GERMANY'S INNOVATION MANUFACTURING: A PATH TO KNOWLEDGE-INTENSIVE ECONOMY

A INOVAÇÃO EM MANUFATURA NA ALEMANHA: UM CAMINHO PARA UMA ECONOMIA INTENSIVA EM CONHECIMENTO

artigo

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Introduction

After the Second World War, German manufacturing moved from mass-production to diversified quality production or DQP (STREECK; SORGE, 2018; STREECK, 1998). The medium-sized and large family-controlled firms, the so-called Mittlestand, led this transformation. As Streeck (2009) reminds us, many small and medium-sized firms are internationally competitive in the German economy, whose encouragement traces back to the 1950s with the ordo-liberalism at the origin of the so-called Social Market Economy. The Mittelstand constituted the primary driver of innovation in manufacturing. In 1972, the creation of the Federal Ministry for Research and Technology (BMFT) aimed to support small and medium-sized firms, including the creation and growth of new firms. The rationale was that the search for new technologies could not rest on the private sector alone and thus, strong political support from the state was politically acceptable.

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Throughout the 1980s and 1990s, Germany veered to a mTarket-oriented approach with a smaller role for the financial support of the state for R&D. Explicit and targeted industrial policies, in general, associated with protectionism, unfair competition, and inefficiencies, started being banned from the policy repertoire in favor of policies to increase competitiveness. During this period, the country partially lost its innovative momentum compared to other industrialized countries, in contrast with its earlier expansion of R&D between 1960 and 1979 (Ifo Institute of Research, 1997).

Nevertheless, Germany, after recovering from the 1980s and 1990s crisis, and particularly after the great crisis of 2008, has shored up innovation policies. It appears to heed the fact that deregulation and the creation of a conducive business environment as the only role of the state have gradually lost support among policymakers and business itself, to a lesser extent. The federal budget for research and development lept from nine billion euros to 15.8 billion. It is a rise of 75% (Bundesbericht Forschung und Innovation 2016). It is in part a result of the 2006 High-Tech Strategie. It is a broad problem-oriented strategy for different programs and initiatives being carried out at three levels; the national, the regional (Länder), and the international.

The main issues addressed are the sustainable economy, environment-friendly energy, efficient health services, smart mobility, and innovative firms. It encourages networking between firms, universities, and research institutes, and supporting the Mittelstand are two guidelines from this encompassing innovation policy in Germany. A significant feature of the High-tech Strategie is its focus on a knowledge-intensive economy and society.

Two underlying reasons in the rebooting strategy from Germany since 2006 were the rise of newly industrialised countries with rapid upgrading processes such as China and other East Asian countries and the prospects of demographic changes with the diminishing supply of highly skilled labour force. To meet these challenges, the country needs to commit itself to increase innovation as the main driver in the global competition.

In its official document about industrial policy's role in developing a knowledge-intensive industrial society, the German Industrial Association (Bundesverband der Deutschen Industrie) claims such policy needs to emphasize research, vocational training technical progress in general. According to the National Industry Strategy 2030, necessary action concerns enabling technologies such as digitalization and artificial intelligence.

Although Germany has not actively pursued an industrial policy, the state has on several occasions intervened in the economy, either to support specific sectors for social and political reasons (e.g., coal mining in old East Germany after re-unification; renewable energy) and even companies (e.g., BMW rescue in the 1960s) or to promote promising high-tech areas. Moreover, as Zettelmeyer tellellingly states:

> Germany has a dense web of industrial policies. It engages in extensive public-private coordination and cooperation, in research, in vocational training and education, and through initiatives such as Industrie 4.0. Its Fraunhofer Institutes, "Europe's largest application-oriented research organization," are widely admired as a model for public and private collaboration in funding, generating and disseminating applied research. German

> companies receive public financial support from multiple sources, including R&D grants awarded by federal and state governments and lowcost SME credit and equity supplied by the Kreditanstalt für Wiederaufbau (KfW), the second-largest national promotional bank in the world (after the Chinese Development Bank). Germany's publicly supported seed capital fund, the High-Tech Gründerfonds, claims to have successfully launched more than 500 high-tech companies since 2005. (ZETTELMEYER, 2019, p. 4)

Recently, the global financial crisis of 2008/2009 led to increasing debates about industrial policy in Germany and in the EU[1]. In 2014, for example, the *Bündnis Zukunft der Industrie* convened industrial and employer associations as well as trade unions around five working groups to discuss policy proposals in five areas: Acceptance – attractive Industry; Investment-strong industry; Future of work in industry and industry-related services; Value creation structures of the future, and International competitiveness of the German industry. An end point to these debates that appears signal a paradigm shift (BOFINGER, 2019) was the issuance in February 2019 of the *Nationale Industriestrategie 2030* (by Economy Minister Peter Altmaier), followed by the revised version *Industriestrategie 2030* at the end of November of the same year designating three industrial policy pillars: 1-Improve national and international framework conditions for the industry; 2-Activate innovation potential and strengthening key technologies, and 3-Protect Germany's technological sovereignty. Furthermore, Germany's Industrie 4.0 plan to promote networked factories and the "internet of things," through standard setting, private-public coordination, digital infrastructure, and R&D grants

The main purpose of this article to examine the status of German innovation manufacturing in view of recent calls for rebooting of Germany's industrial policy to prepare towards its transition to knowledge-intensive manufacturing. It does show by presenting and analyzing, first, the recent trajectory of innovation manufacturing, and second, the challenges and institutional change around the Mittelstand. The article draws on data from the German innovation surveys and data on German exports, reports from the German government and consulting firms as well as qualitative data from indepth interviews. The analysis includes descriptive statistics as well as qualitative assessments.

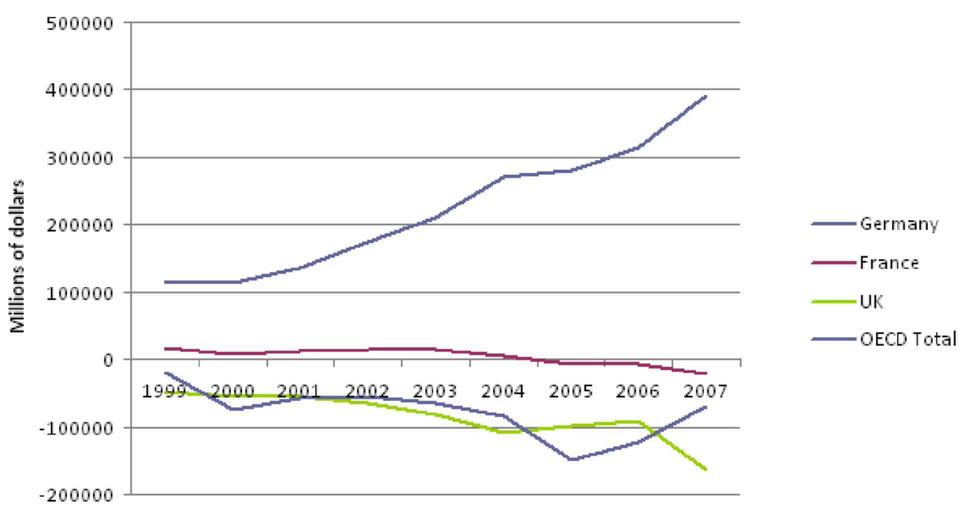
The article is divided into two sections, following this introduction, and a section with final considerations. The first characterizes Germany's manufacturing prowess and the recent trajectory of its industrial policy, with a focus on its innovation performance, in comparison to other advanced industrial economies, and on firm level data on the development of innovation. The second presents, first, the family-owened German SMEs (*Mittelstand*) as a national institution and discusses its key role in the country's innovation manufacturing. Next, it considers the key institutional arrangement for industrial support, financial system, and discusses its critical complementarity with the German Mittelstand.

1. https://ged-project.de/globalization/industrial-policy-eu/. February 14, 2020 Daniela Arregui Coka, Markus Overdiek. The Future of European and German Industrial Policy – Challenges for the EU and Germany.

1. Manufacturing and Innovation in Germany

Among the industrialised countries in the European Union and the OECD, Germany stands out by the growing importance of manufacturing. Germany was the only major industrial country in which manufacturing as a share of value added increased (slightly) between 1995 and 2016. The country's share of manufacturing in GDP currently at 23 percent - twice that of France or the United States – and in the European Union 14 percent. Germany's National Industrial Strategy 2030 issued in April 2019 aims to raise this share to 25 percent) and 20 percent, respectively (ZETTELMEYER, 2019)[2]. Since 1999, German manufacturing trade balance (Figure 1) has grown significantly.

Figure 1 – Trade balance in manufacturing



Source: OECD STAN Indicators apud Hancké and Coulter, 2013

German manufacturing firms' industrial system is widely known as Diversified Quality Production (DQP), a product strategy which applies the techniques of volume production to high quality product lines (STREECK, 1997). It is a differentiation instead of a cost-driven competitive strategy. The DQP system is supported by a wide and dense mesh of institutions promoting 'strategic' interaction between firms and other actors. This supports an innovation process that allows for steady, 'incremental' improvements to product lines. Innovation mainly takes place inside the firm by cooperative workers with a high degree of technical skill and with considerable operational autonomy and responsibility for specific tasks (HANCKÉ; COULTER, 2013).

A recent report by the Brookings Institution comparing manufacturing in the United States and Germany aptly summarizes the competitive advantages and socio-e-

2. In 2017, manufacturing share of German value added was 22.9 percent.

conomic benefits of Germany's prowess in manufacturing:

> Germany offers an example of an advanced economy that has been able to sustain manufacturing as a relevant source of employment, growth, and exports. Manufacturing in Germany accounts for 20 percent of employment, nearly twice the share as in the United States. Manufacturing generates 22 percent of total German GDP and 82 percent of German goods exports. In stark contrast to the United States' $667 billion manufactured goods trade deficit, Germany's trade surplus in manufacturing is about $425 billion.
> These strong labor market, growth, and trade outcomes reflect Germany's ability to infuse technology into its manufacturing sector to remain globally competitive.
> Medium and high-technology industries account for a larger share of the sector's total output in Germany (58 percent) than in the United States (42 percent). Yet a cross-national comparison reveals that Germany invests only marginally more in public R&D as a share of its economy; U.S. universities exhibit much greater scientific impact; and entrepreneurship (as measured by new firm creation) is actually lower in Germany." (PARILLA; TRUJILLO; BERUBE, 2015, p. 6)

However, manufacturing exports only tell part of the story of German's successful adaptation to globalization. As Herrigel (2015, p. 133) demonstrates, the German manufacturing production model has changed with globalization:

> German manufacturing MNCs are shifting from servicing global demand via exports to a strategy of "produce where you sell" FDI expansion in emerging global markets. This strategy is generating recursive dynamics that are transforming the demographic and role composition of German home country production locations. (p. 133).

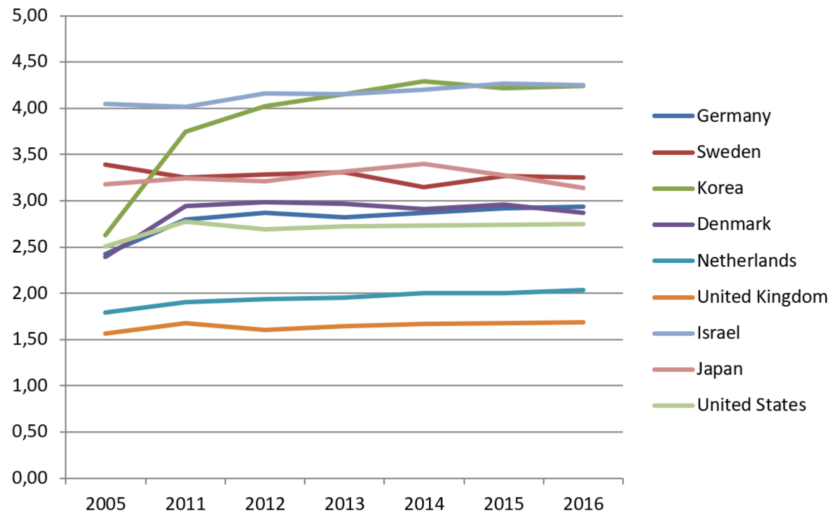
The model was focused on exports in the high quality end of global markets through offers of sophisticated and/or specialized technological solutions and was based on commitments to skilled labor, cooperative labor relations, and institutional supports for training and technological research. According to OECD data, Germany's R&D spending as a share of GDP has been rising since the mid-1990s and now exceeds 3 percent, in line with Japan (3.2 percent) and the United States (2.8 percent).

Südekum (2018) suggests that Germany's recent manufacturing growth was due. First, China's rise created more jobs in Germany as it was capable of supplying intermediate manufactures and capital goods necessary for China's growth and, second, increase in German savings, which depressed demand for services and contributed to a sharp rise in the current account surplus during the 2000s. As these factors are unlikely to continue in the future, a decline in the German manufacturing share is expected, as it happened in other advanced economies.

German manufacturing firms' R&D expenditure is high, reaching in 2010 €46.9bn, about 86%percent of the private economy's total R&D expenditure, according to the Federal Statistical Office (HANCKÉ; COULTER, 2013). Moreover, German technology firms have succeeded in specialized niches using 'platform' technologies, such as business software services (CASPAR; LEHRER, SOSKICE, 2009).

Among the industrialised countries, Germany stands out from its European neighbours in the innovation rate when considering the patent grants and R&D spending as a GDP share. As can be seen from Figure 2, Germany has had an increase in the share of GDP on R&D spending. It went up from 2.4% in 2005 to nearly 3% in 2016. The country is well above the United States and Denmark and well above the Netherlands and the United Kingdom. On the other hand, the countries standing above Germany (Sweden, South Korea, Israel, and Japan) in the R&D investments as the GDP share are those stronger in ICT.

Figure 2 – R&D spending as share of GDP (%)

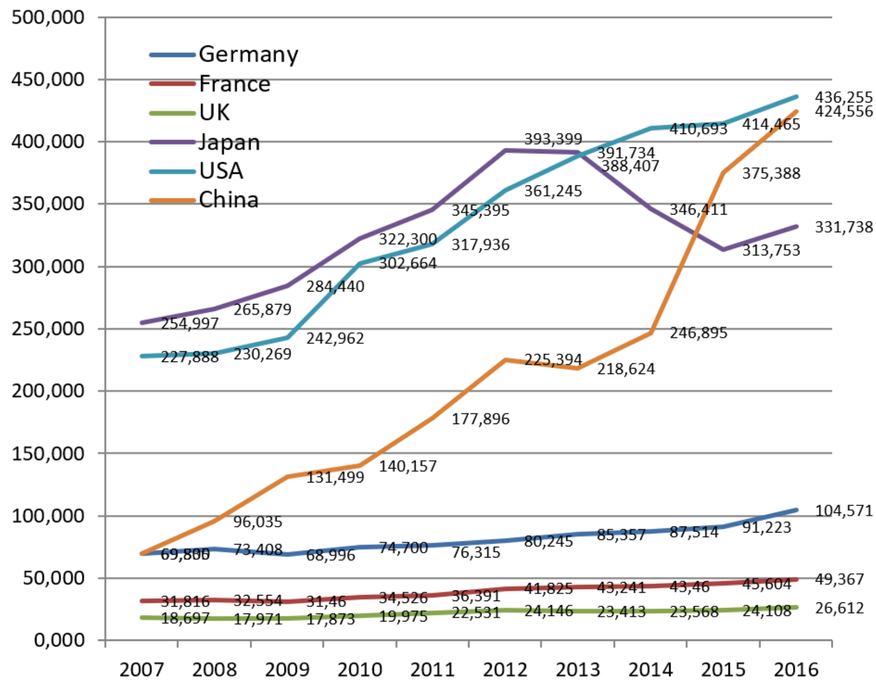


Source: OECDStat, 2018

When the number of granted patents is considered, Germany had more than the half of France's granted patents and more than two thirds of the UK. As for the rate of growth, the number of granted patents in Germany rose by 50% between 2007 and 2016 (Figure 3). The rate of growth was higher than the UK with a 40% increase and slightly lower than France with a 55% increase. However, the number of granted patents cannot be seen as the sole and main indicator of innovativeness. It is worth to remind that the medium-sized firms play a relevant role in the German overall rate of innovation and these firms tend to concentrate on very incremental product and process innovation which is not necessarily related to obtaining patent grants. As it can be seen from Figure 3, China had by far the fastest growth in the number of patent grants, going from nearly 70 thousand in 2007 to 424.5 thousand in 2016.

The US had the second largest growth, moving from 228 thousand in 2007 to 436 thousand in 2016. In the interviews with German officials and representatives from business associations, a major concern towards innovation was the small amount of start-up in comparison to other developed countries. For Start-up firms, patent grant is virtually an assumption for its very existence. Such firms are entirely oriented to one or few products and patenting is the most important mechanism to protect their intellectual property.

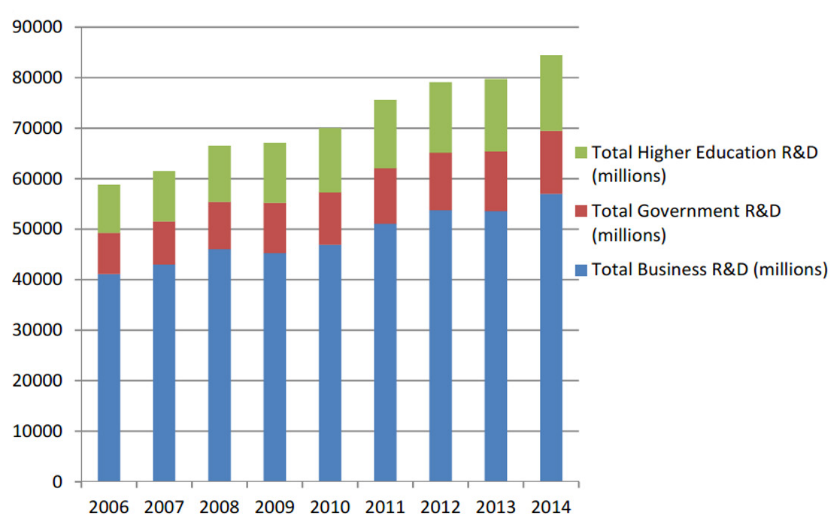
Figure 3 – Number of Patent Grants between 2007 to 2016



Source: World Intellectual Property Organization (WIPO), 2018

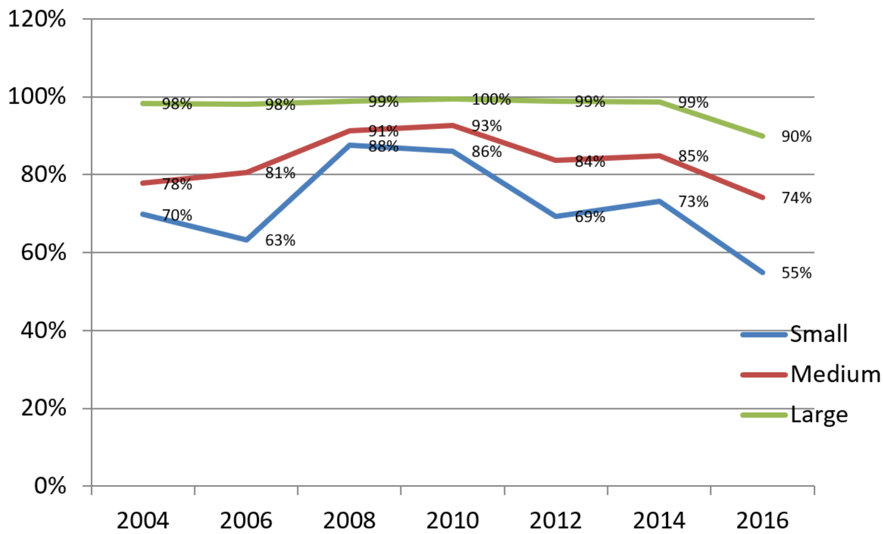
In this sense, it is worth perceiving the growing share from public R&D from 30% in 2006 to 33% in 2014 as well as the total increase from nearly 60 billion in 2006 euros to more than 80 billion euros in 2014 (Figure 4).

Figure 4 – Type of R&D investment in Germany



Source: OECDStat, 2020

Figure 5 – Share of innovative firms by size between 2004 and 2016



Source: Community Innovation Survey for Germany (2006-2016)

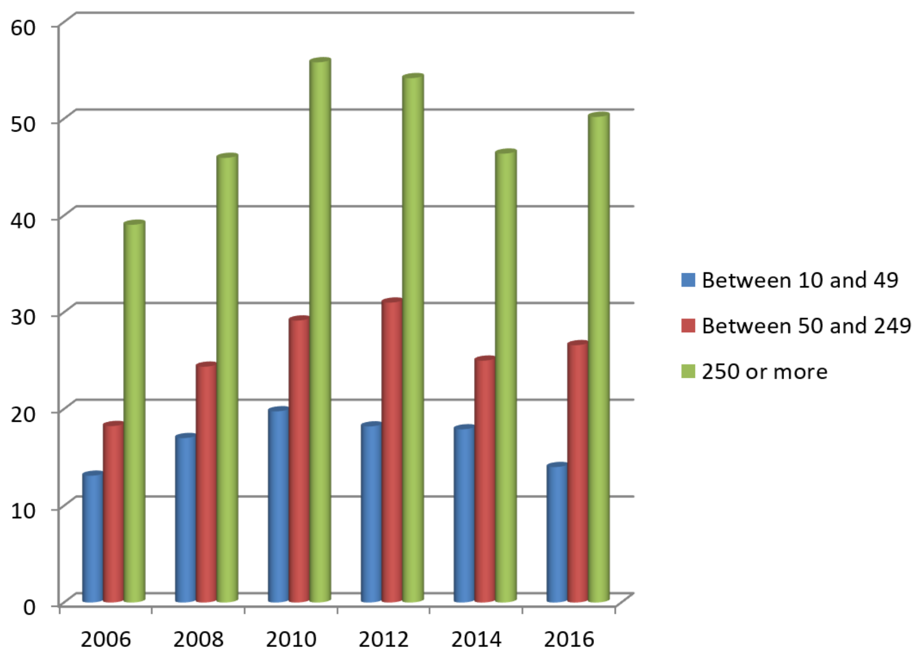
Although most of the innovations come from new products or processes developed by the individual enterprises or enterprises group, there was a substantial increase in the innovation developed by the firm in cooperation with other firms and institutions between 2006 and 2014. This cooperative development increased from around 25% in 2006 to 40% in 2014 (Figure 6). Such an increase can be associated with policies which encourage cooperation such ZIM (*Zentrales Innovationsprogramm Mittelstand*) from the Ministry of Economics.

This program started operating in 2008 and has three modalities. One is the funding of individual firms' new product/process development project, so that the funding is for the individual firm research and development (*FuE-Einzelprojekte in Unternehmen*). The second modality refers to cooperation projects for two firms or one firm and a research organization (*ZIM-Kooperationsprojekte*). The third modality encourages the building of firm networks for research and development with a minimum of six firms.

This policy funds 25% of the firms` investment in R&D up to a cap of 3 million euros and until 2,000 employees. Between 2008 and 2015, there were 12,369 R&D projects supported by ZIM (KAUFMANN et al., 2019). In 2015, the small firms, ranging from 10 to 49 employees, accounted for 55.3% of the R&D projects, and medium-sized firms (from 50 to 249 employees) got 23.4% of the total projects. Larger firms, ranging from 250 to 499 employees, had a share of only 0.9%. Between 2008 and 2018, the share of small and medium-sized firms with funded R&D projects relatively stable (KAUFMANN et al., 2019). According to a survey carried out with the beneficiary firms from ZIM, the most urgent thing to improve in the program is the percentage of costs funded.

The most frequent learning effects from joint projects in cooperation with other firms or organizations were applied know-how and technological knowledge (KAUFMANN et al., 2019). Although the ZIM essentially supports incremental innovation, 39% of the projects stand as applied research to put an idea into a new product or service. The majority of the projects (57%) relate to applied research in developing prototypes, new processes, and technical services, being more incremental than creating new stuff.

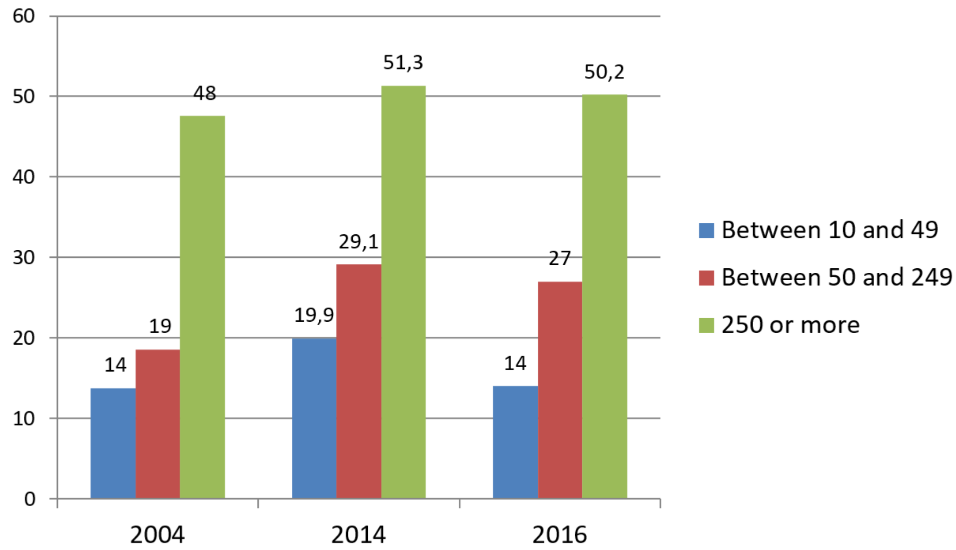
Figure 6 – Cooperation by firm size (%)



Source: Community Innovation Survey for Germany (2006–2016)

When the cooperation arrangements on innovation are seen by firm size, the medium-sized firms had the largest growth rate going from 19% of the firms in 2004 to 29% in 2014. As it can be seen from Figure 7, firm size matters for cooperation on innovation, so that 51.3% of firms with 250 or more employees have at least one type of cooperative arrangement. Surprisingly, the percentage of small firms with cooperation is not negligible with nearly 20% having cooperative arrangement on innovation.

Figure 7 – Cooperation arrangements on innovation activities by firm size



Source: Community Innovation Survey for Germany (2006-2016)

2. The *Mittelstand*: the cornerstone Germany's manufacturing innovation

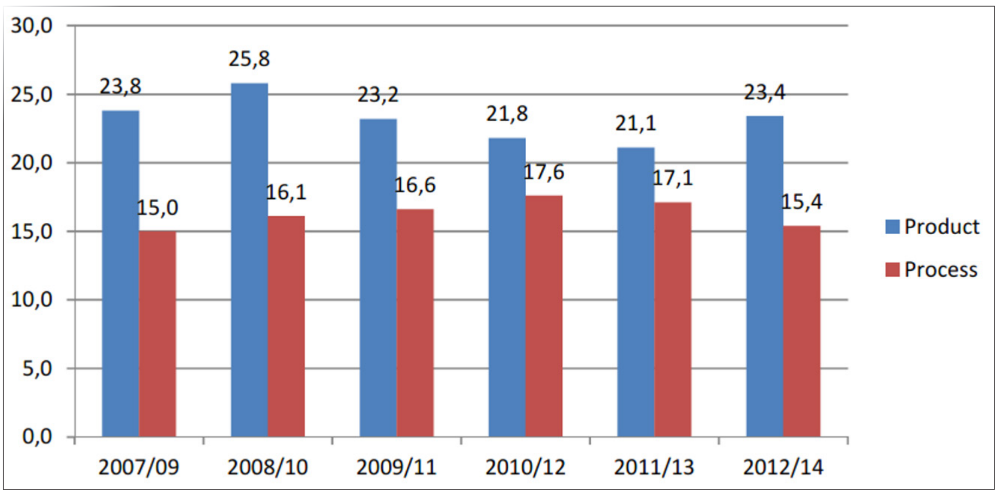
After World War II, the large German companies, due to their association with the Nazi regime, had been encouraged to sell out assets and become smaller. Ordoliberalism became the predominant economic ideology in Germany. The very concept of the social market economy stemmed from the idea that it was necessary to strengthen SMEs to ensure a more efficient market economy. One of the tenets of Ordoliberalism is to assure an efficient and productive economic order with a general level of welfare, and this can only be achieved with a more regulated economy without hampering the flourishing of a competitive market economy (WÖRSDÖRFER, 2014). Ordoliberalism was virtually the ideology connecting the economic thinking with the German welfare state. The modern German welfare state after World War II had much in common with the principles of Ordoliberalism.

From the 1950s onwards, the social market economy became firmly embedded in German society. Mittelstand became a crucial driver of the postwar economy and a national institution differentiating German capitalism. In the 1950s, the institute of research on Mittelstand in Bonn had been founded (Institut für Mittelstandsforschung). Röpke, one of the thinkers of Ordoliberalism, pleaded for the fostering of the small and medium-sized firms as a strategy to democratize capital, decentralize power structures and strengthen the market economy (WÖRSDÖRFER, 2014).

The fact Mittelstand became increasingly interwoven with the German effort to structurally recover its economy contributed to change it into a national institution. Also, Mittelstand is key to quality production (STREECK, 1997). Because the scale-based competition was not viable to the German economy anymore, the focus on differentiated and quality production fits well with the structure and capabilities from Mittelstand. The role played by Mittelstand in the German economy demanded supportive institutions to strengthen the country's competitiveness based on quality production. In this sense, technological development and innovation became a sine qua non condition to prosper in a context of rising wage levels, which could only be compensated by high productivity levels. It is what Streeck (1998) calls the beneficial constraint. The initial constraint on lower labour costs turned into a beneficial focus on innovation and differentiation.

As shown in Figure 8, the rate of innovators in German Mittelstand is very stable between 2009 and 2014. The product innovators accounted for 23.4 in 2014, and this percent was 23.8 in 2009. In process innovators, there was virtually no change between 2009 with 15% and 2014 with 15.4%. It poses a challenge to increase the innovation rate in these firms. Or does it mean that the innovation potential from these firms has run out of steam?

Figure 8 – Share of product and process innovators in Mittelstand (%) (2007-2014)



Source: KfW-Mittelstandspanel, 2017

Whe compared to large firms, the average turnover percent to invest in R&D is 1.4% in Mittelstand and 4.9 for large firms in 2014. This gap was smaller in 1995 with 3% for large firms and 2.7 for *Mittelstand* (ASTOR, 2016). Spending on innovation activities also slightly dropped from 34 billion euros in 2008 to 32 billion in 2014 (ASTOR,2016).

At the same time, there was an increase in the percentage of firms facing obstacles to innovate. Between 2006 and 2014, the percent of firms considering high risks and high costs to innovate went up from nearly 25% to 40%. The third major obstacle is the shortage of skilled labour force with 33% in 2014. In 2006, this obstacle accounted for 15% (ASTOR, 2016).

Innovation activities show an unstable trend (**Table 1**). The percentage of small and medium firms with innovation activity increased from 70% to 88% between 2004 and 2008 and then, after the crisis, went down to 73%. As for the medium-sized firms, the share of firms with innovation activities went up from 78% in 2004 to 93% in 2010 and then fell to 85% in 2014.

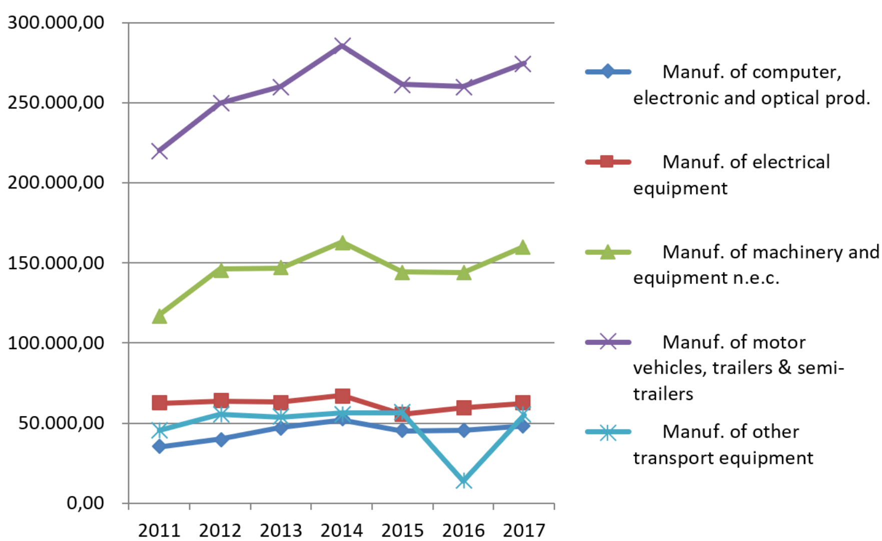
Table 1 – Share of firms with innovation activity by size

Share of firms with at least one innovation activity (Manufacturing)	Year						
	2004	2006	2008	2010	2012	2014	2016
Small	60%	57%	78%	77%	63.3%	62.9%	44.6%
Medium	74%	72%	84%	86%	74.3%	75.5%	62.1%
Large	89%	87%	95%	94%	92.2%	93.9%	79.5%

Source: Community Innovation Survey for Germany (2006-2016)

The strength of the Mittelstand is also revealed by Germany's export performance. The most performing industries in the German exports are those where the *Mittelstand* and the so-called 'hidden champions' (highly specialized firms which are the best in their niches) stand out. Machinery and equipment export almost doubled between 2000 and 2011 from less than 150 billion dollars to nearly 300 billion. A sharp increase is also present in the exports of electrical machinery and apparatus.

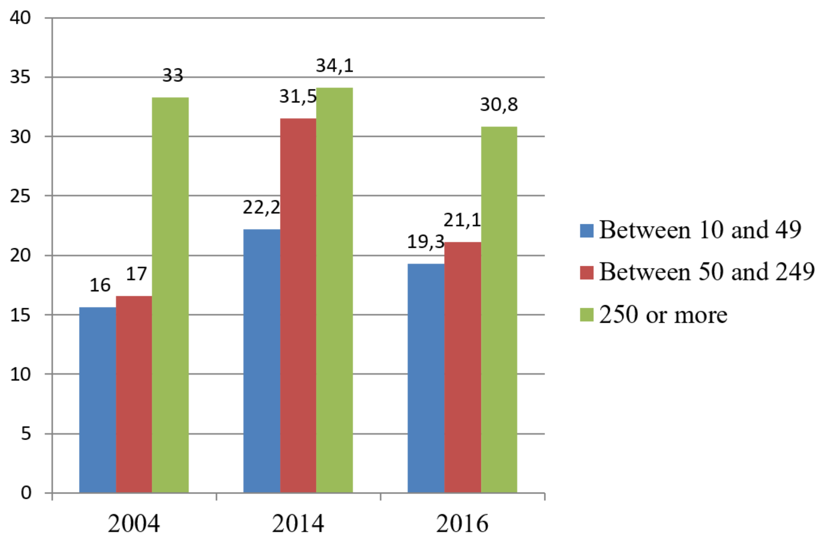
Figure 9 - German Exports in selected industries (US million dollars) from 2000 to 2017



Source: OECDStat, 2020.

Between 2004 and 2014, there has been an increase in the number of innovative firms receiving public funds to invest on innovation. It is worth noting that the higher growth took place in firms in the range between 50 and 249 employees. 31.5% of these firms received public funding in 2014 comparing to 17% in 2004. The range between 10 and 49 employees rose by 6.2% from 16% to 22.2%. On the other hand, firms with 250 employees or more had a very negligible increase from 33% to 34.1%. This result seems to be coherent with the larger emphasis on typical medium-sized firms from government programs.

Figure 10 – Innovative firms that received public funding by firm size (number of employees)

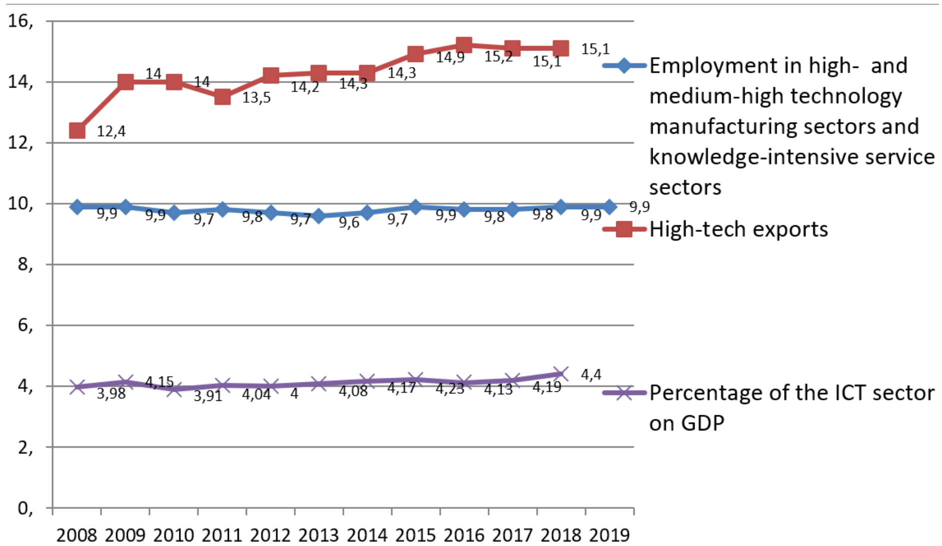


Source: Community Innovation Survey for Germany (2006-2016)

Probably the biggest challenge for the innovativeness of Mittelstand comes from the Industry 4.0 (SAAM et al., 2016). It is also where the state support to develop science-based firms and IT start-ups is most needed. The combination of modern Information and Communication Technologies with manufacturing requires competences and skills which lay beyond the domain of most Mittelstand firms. Industry 4.0 requires the internet of things and the digital networking of the production process.

This is also supported by the results from Strobel and Kratzer (2017) in which the authors identified that the lack of standards for knowledge management leads to a decline of innovation potential. We argue that the transition to Industrie 4.0 demands more of knowledge management skills. The lack of standards together with the demands for knowledge-intensive ICT can hamper the innovative potential from *Mittelstand*. Employment in high and medium-tech manufacturing, ICT share in the GDP and high-tech exports are virtually stagnated over the last decade and the industrial policy should heed these early signals.

Figure 11 – Share of knowledge-intensive employment in high and medium-high technology in manufacturing and services and share from ICT industries in the German



Source: OECD Productivity Statistics (database), February 2016

The smaller number of start-ups in Germany comparing to other industrialised countries indicates a disadvantage in the German innovation system. At the same time, differently from the US and the UK, the creation of firms stemming from universities and the presence of academic entrepreneurs is weaker in Germany. Larger manufacturing firms are compensating this by supporting the founding of start-ups (SAAM et al., 2016).

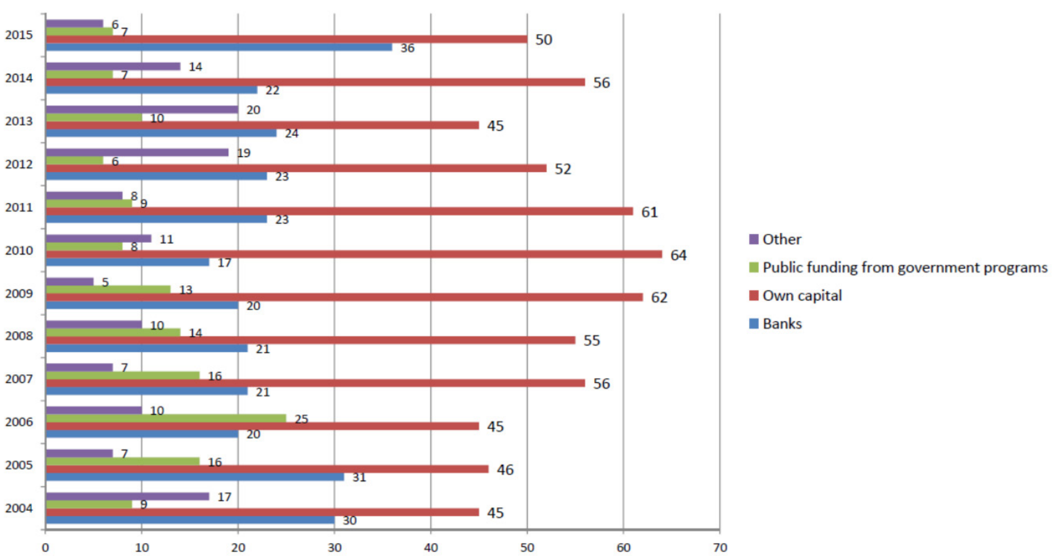
3. Financing the *Mittelstand*

Germany has five main types of financial institutions, and all of them allocate financial resources to the credit of industrial firms (to a lesser extent, the cooperative banks). These are private banks, regional banks (Landesbanken), Cooperative Banks (Genossenschaft), Saving Banks (Sparkassen), and a development bank called Kreditanstalt für Wiederaufbau. A unique feature of the German banking system is the high competition levels between different types of banks and the relationship with loans to finance manufacturing firms. Despite the growth of the capital market in Germany, German firms are still very bank-oriented when raising financial assets (DEEG, 2010). It is especially true in the case of the so-called Mittelstand or family-owned business. Deeg (2010) reminds us that Small and Medium-sized (SME) firms in Germany have had the highest level of bank loans as a share of company liabilities. However, this has changed over the last years, with a growing number of firms relying more on private equities than on bank loans (Figure 12). Also, despite ongoing changes in large firms' corporate governance with a more prominent role for institutional investors and capital markets, there is substantial stability in bank borrowing to SMEs (DEEG, 2010).

The German banking system's diversity is a crucial factor for the 'patient capital,' the type of capital based upon long-term performance rather than the kind of capital with a higher likelihood of exit because it is motivated by short-term performance (DEEG; HARDIE, 2016). Deeg and Hardie (2016) stress that patient capital is not only related to blockholders and ownership from relational banks but is related to a diversity of financial organizations. In this sense, it is argued that higher competition between different types of financial organizations with a mix of regional banks, savings banks, and a development bank contribute to the access from Mittelstand to patient capital without ownership interlocking between banks and firms.

After private equity as a significant source of funding for the Mittelstand, credit banks and government incentives are in the form of public money as in the ZIM program and special loans coming from KfW. Within bank credit, cooperative and savings banks are particularly relevant for small firms (HUMMEL, 2011). Schäfer and Werwatz (2004) also found out that the degree of novelty was not associated with a project financed by private equity, and German banks do not rule out high-tech financing Small and Medium-sized Enterprises (SMEs). As seen from Figure 12, banks and own capital account for the highest percentage of funding for investment projects from SMEs in industries with more R&D investments.

Figure 12 – Types of financial support to Mittelstand in R&D intensive industries (%) (2007-2015)



Source: KfW-Mittelstandspanel, 2005-2019

In his study on the financial resources needed to finance innovation projects, Hummel (2011) identified the need for external funding for projects above 50,000 euros, especially for small firms. The capital need between 50,000 and 200,000 euros does not seem attractive to investors, and this is where the bank credit is most needed. However, financing innovation as an intrinsically uncertain and risky activity is not suitable for bank loans. The loan guarantees are an obstacle to funding. This obstacle is a gap in the innovation funding to Mittelstand. Moreover, this is where Government money is most needed to fund innovation projects.

In a recent work on the relationship between finance and industrial policy, Cozzi and colleagues (2016) remark that financial sector regulation and industrial policy have been discussed separately, and it should not be this way. However, the authors claim predictable and suitable finance for the industry is critical for the industrial policy's success. Better access to finance for business, particularly for SMEs, is a relevant component of a new industrial policy (COZZI et al., 2016).

One may say the diversity of the German financial system and the Mittelstand constitute an institutional complementarity for the German innovation system once they both contribute to a better performance of innovation in firms' population. The German financial system's institutional features reinforce the efficiency of the Mittelstand (AMABLE; EKKEHARD; PALOMBARINI, 2005; HÖPNER, 2005). On the other hand, this institutional complementarity is limited when entrepreneurship performs a more prominent role in the innovation landscape. From the perspective of many interviewees, this seems to be a substantial challenge of the German innovation system because public or private venture capital is required to encourage start-ups.

There were other public programs aimed at reversing the lack of financial and credit sources for manufacturing firms. Since 1997, for example, with the Neuer Market's creation, a segment of the Frankfurt stock market, it has targeted fast-growing companies. As a result, there was a substantial expansion in this funding source. The reform of the pension system in 2001 also reinforced the flow of resources to the capital market. Credit unions have recently contributed to supply credit demand. The cooperative network has more than a thousand associated banks, including banks operating in niches and free admission.

The largest of these entities is the Federal Association of Popular Banks (BVR - Bundesverband der Deutschen Volksbanken um Raiffeisenbanken). The free adhesion model, the capillarity of the System, and the proximity to manufacturing in the governance model promote the necessary synergy.

The massive public banks associated with the network of saving cooperatives irrigate credit in the industrial network. In contrast to the North American model that dispersed the production control, the German still relies on investment projects networking firms and different types of banks, creating more long-term commitments between managers and workers (JACKSON, 2005). Although the 2008 crisis impacted the industry, the coordinated capitalism model still preserves the relationships between small and medium-sized companies, small and medium investors, and assets through the patient capital flow. New forms of financing emerged after the closure of the Neuer Market in 2003. Banks were encouraged to invest and manage assets, especially small businesses (HACKENTHAL; SCHMIDT; TYRELL, 2005).

Final Considerations: Germany's responses to knowledge economy challenges

As shown above, Germany's manufacturing innovation has worked well so far. Its production model institutional arrangement has again proved its resilience and adaptability in the aftermath of the 2008 great recession. Without disregard for the important role of multinational corporations in the country's manufacturing innovation system, the innovative capabilities from Mittelstand and its complementarity with a diverse financial system constitute an enduring institutional feature of German capitalism.

In the end, the German latest controversial industrial policy statement, National Industrial Strategy 2030, appears to be voided by the manufacturing innovation performance of the existing traditional bottom-up industrial regime diverse policies (Various, 2019). The National Industrial Strategy 2030 has been highly criticized for its lofty goals, weak assumptions, poor diagnostic, and misguided orientations (BOFINGER, 2019; ZETTELMEYER, 2019). Notwithstanding such criticisms, it is worth reminding that this initiative has more to do with geoeconomic disputes than innovation. Its rationale is to protect German firms, especially Mittelstand, from hostile takeovers by foreign companies, mainly Chinese. It reflects this new geopolitical situation with less multilateralism and more decisive roles for the national states.

However, the model faces new challenges from two transformations in the global manufacturing landscape. One is the continuous upgrading from latecomers such as China and other East Asian nations, moving rapidly in the global value chain. Moreover, more recently, the ambitious Made in China 2025 strategy (announced on May 19, 2015), an industrial policy plan that seeks to gradually replace foreign with Chinese technology in all high-tech industries (KUO; SHYU; DING, 2019). The Chinese menace is one of the fundamental assumptions behind the industrial policy goals and instruments of the National Industrial Strategy 2030 (ZETTELMEYER, 2019; BARKIN, 2020). The second transformation has to do with the so-called growing digitalization needs of manufacturing. The former points out that German Mittelstand manufacturing will need to continue investing more and more in innovation.

Both transformations are interdependent because Germany's Industry 4.0 contributes to maintaining the new competitors' steps (SCHROEDER, 2019).

Nevertheless, Germany's share of ICT investment lags behind other competitive and more knowledge-intensive economies such as the USA, Japan, Sweden, and the Netherlands. The German share stood at 1.72% of the GDP compared to 3.43% in Sweden, 3.40% in Japan, 3.28% in the Netherlands, and 3.15% in the USA (OECD, 2016).

Thelen (2019, p. 311) seminal comparative political economy analysis of pathways toward a knowledge economy in Germany, the Netherlands, and Sweden, concludes about Germany: "The German case stands out for the remarkable continuity in the composition of economic activity, even as digital technologies are revolutionizing traditional products and production processes. In this case, a powerful and resilient cross-class coalition in manufacturing, supported and reinforced by state policy, is presiding over the transition to the knowledge economy."

However, Thelen (2019, p. 312) notices several possible trajectories of change toward a knowledge economy transition depend on the political dynamics and coalitions. She remarks that "each is vulnerable to somewhat different pathologies and associated with different distributional outcomes." She suggests that Germany's successful manufacturing exports continued to focus on traditional sectors like automobiles, leaving producers vulnerable to ever griping cost pressures. However, according to Puls and Fritsch (2020), between 2008 and 2018, the German automotive industry experienced a golden age. It reached record sales, mainly driven by the healthy growth of the Chinese market. The sector increased its value-added in Germany, outgrowing all other manufacturing segments, further amplifying its economic importance in the country during this period. Moreover, it increased its contribution to innovation as 47.5 percent of all patent applications of legal persons in Germany were from the automotive industry.

Still, dark clouds are gathering in the future. From 2019, the global automotive market began to shrink, and the drive train technology began to shift towards electrification, representing a significant challenge to small and medium-sized suppliers. Then in the spring of 2020, the Corona-Pandemic hit it with gale winds: global supply chains were interrupted, most automotive production halted, and close to 60 percent of the German industry's total employment put on short-time work (PULS and FRITSCH, 2020). However, it appears that the German model continues to respond well to the innovation challenge. Results of a study analyzing the latest trends in vehicle-related patenting activity by German manufacturers, suppliers, and service providers reveal that, first, German vehicle manufacturing accounts for a 40 percent share of overall German patent applications (by far the most innovative sector); second just 30 percent of vehicle-related patent applications are in the conventional power train (combustion engine, power transmission, exhaust system, etc.) whereas 70 percent share is in future new technologies segments such as vehicle electrics and electronics, interior and exterior, chassis, tires, brakes, locks, etc.; third, German automotive firms lead in digitization, with a 43 percent share of total entries in the IPC subclass "Electric Digital Data Processing", and for more than one in six entries in "Additive Manufacturing" (for example, in vehicle-related digitization technology are autonomous driving, additive manufacturing of light constructional components, and driver assistance systems); and fourth, suppliers are responsible for the core innovations in German vehicle manufacturing with two thirds of vehicle-related patent applications, mainly system suppliers like Bosch, Brose, Continental, Schaeffler, and ZF (KOPPEL; PULS; RÖBEN, 2018).

Innovative manufacturing in Germany's this transition to a knowledge-intensive economy calls for more than steady and efficient incremental innovation. It requires increased science-based outputs supported by activities and practices efforts, partially underway, with the High-Tech Strategie mechanisms and all the ongoing and planned initiatives concerning the transition to related to the Industry 4.0 framework, such as the encouragement of entrepreneurship with start-ups to assist the Mittelstandcompanies to meet the digitalization and overcome research-driven global competition, particularly from China. Germany's conundrum is to what extent such changes will also require changing the institutions supporting its hugely successful innovation manufacturing model centered on DQP. Moreover, more critically, what the outcome of these changes will be. As institutional changes may affect the country's unique, historically successful institutional complementarities, there is always the risk of throwing the baby out with the bathwater.

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ABSTRACT

German manufacturing firms' industrial system is widely known as Diversified Quality Production, a product strategy which applies the techniques of volume production to high quality product lines (STREECK, 1997). It is a differentiation instead of a cost-driven competitive strategy. The DQP system is supported by a wide and dense mesh of institutions promoting 'strategic' interaction between firms and other actors. However, the transition to Industrie 4.0 demands knowledge-intensive ICT which can hamper the innovative potential from Mittelstand. Employment in high and medium-tech manufacturing, ICT share in the GDP and high-tech exports are virtually stagnated over the last decade and the industrial policy should heed these early signals. The conundrum faced by Germany is to what extent changes in manufacturing will also require changing the institutions which supported its successful innovation manufacturing model centred on Diversified Quality Production.

KEYWORD

Mittelstand. Industrie 4.0. Knowledge-intensive. Manufacturing innovation.

RESUMO

O sucesso das empresas médias alemãs é amplamente conhecido como Produção com Qualidade Diversificada (PQD), uma estratégia de produto que aplica as técnicas de produção em escala às linhas de produtos de alta qualidade (STREECK, 1997). A ênfase é na diferenciação ao invés de uma estratégia competitiva baseada em custos. A PQD é apoiada por rede de instituições que promovem a interação "estratégica" entre empresas e outros atores. No entanto, a transição para a Indústria 4.0 exige um conhecimento intensivo de TIC que pode dificultar o potencial inovador da *Mittelstand*. O emprego na manufatura de alta e média tecnologia, a participação das TIC no PIB e as exportações de alta tecnologia estão estagnadas na última década e a política industrial deve estar atenta a estes sinais. Até que ponto as mudanças na manufatura na Alemanha também exigirão mudanças nas instituições que apoiaram seu modelo inovador bem sucedido da PQD.

PALAVRAS-CHAVES

Mittelstand. Industrie 4.0. Intensivo em conhecimento. Inovação na manufatura.

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