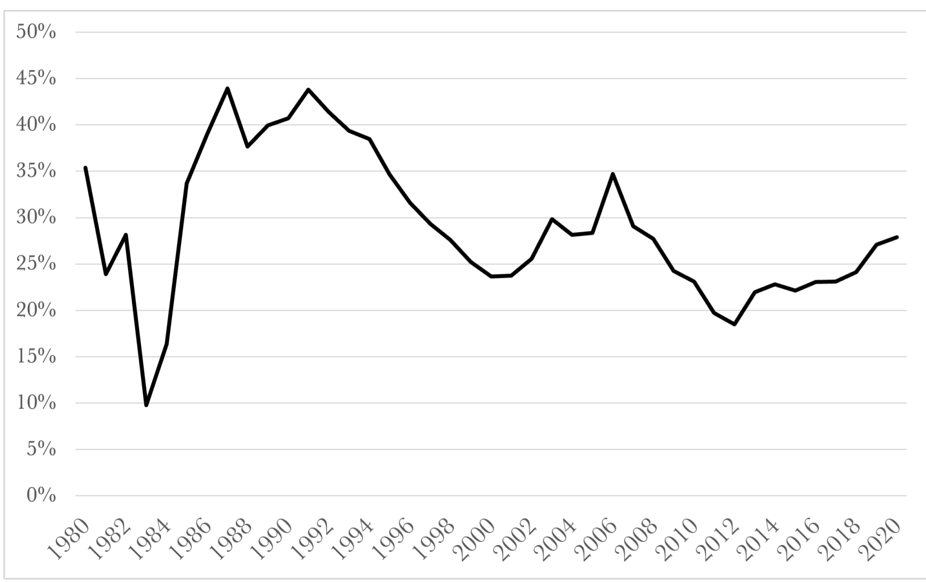
[21] The growth rate in innovation as measured by patenting in Figure 2 was particularly rapid between roughly 1923 and 1938 and gave rise to a first peak in innovation by 1938. This is interesting in light of the analysis of Field (2003, p.1399) which shows that for the United States "the years 1929–1941 were, in the aggregate, the most technologically progressive of any comparable period in US economic history".

Figure 2: Total patent applications in Germany, 1883-2020 (10-year moving average)



Data source: WIPO IP Statistics Data Centre at `https://www3.wipo.int/ipstats/`.

Figure 3: Patents granted as % of total patent applications in Germany, 1980-2020



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

are not a perfect measure of innovativeness[22], and that some caution is warranted in making

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

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).

Nevertheless, and despite these considerations, that the trend in patenting is consistent with a decline in innovation is also suggested by other evidence - evidence that suggests that the quality of German patents is declining. A 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.

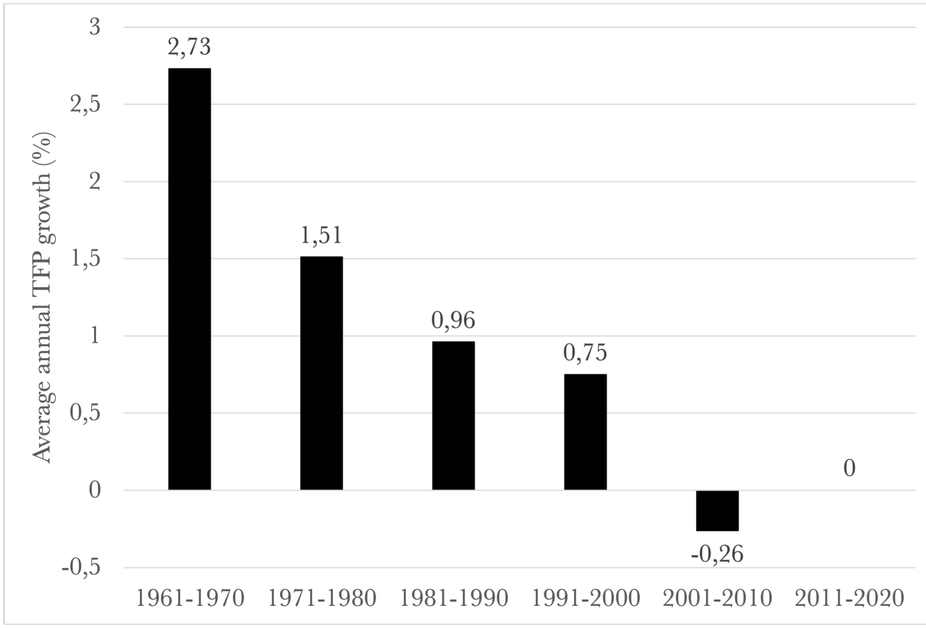
A second measure of innovation, apart from patent data, is total factor productivity (TFP) (Hall, 2011). As the OECD (2016) notes, TFP growth has been on a long-term decline in Germany. Figure 4 shows that German TFP annually grew by 2.73% on average between 1961 and 1970, and that growth declined over the subsequent decades, with a shrinkage in total factor productivity (-0.26%) experienced between 2001 and 2010. Since 2011, TFP growth has been stagnant.

The skeptical reader could counter-argue at this point that TFP is a also another poor measure of innovation. It could be a poor measure because it may be affected by the "Baumol's disease", that is the expansion of the share of low productivity growth sectors, such as services, in the economy (Baumol, 1967). Although we cannot rule out that such effects are contributing to declining TFP growth in Germany, there are two reasons that speak against. First, as Oulton (2001) noted, increases in the share of services do not automatically lead to declining productivity growth, if the share of intermediate services increases as well. Second, Rial & Herrero (2014, p.1), using German data from 2001-2014, found that "Baumol's

not to take this into account when measuring innovation.

growth disease does not substantially lower aggregate labour productivity growth over the period".

Figure 4: Average annual TFP growth in Germany, 1960-2020



Data source: European Commission AMECO database online and The Conference Board Total Economy Database, August 2021.

The 1960s and 1970s[23] were thus, at least measured by TFP, Germany's period of peak innovation in the post-war period. The comparison of inventions and discoveries in the appendix indicates that there is no comparable long list of breakthrough innovations and/or broad inventions and discoveries in the seventy years of post-1945 period, as opposed to the seventy years before (ca. 1870-1945). It likely reflects that most innovations after 1945, in particular by the rising *Mittelstand*, were more 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[24] of the so-called 4th Industrial Revolution[25] (Mroczkowski, 2014).

[23]Blum et al. (2017, p.419) plots TFP growth in Germany between 1851 and 2007 showing that TFP growth peaked at roughly 2,8% around 1958.

[24]For those readers wondering how nanotechnology, molecular biology and others are driving the 4th Industrial Revolution, we refer to Marr (2020).

[25]The 4th Industrial Revolution is distinct from Industrie 4.0 which refers specifically to Germany's approach towards digitising manufacturing and establishing leadership in smart production.

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 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%). Lehrer et al. (2009) documents that between 1994 and 2005 Germany registered only 0.11 patents per million inhabitants in the cutting-edge field of biotechnology at the EPO - compared to 6.0 of the UK, 17 of Israel and 18 of the USA.

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 virtually 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 innovation slowdown?

What caused the innovation slowdown noted in the previous section? In Section 2.1, we identified four driving forces of the rise in innovation (and the country's industrialisation). These were the abilities to incentivise and fund radical innovations, rapidly diffuse new technologies through higher education-private sector-government collaboration, a vibrantly relevant education and research sector, and a culture of entrepreneurship supported by an entrepreneurial state. In what follows, we argue that the decline in innovation over the past half a century has largely been the consequence of these driving forces dissipating. We therefore discuss four main reasons for the decline in German innovation in this historical context: (i) fewer radical innovations, (ii) slower diffusion of technology, (iii) a reduced capacity to learn and adapt new technologies, and (iv) a relatively weak entrepreneurial system, which also contributed to the aforementioned three factors.

4.1 Predominant engagement in incremental innovation

One reason for the decline in innovation is the conspicuous lack of radical or breakthrough innovations in the period after the Second World War, and the predominance of incremental innovations Mroczkowski (2014). This is the result of "the relative mediocrity of the modern German universities and their weakness in academic entrepreneurship as compared with the world leader the USA" (Mroczkowski, 2014, p.415). In Section 4.4, we discuss the decline in university entrepreneurship in more detail.

There is another reason for the predominantly incremental-innovation focus of the post-1945 German economy, and that is the rise of the *Mittelstand*. Heider et al. (2020, p.1) pointed 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[26]. 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".

[26] 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.

Finally, the lack of radical innovations in the period after World War II may reflect its impact or legacy. 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."

4.2 Slower diffusion of technology

A second possible reason for the decline in innovation, and in particular for the decline in (imperfect) 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 radical innovations and in Schumpeterian entrepreneurship in Germany and to the defensive corporate strategies previously discussed, the diffusion of technology may have slowed down as a result of two further factors. One channel is through the reduction gross capital formation and another is relatively poor management practices.

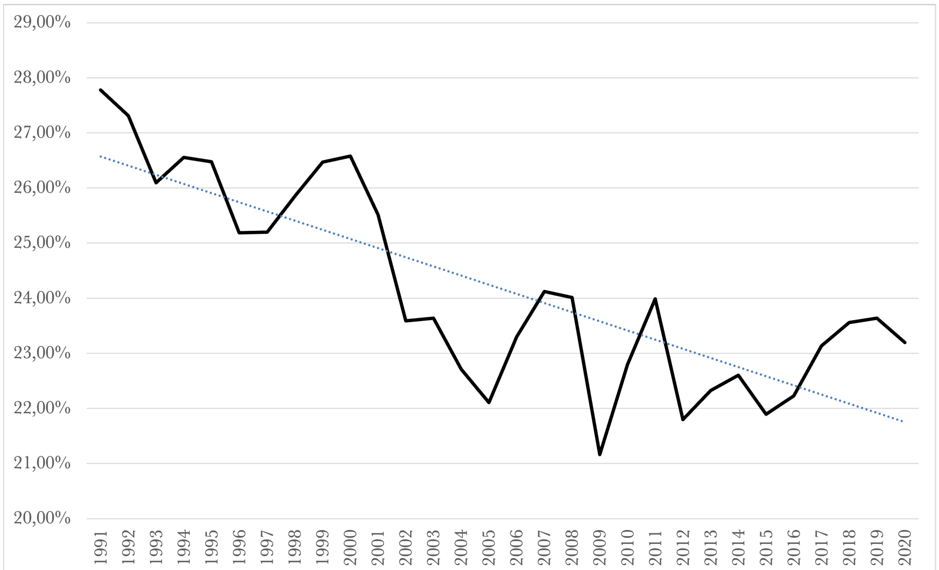
Gross capital formation[27] in Germany has, according to Erixon & Weigel (2016, p.30) declined "pretty dramatically". Given that technology diffuses through the economy embodied in capital investment, this is an obvious mechanism that will slow down the diffusion of technology.

In Figure 5, the decline in gross capital formation as share of GDP in Germany between 1991 and 2020 is depicted. The figure shows the steady decline from unification to 2009, and shows that after 2009 (global financial crisis), the share increased somewhat, although it has remained below pre-2000 levels. We speculate that the small increase in the gross capital formation share since 2009 may reflect 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[28] and hence investment.

[27] 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".

[28] It is well established in the literature - e.g. Auguste (2021); Lloyd-Ellis & Bernhardt (2000) – that

Figure 5: Gross capital formation as share of GDP (at 2015 prices) in Germany, 1991-2020



Data source: World Development Indicators online.

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) 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". While we recognise this as a potential problem based on the literature, clearly more research is needed to understand how changes in management practices and quality over time have affected the adoption of new technology.

The effects of declining gross capital formation and sub-optimal management practices may have been exacerbated by the decline in collective bargaining in the country. Germany had a strongly unionised labour market with a peak in unionisation in the early 1990s, which subsequently declined (Naudé & Nagler, 2017). This decline could have exacerbated relatively poor management practices as strong worker participation in management in the past

credit constraints affect start up activity, and that with high inequality access to own wealth for startups are limited to the rich.

facilitated the adoption and diffusion of new technology through, amongst others, investment in gross capital. See also the arguments of Addison et al. (2013) in this regard.

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 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. Specific labour markets policies, such as the practice of short-time work[29], may have contributed to the same phenomenon. At least in normal (non-crisis) times[30], 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 due to weaknesses in the education system. While this system has traditionally been much-praised, and indeed is of high quality and relevance, it is often ranked 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[31]. 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

[29]See Brenke et al. (2011) for a discussion and evaluation of the short-time work programs, which they describe as context specific to Germany.

[30]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.

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

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[32]. 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[33]. The authors warn that "[a] country like Germany with a training 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 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, compared 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 2.2% 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.

Whereas the relatively specialised nature of Germany's education system is widely recognised, it is less clear whether is able to keep up "the production and delivery" of highly skilled workers (researchers) that are needed in the R&D sector. For instance, 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. 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. However, increasing the number of researchers in R&D further may not necessarily result in boosting innovation and growth, given the likelihood that the country is, as some other advanced economies, already facing possible declining rates of return to researchers in R&D. This is

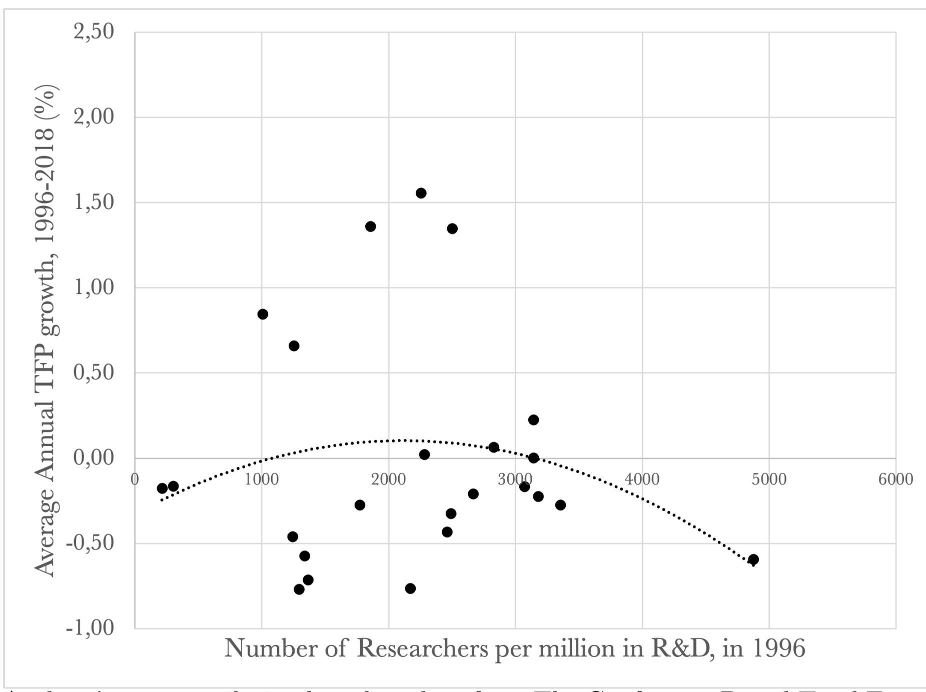
[32] Data source: World Development Indicators.

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

generally a well-recognised phenomena in some other advanced economies, such as the USA, where a studies have documented the decline in the rates of return to R&D, see for instance Bloom et al. (2020).

In Figure 6, we plot the relationship between researchers in R&D in 1996 and subsequent TFP growth in OECD countries. It can be seen that there is an inverted U-shaped relationship between the number of researchers in R&D and subsequent TFP growth in the OECD. This is consistent with the idea of diminishing returns. Specifically, the turning point seems to be around 2,200 researchers in R&D per million inhabitants. Germany was already above this turning point in 1996, with around 2,831 researchers in R&D per million. Almost no country with more than 3,000 researchers in R&D per million in 1996 achieved positive average annual TFP growth in the period 1996 to 2018. Thus, from the cursory analysis reflected in Figure 6, one may conclude that Germany's R&D sector is facing diminishing returns. This is a conclusion which is consistent with findings of Boeing & Hünermund (2020) and Lang (2009).

Figure 6: Researchers in R&D per million and subsequent TFP growth in OECD countries, 1996 to 2018



Data source: Authors' own compilation based on data from The Conference Board Total Economy Database, August 2021 and the World Bank Development Indicators online (number of researchers).

Why has the education system not been more dynamic in light of the weaknesses and trends noted in the preceding paragraphs? One possibility may be that the higher education sector 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 has been argued to be too much tailored to industrial needs (Malmer & Tholen, 2015). And 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".

We cannot make any conclusion here as to whether the education sector in Germany has been stagnant and whether it is characterised by coddled university academics, and moreover whether this is a significant factor in the decline in the country's relative innovativeness over time. A proper evaluation of these findings and claims fall outside of the scope of our paper - but we hope that by flagging it, we may motivate future research.

4.4 Entrepreneurship stagnation

The fourth reason for the decline in innovation is a relatively weak(er) entrepreneurial system - and even entrepreneurial stagnation. As Aly & Galal-Edeen (2021, p.1376) bluntly put it, "[t]he entrepreneurial performance of Germany has been notoriously dismal".

Most scholars and German policy makers seem oblivious of this fact. Audretsch & Lehmann (2016b, p.302) even claim that the country's economic performance is the result of "a vibrant entrepreneurship scene, which is the most dynamic in continental Europe". This is despite the fact that Germany 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.[34] Aly & Galal-Edeen (2021) argues that German culture has become more risk averse. Consistently, 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

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

‘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[35]. 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[36], 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 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

[35]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).

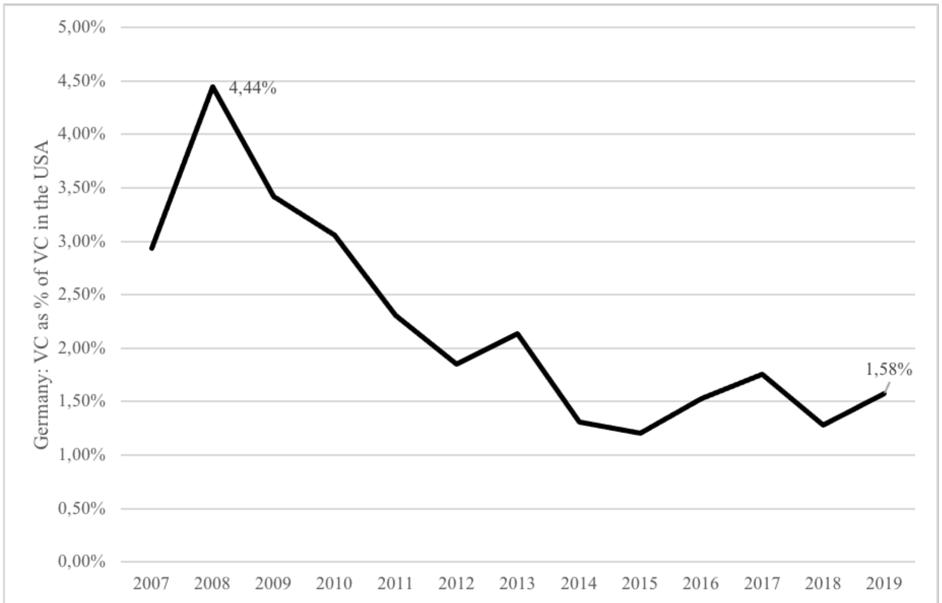
[36]This suggests a need for better competition policy. Watzinger et al. (2020) argue that competition policy is beneficial for the diffusion of technology, discussing the example of the *Bell Labs* in the United States.

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.

Considering more recent VC data from the OECD, we find that, although the absolute value of VC increased 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.

Finally, entrepreneurial stagnation in Germany is not only reflected in the measures discussed above, but also in the declining entrepreneurialism of its university sector Mroczkowski (2014). Lehrer et al. (2009, p.270) document what they describe as the "relative decline of German university dynamism after 1945" which is visible in, amongst others, the relative decline in Nobel Laureates. Between 1901 and 1956 the German university system won 38 Nobel Prizes - and between 1956 and 2005 only four. In comparison, the US university system gathered 189 Nobel Prizes during the latter period (Lehrer et al., 2009).

5 Concluding remarks

In their book *The Seven Secrets of Germany*, Audretsch & Lehmann (2016a, p.7) argued 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), 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) 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. Mazzucato (2015, 2020) has a similar comprehensive approach in mind by arguing for mission-oriented industrial policies - akin to "moonshots" to reinvigorate innovation in Europe. Finally, although we did not deal in this paper on the links between innovation and energy, the 2022 European energy crisis is a stark reminder of the centrality of energy for business dynamics and of the complexity of the challenge of (green) energy security. It a potent call for comprehensive steps to reverse the decline in innovation and entrepreneurship that we had described in this paper.

A discussion and evaluation of these proposals, including that of the challenges and opportunities of energy, 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 linked to a more entrepreneurial state. The latter may be particularly important, and at the same time an unappreciated tool to improve entrepreneurship and innovation. It should be kept in mind that Germany's industrialisation was greatly facilitated by and entrepreneurial state 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 entrepreneurial state-social welfare approach.

Acknowledgement

This paper is a substantially revised version of our earlier IZA Discussion Papers no. 14154 and no. 11194.

References

Acs, Z., Szerb, L., & Lloyd, A. (2017). The Global Entrepreneurship Index, 2018. *Washington DC: The Global Entrepreneurship and Development Institute.*

Addison, J., Teixeira, P., Evers, K., & Bellmann, L. (2013). Collective Bargaining and Innovation in Germany: Cooperative Industrial Relations. IZA Discussion Paper No. 7871. Bonn: Institute for the Study of Labor.

Adelet McGowan, M., Andrews, D., & Millot, V. (2017). Insolvency Regimes, Technological Diffusion and Productivity Growth: Evidence from Firms in OECD Ccountries. *OECD Economics Department Working Paper No. 1425. OECD: Paris.*

Akcigit, U. & Ates, S. (2019). Ten Facts on Declining Business Dynamism and Lessons from Endogenous Growth Theory. *CEPR Discussion Paper no. 13668, Centre for Economic Policy Research.*

Akcigit, U., Grigsby, J., & Nicholas, T. (2017). The Rise of American Ingenuity: Innovation and Inventors of the Golden Age. *Working Paper No. 23047, National Bureau of Economic Research.*

Alfani, G., Gierok, V., & Schaff, F. (2022). Economic Inequality in Preindustrial Germany, ca. 1300-1850. *The Journal of Economic History*, 82(1), 87–125.

Aly, M. & Galal-Edeen, G. (2021). Why is Germany Less Entrepreneurial? A Behavioral Reasoning Perspective. *The Journal of Technology Transfer*, 46, 1376 – 1416.

Andrews, D., Criscuolo, C., & Gal, P. (2016). The Best versus the Rest: The Global Productivity Slowdown, Divergence across Firms and the Role of Public Policy. OECD Productivity Working Papers No. 5. Paris: OECD Publishing.

Andrews, M. J., Chatterji, A., & Stern, S. (2020). Beyond 140 Characters: Introduction to The Role of Innovation and Entrepreneurship in Economic Growth. *Working Paper No. 28105, National Bureau of Economic Research.*

Arora, A., Belenzon, S., Patacconi, A., & Suh, J. (2019). The Changing Structure of American Innovation: Some Cautionary Remarks for Economic Growth. *NBER Working Paper No. 25893. National Bureau of Economic Research.*

Audretsch, D. & Lehmann, E. (2016a). *The Seven Secrets of Germany: Economic Resilience in an Era of Global Turbulence.* Oxford: Oxford University Press.

Audretsch, D., Lehmann, E., & Schenkenhofer, J. (2018). Internationalization Strategies of Hidden Champions: Lessons from Germany. *Multinational Business Review*, 26, 2–24.

Audretsch, D. & Thurik, A. (2004). A Model of The Entrepreneurial Economy. *International Journal of Entrepreneurship Education*, 2(2), 143 –166.

Audretsch, D. B. & Lehmann, E. (2016b). Industrial Policy in Italy and Germany: Yet Another Look. *Economia e Politica Industriale*, 43(3), 291–304.

Auguste, D. (2021). The Impact of Economic Inequality on Entrepreneurship: Does a Societys Stage of Development Make a Difference? *Sociological Perspectives*, 64(2), 176–195.

Bairoch, P. (1982). International Industrialization Levels from 1750 to 1980. *The Journal of European Economic History*, 11, 269–310.

Bartels, C. (2019). Top Incomes in Germany, 1871-2014. *The Journal of Economic History*, 79(3), 669–707.

Baumgarten, D. (2013). Exporters and the Rise in Wage Inequality: Evidence from German Linked Employer-Employee Data. *Journal of International Economics*, 90(1), 201–217.

Baumol, W. (1967). Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crisis. *American Econ.omic Review*, 57(3), 415–426.

Beise, M. & Stahl, H. (1999). Public Research and Industrial Innovations in Germany. *Research Policy*, 28(4), 397–422.

Bessen, J., Denk, E., Kim, J., & Righi, C. (2020). Declining Industrial Disruption. *Boston University School of Law Law and Economics Series Paper No. 20-28*.

Bhaskar, M. (2021). Human Frontiers: The Future of Big Ideas in an Age of Small Thinking. *The Bridge Street Press*.

Bhattacharya, J. & Packalen, M. (2020). Stagnation and Scientific Incentives. *NBER Working Paper no. 26752. National Bureau of Economic Research*.

Bijnens, G. & Konings, J. (2018). Declining Business Dynamism in Belgium. *Small Business Economics*, (pp. 1–39).

Blind, K., Edler, J., Frietsch, R., & Schmoch, U. (2006). Motives to Patent: Empirical Evidence from Germany. *Research Policy*, 35(5), 655–672.

Bloom, N., Jones, C., van Reenen, J., & Webb, M. (2020). Are Ideas Getting Harder to Find? *American Economic Review*, 110(4), 1104–1144.

Blum, M., McLaughlin, E., & Hanley, N. (2017). Accounting for Sustainable Development Over the Long-Run: Lessons from Germany. *German Economic Review*, 20(4), 410–446.

Boeing, P. & Hünermund, P. (2020). A Global Decline in Research Productivity? Evidence from China and Germany. *Economics Letters*.

Bolt, J., Timmer, M., & van Zanden, J. (2014). GDP per capita Since 1820. *In J.L. van Zanden, et al. (eds.). How Was Life? Global Well-Being since 1820. Paris: OECD Publishing*.

Bolt, J. & van Zanden, J. (2020). Maddison Style Estimates of the Evolution of the World Economy. A New 2020 Update. *Maddison-Project Working Paper WP-15*.

Brandau, D. (2012). Cultivating the Cosmos: Spaceflight thought in Imperial Germany. *History and Technology*, 284(3), 225–254.

Brautzsch, H., Günther, J., Loose, B., Ludwig, U., & Nulsch, N. (2015). Can R&D Subsidies Counteract the Economic Crisis? Macroeconomic Effects in Germany. *Research Policy*, 44(3), 623–633.

Bravo-Biosca, A. (2016). Firm Growth Dynamics Across Countries: Evidence From a New Database. *Nesta Working Paper 16/03*, December.

Brenke, K., Rinne, U., & Zimmerman, K. (2011). Short-Time Work: The German Answer to the Great Recession. *IZA DP. No. 5780, IZA Institute of Labor Economics*.

Broadberry, S. (1997). Anglo-German Productivity Differences 1870-1990: A Sectoral Analysis. *European Review of Economic History*, 1(2), 247–267.

Broszeit, S., Laible, M., Fritsch, U., & Görg, H. (2019). Management Practices and Productivity in Germany. *German Economic Review*, 20(4), e657–e705.

Brynjolfsson, E., Rock, D., & Syverson, C. (2017). Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics. *NBER Working Paper No. 24001. National Bureau of Economic Research*.

Burda, M. (2016). Book Review of The Seven Secrets of Germany: Economic Resilience in an Era of Global Turbulence. *Journal of Economic Literature*, LIV, 1396–1398.

Burda, M. & Severgnini, B. (2018). Total Factor Productivity Convergence in German States since Reunification: Evidence and Explanations. *Journal of Comparative Economics*, 46(1), 192–211.

Burhop, C. (2006). Did Banks cause the German Industrialization? *Explorations in Economic History*, 43(1), 39–63.

Burhop, C. & Wolff, N. (2005). A Compromise Estimate of German Net National Product, 1851-1913, and its Implications for Growth and Business Cycles. *Journal of Economic History*, 65(3), 613–657.

Comin, D., Trumbull, G., & Yang, K. (2016). Fraunhofer: Innovation in Germany. *In Comin, D., ed. Drivers of Competitiveness. Singapore: WorldScientic Press*, (pp. 409–444).

Cooper, R., Meyer, M., & Schott, I. (2017). The Employment and Output Effects of Short-Time Work in Germany. *NBER Working Paper No. 23688. National Bureau for Economic Research.*

Cowen, T. (2010). The Great Stagnation. *New York: Penguin (Dutton).*

Cowen, T. (2016). Is Innovation Over? The Case Against Pessimism. *Foreign Affairs*, March/April, 42–46.

Cowen, T. (2017). The Complacent Class: The Self-Defeating Quest for the American Dream. *New York: Picador.*

Criscuolo, C., Gal, P., & Menon, C. (2014). The Dynamics of Employment Growth: New Evidence from 18 Countries. *CEP Discussion Paper No. 1274.*

Decker, R., Haltiwanger, J., Jarmin, R., & Miranda, J. (2014). The Role of Entrepreneurship in US Job Creation and Dynamics. *Journal of Economic Perspectives*, 28(3), 3–24.

Decker, R., Haltiwanger, J., Jarmin, R., & Miranda, J. (2016). Declining Business Dynamism: What we Know and the Way Forward. *American Economic Review, Papers and Proceedings*, 106(5), 203–207.

Decker, R., Haltiwanger, J., Jarmin, R., & Miranda, J. (2017). Declining Dynamism, Allocative Efficiency, and the Productivity Slowdown. *American Economic Review, Papers and Proceedings*, 107(5), 322–326.

Dubner, S. (2017). What are the Secrets of the German Economy - and Should We Steal Them? *Freakonomics Podcast*, 11 October.

Dusdal, J., Powell, J., Baker, D., Fu, Y., Shamekhi, Y., & Stock, M. (2020). University vs. Research Institute? The Dual Pillars of German Science Production, 1950-2010. *Minerva*, 58, 319–342.

Edison, H., Ali, N., & Torkar, R. (2013). Towards Innovation Measurement in the Software Industry. *Journal of Systems and Software*, 86(5), 1390–1407.

Elert, N., Henrekson, M., & Stenkula, M. (2017). Institutional Reform for Innovation and Entrepreneurship: An Agenda for Europe. *SpringerOpen: Springer Briefs in Economics.*

Erixon, F. & Weigel, B. (2016). *The Innovation Illusion.* New Haven: Yale University Press.

Faccio, M. & McConnell, J. J. (2020). Impediments to the Schumpeterian Process in the Replacement of Large Firms. *Working Paper No. 27871, National Bureau of Economic Research.*

Falck, O., Koenen, J., & Lohse, T. (2019). Evaluating a Place-Based Innovation Policy: Evidence from the Innovative Regional Growth Cores Program in East Germany. *Regional Science and Urban Economics*, 79, 1–23.

Fear, J., Venohr, B., & Witt, A. (2015). Best of German Mittelstand - The World Market Leaders. In F. Langenscheidt & B. Venohr (Eds.), *The Best of German Mittelstand: The World Market Leaders* (pp. 10–27). Cologne: Deutsche Standards.

Field, A. (2003). The Most Technologically Progressive Decade of the Century. *American Economic Review*, 93(4), 1399–1413.

Florida, R. & King, K. (2016). Rise of the Global Startup City: The Geography of Venture Capital Investment in Cities and Metros across the Globe. Martin Prosperity Institute, University of Toronto.

Fohlin, C. (1998). Financial System Structure and Industrialization: Reassessing the German Experience before World War I. Social Science Working Paper No. 1028, CIT, Pasedena.

Fohlin, C. (2016). The Venture Capital Divide: Germany and the United States in the Post-War Era. Department of Economics, Emory University.

Friedman, T. (2016). Thank You for Being Late: An Optimist's Guide to Thriving in the Age of Accelerations. *New York: Picador.*

Girotra, K. & Netessine, S. (2013). Extreme Focus and the Success of Germany's Mittelstand. Harvard Business Review, 12 February.

Gokmen, G. & Morin, A. (2019). Inequality in the Aftermath of Financial Crises: Some Empirical Evidence. *Applied Economics Letters*, 26(19), 1558–1562.

Gordon, R. (2012). Is U.S. Economic Growth Over? Faltering Innovation Confronts the Six Headwinds. *NBER Working Paper No. 18315. National Bureau for Economic Research.*

Gordon, R. (2015). Secular Stagnation: A Supply-Side View. *American Economic Review*, 105(5), 54–59.

Gordon, R. (2016). The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War. *Princeton: Princeton University Press.*

Grupp, H., Dominguez Lacasa, I., Friedrich-Nishio, M., & Jungmittag, A. (2005). Innovation and Growth in Germany in the Past 150 Years. In *Entrepreneurship, the New Economy and Public Policy* (pp. 267–287). Springer Verlag.

Gutiérrez, G. & Philippon, T. (2019). The Failure of Free Entry. *Working Paper No. 26001, National Bureau of Economic Research.*

Hall, B. (2011). Using Productivity Growth as an Innovation Indicator. *Report for the High Level Panel on Measuring Innovation, DG Research, European Commission.*

Harhoff, D. & Hoisl, K. (2007). Institutionalized Incentives for Ingenuity: Patent Value and the German Employees' Inventions Act. *Research Policy*, 36(8), 1143–1162.

Heider, A., Gerken, M., van Dinther, N., & Hülsbeck, M. (2020). Business Model Innovation Through Dynamic Capabilities in Small and Medium Enterprises - Evidence from the German Mittelstand. *Journal of Business Research*, early online.

Henrekson, M. & Sanandaji, T. (2017). Schumpeterian Entrepreneurship in Europe Compared to other Industrialized Regions. *IFN Working Paper no. 1170.*

Hesse, K. & Fornahl, D. (2020). Essential Ingredients for Radical Innovations? The Role of (Un-)Related Variety and External Linkages in Germany. *Papers in Regional Science*, 99, 1165–1183.

Hornung, E. (2014). Immigration and the Diffusion of Technology: The Huguenot Diaspora in Prussia. *American Economic Review*, 104(1), 84–122.

Huebner, J. (2005). A Possible Declining Trend for Worldwide Innovation. *Technological Forecasting & Social Change.*

Iversen, T. & Cusack, T. (2000). The Causes of Welfare State Expansion: Deindustrialization or Globalization? *World Politics*, 52(3), 313–349.

Jensen, M., Johnson, B., Lorenz, E., & Lundvall, B. (2007). Forms of Knowledge and Modes of Innovation. *Research Policy*, 36(5), 680–693.

Johnson, G. (2014). Hills to Scientific Discoveries Grow Steeper. *The New York Times*, 17 Feb.

Johnson, S. & Kwak, J. (2012). Is Financial Innovation Good for the Economy? *In J. Lerner and S. Stern (eds.) Innovation Policy and the Economy, Volume 12. Chicago: University of Chicago Press.*

Jones, B. (2009). The Burden of Knowledge and the Death of Renaissance Man: Is Innovation Getting Harder? *Review of Economic Studies*, 76(1), 283–317.

Jones, C. (2020). The End of Economic Growth? Unintended Consequences of a Declining Population. *Mimeo, Stanford University.*

Jones, R. & Jin, Y. (2017). Boosting Productivity for Inclusive Growth in Japan. OECD Economics Department Working Paper No. 1414.

Karnofsky, H. (2021). The Most Important Century (in a nutshell). *Cold Takes Blog*, 23 Sept.

Kopsidis, M. & Bromley, D. (2016). The French Revolution and German Industrialization: Dubious Models and Doubtful Causality. *Journal of Institutional Economics*, 12(1), 161–190.

Kwon, S., Lee, J., & Lee, S. (2017). International Trends in Technological Progress: Evidence from Patent Citations. *The Economic Journal*, 127, F50–F70.

Lang, G. (2009). Measuring the Returns of R&D: An Empirical Study of the German Manufacturing Sector over 45 Years. *Research Policy*, 38(9), 1438–1445.

Leceta, J., Renda, A., Konnola, T., & Simonelli, F. (2017). Unleasing Innovation and Entrepreneurship in Europe. *Brussels: Centre for European Policy Studies.*

Lehmann-Hasemeyer, S. & Streb, J. (2016). The Berlin Stock Exchange in Imperial Germany: A Market for New Technology? *American Economic Review*, 106(11), 3558–3576.

Lehrer, M., Nell, P., & Gärber, L. (2009). A National Systems View of University Entrepreneurialism: Inferences from Comparison of the German and US Experience. *Research Policy*, 38(2009), 268–280.

Lloyd-Ellis, H. & Bernhardt, D. (2000). Enterprise, Inequality and Economic Development. *Review of Economic Studies*, 67(1), 147–168.

Malmer, T. & Tholen, J. (2015). Industrial Policies in Germany and Sweden - the Example of the Chemical and Pharmaceutical Industries: A Comparative Survey. Mimeo.

Marr, B. (2020). Tech Trends in Practice: The 25 Technologies that are Driving the 4th Industrial Revolution. *London: Wiley.*

Mazzucato, M. (2013). The Entrepreneurial State: Debunking the Public vs. Private Myth in Risk and Innovation. *Anthem Press: London, UK.*

Mazzucato, M. (2015). Which Industrial Policy does Europe need? *Intereconomics*, 50(3), 120–155.

Mazzucato, M. (2020). Mission-Oriented Innovation and Industrial Policies. *In WTO, World Trade Report 2020: Government Policies to Promote Innovation in the Digital Age. Geneva. World Trade Organization*, (pp. 101).

Meyer-Thurow, G. (1982). The Industrialization of Invention: A Case Study from the German Chemical Industry. *ISIS*, 73(3), 363–381.

Milanovic, B. (2020). After the Financial Crisis: The Evolution of the Global Income Distribution between 2008 and 2013. *MPRA Paper No. 101560.*

Mokyr, J. (2010). The Contribution of Economic History to the Study of Innovation and Technical Change: 1750-1914. *In Halland, B.H. and N. Rosenberg: Handbook of the Economics of Innovation. Volume I, Burlington: Academic Press*, (pp. 11–50).

Moser, P., Voena, A., & Waldinger, F. (2014). German Jewish Emigres and US Invention. *American Economic Review*, 104(10), 3222–3255.

Mroczkowski, T. (2014). From Breakthrough to Incremental Innovation Leadership: Lessons from Germany. *Journal of Knowledge Economics*, 5(2), 409–426.

Naudé, W. (2022). From the Entrepreneurial to the Ossified Economy. *Cambridge Journal of Economics*, 46(1), 105–131.

Naudé, W. & Nagler, P. (2017). Technologische Innovationen und Inklusives Wachstum in Deutschland. *Policy Brief 2017/08, Bertelsmann Stiftung.*

Niehues, J. (2015). Financialization and Income Inequality - the Case of Germany. Institut der Deutschen Wirtschaft Köln.

OECD (2005). Oslo Manual - Guidelines for Collecting and Interpreting Innovation Data. *3rd edition. OECD Publishing.*

OECD (2016). The Productivity-Inclusiveness Nexus. Paris, France: Organisation for Economic Co-operation and Development.

Ogilvie, S. (1996). The Beginnings of Industrialization. In S. Ogilvie (Ed.), *Germany: A New Social and Economic History, Vol. II: 1630-1800.* London: Hodder Arnold.

Oulton, N. (2001). Must the Growth Rate Decline? Baumols Unbalanced Growth Revisited. *Oxford Economic Papers*, 53(4), 605–627.

Parada, J. (2018). Veblen's Imperial Germany and the Industrialization of Latin America. *Journal of Economic Issues*, 52(3), 637–651.

Pfister, U. (2019). The Crafts-Harley View of German Industrialization: An Independent Estimate of the Income Side of Net National Product, 1851-1913. *European Review of Economic History*, 24, 502–521.

Prados de la Escosura, L. & Rosés, J. (2020). Accounting for Growth in Spain, 1850-2019. *CEPR Discussion Paper 15380.*

Rammer, C. & Schubert, T. (2016). Concentration on the Few? R&D and Innovation in German Firms 2001-2013. *ZEW Discussion Paper No. 16-005.*

Rammer, C. & Schubert, T. (2018). Concentration on the Few: Mechanisms Behind a Falling Share of Innovative Firms in Germany. *Research Policy*, 47(2), 379–389.

Razin, A. (2020). De-globalization: Driven by Global Crises? *NBER Working Paper No. 27929. National Bureau of Economic Research.*

Rial, A. & Herrero, D. (2014). Testing Baumols Diseases in the German Economy. *Mimeo : Complutense Institute for International Studies (ICEI).*

Ridley, M. (2020). How Innovation Works: And Why It Flourishes in Freedom. *London: HarperCollins.*

Schoellhammer, R. (2022). The German Economy is on the Brink. *The Post*, 7 July.

Schwab, K. (2016). *The Fourth Industrial Revolution*. Portfolio Penguin.

Simon, H. (2009). *Hidden Champions of the 21st Century: Success Strategies of Unknown Market Leaders*. Heidelberg: Springer Dordrecht.

Sinn, H.-W. (2006). The Pathological Export Boom and the Bazaar Effect: How to Solve the German Puzzle. *The World Economy*, 29(9), 1157–1175.

Thierer, A. (2016). Permissionless Innovation and Public Policy: A 10-Point Blueprint. *Mercatus Centre: George Mason University*.

Twarog, S. (1997). Heights and Living Standards in Germany, 1850-1939: The Case of Wurttemberg. In R. H. Steckel & R. Floud (Eds.), *Health and Welfare during Industrialization*. University of Chicago Press.

Veenstra, J. (2015). Output Growth in German Manufacturing,1907-1936: A Reinterpretation of Time-Series Evidence. *Explorations in Economic History*, 57, 38–49.

Veugelers, R., Ed. (2013). *Manufacturing Europe's Future*. Brussels: Breugel Blueprint 21.

Waldinger, F. (2016). Bombs, Brains and Science: The Role of Human and Physical Capital for the Creation of Scientific Knowledge. *The Review of Economics and Statistics*, 98(5), 811–831.

Watson, P. (2010). *The German Genius: Europe's Third Renaissance, the Second Scientific Revolution and the Twentieth Century*. London: Simon & Schuster.

Watzinger, M., Fackler, T., Nagler, M., & Schnitzer, M. (2020). How Anti-Trust Enforcement can spur Innovation: Bell Labs and the 1956 Consent Degree. *American Economic Journal: Economic Policy*, 12(4), 328–359.

Weinstein, E. (2012). Einstein's Revenge: The New Geometric Quantum. *The Edge*, (pp. https://www.edge.org/response–detail/11441).

WIPO (2015). *Breakthrough Innovation and Economic Growth*. Technical report, World Intellectual Property Organization.

Yamashita, N. (2021). Economic Crisis and Innovation Capacity of Japan: Evidence from Cross-Country Patent Citations. *Technovation*, 101.

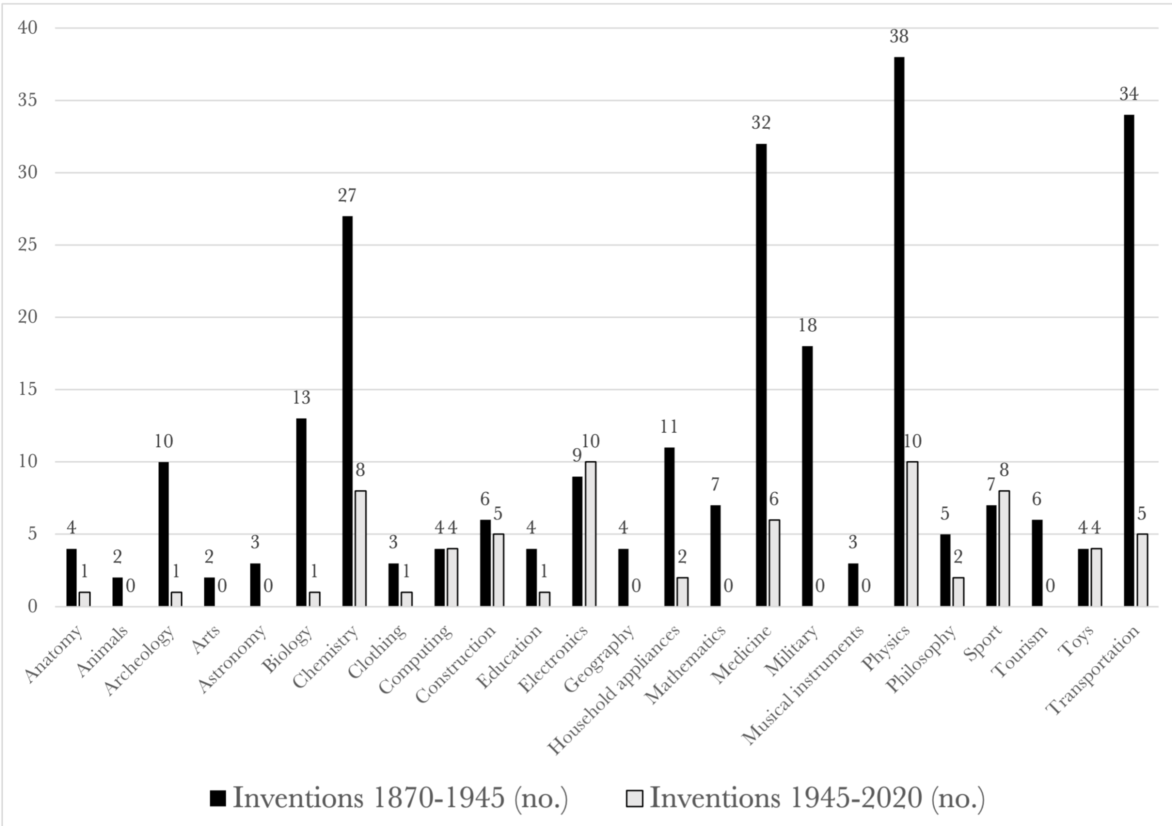
Zabala-Iturriagagoitia, J., Aparicio, J., Ortiz, L., Carayannis, E., & Grigoroudis, E. (2021). The Productivity of National Innovation Systems in Europe: Catching Up or Falling Behind? *Technovation*, 102.

Data availability

The data for all figures in this study are available at OSF, at https://osf.io/7agx4/?view_only=af9465821be24a2cb01c0aab45d6277a

Appendix

Figure A1: Inventions and Discoveries in Germany, 1870-1945 compared with 1946-2020



Data source: Extracted from Wikipedia (`https://en.wikipedia.org/wiki/List_of_German_inventions_and_discoveries`).