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Critical thoughts on advanced manufacturing: the experiences of Germany and USA

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Abstract

Purpose – The purpose of this paper is to analyze the conventional approach to advanced manufacturing initiatives. Buzzwords like smart manufacturing or industrie 4.0 are directly linked to the discussions about the future of industrial activity. Little is said, however, about developed countries actively reinforcing their bets on the relevance of manufacturing.

Design/methodology/approach – This study opted for analyzing academic papers and governmental white papers. Somehow similar to those studies on compared experiences, here the US and German initiatives are put into perspective.

Findings – The critical interpretation of several works allows us to state that advanced manufacturing experiences consist in a set of policies aiming at industrial and technological leadership in a scenario of fierce competition. The initiatives seek to strengthen manufacturing activities by means of a mission-oriented approach, fostering enabling key technologies.

Originality/value – This paper fulfills an identified need to critically study the advanced manufacturing initiatives. Away from conventional approaches, the paper puts into perspectives the main ongoing initiatives on advanced manufacturing and interprets them as deliberated national efforts to strengthen manufacturing activities by means of enabling technologies. The paper also points out preliminary recommendations for Brazil.

Keywords Industrie policy, Advanced manufacturing, Industrie 4.0

Paper type General review

1. Introduction

Worldwide, topics like advanced manufacturing or industrie 4.0 are being deeply discussed. In Brazil, this subject has been widespread by large multinational companies. The debates come with high expectations around several technologies that could transform manufacturing, although hardly ever accompanied by due considerations.

Therefore, it seems appropriate to take a step back and make a critical reflection on the broad “advanced manufacturing” issue. The topic is intertwined with national efforts to revitalize manufacturing and pursue technological leadership. Thus, advanced manufacturing is part of a framework that translates this perception and originates policies based on each country’s specificities.

For organizational purposes, besides this introduction, this paper presents four sections. The second discusses the most widespread approach to the “fourth industrial revolution”. The third states that advanced manufacturing must be discussed from a broader industrial policy perspective. The fourth section intends to analyze the American

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and German plans for strengthening their own manufacturing activity. Finally, the last section proposes a brief reflection on the subject and point out some preliminary recommendations for Brazil.

2. The future of manufacturing and the bazaar of technologies

Normally the specialized literature emphasizes that the world is facing a new industrial revolution. This revolution takes place in a new era in which the internet plays a leading role, contributing to the convergence of various technologies, now being introduced in all industries and reaching machinery and equipment. The essential elements would be the “merging” of the virtual and real world; the use of cyber physical systems; and supply chain flexibility, with real-time information available to suppliers and customers (Schwab, 2016).

As the digital base is incorporated into the shop floor, it becomes possible for production to take place with more flexibility and to make use of less labor requirements, allowing a customized manufacturing. The benefits to employment and productivity are usually exalted as the new production techniques will be more automated and require more skilled workers[1].

This interpretation is part of a wider discussion on the future of manufacturing, having McKinsey Global Institute (MGI, 2012) and Organisation for Economic Co-operation and Development (OECD, 2015) as representative works. Both highlight the constraints imposed by the ongoing global changes, their implications for the advanced economies and the consequences for manufacturing activity.

In fact, MGI (2012, p. 9) pronounces the arrival of “an exciting new era of global manufacturing.” Somehow more cautiously, OECD (2015, p. 10) points in the same direction: “[t]here is a growing debate that the world is on the brink of similar industrial revolution(s) and a reshuffling of production will take place in the next 10-15 years.”

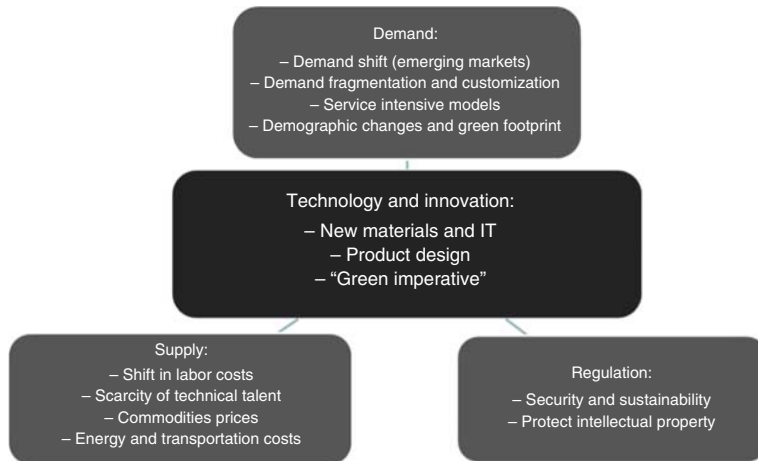
According to MGI (2012), some elements are notably relevant: demand reorientation toward developing countries, due to their higher growth rates; products proliferation and fragmented consumer’s demand; increased value-added services; greater pressure on the supply of natural resources; and more efficient and sustainable processes.

The reorientation toward developing countries and demand’s fragmentation are especially relevant. These new markets are presumed to be made up of consumers that require different products to satisfy their preferences, pushing producers to offer a greater variety of products. At the same time, in established markets there is also demand for variety, given faster production cycles, reinforcing the tendency toward fragmentation. In addition, there is a tendency toward increased value-added services. Companies would produce a “bundle” in which services are inseparably from the product. Also, there are major advances in regard to information and communication technologies, advanced materials and robotics, enabling efficiency gains and flexibility in production. According to MGI (2012), these trends modify how firms seek new markets and expand production and R&D. The main features are represented by Figure 1.

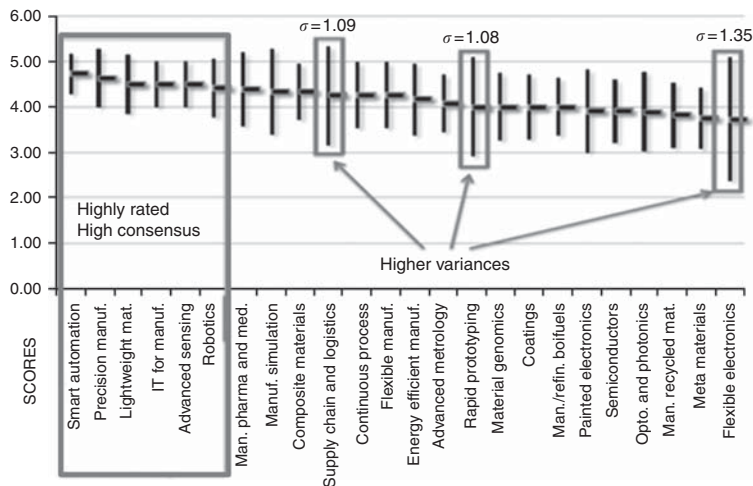
Shipp *et al.* (2012) and De Weck *et al.* (2013) list promising areas of technology related to advanced manufacturing. Both identify which technologies are strategic (hereinafter we shall refer to it as enabling technologies). Figure 2 shows a hierarchy of technologies and one can note that all mentioned technologies “have been around for a while” (OECD, 2015, p. 10), but only recently a broader application is perceived. Individual firms’ and nations’ overall competitiveness would increasingly depend on the application of advanced technologies.

From a microeconomic standpoint, firms shall adopt new business models if they are to benefit from many of the opportunities posed by new technologies. Thus firms would be able to respond quickly to consumers’ demands and supply’s conditions, as the digital

Figure 1.
The future of manufacturing is influenced by several factors



Source: Adapted from MGI (2012)



Notes: Obs., scores ranged from one to five (five being the most promising). The horizontal bar shows the average score achieved; the vertical bar shows \pm standard deviation (σ) assessment from the mean

Source: De Weck *et al.* (2013)

production allows a more flexible organization and also because of reductions in product design cycles.

Several authors, such as Schwab (2016), emphasize that the world is on the brink of a big wave of technological advances and profound systemic transformations. It is often treated as an inexorable (positive) wave for job creation, output value, new processes, and so on.

The conventional approaches correctly identify a series of global trends. Also, they somehow reaffirm manufacturing's special role for long-term development. However, it seems misleading, among other things, in interpreting how nations absorb technological progress. The conventional underlying view is based on the idea that technological advances are

exogenous, as if there was a “bazaar” of technologies – a term coined by Sinn (2006). Also, it would be enough (for nations) if firms simply choose the best way of incorporating the new technologies into their productive processes.

Instead, the paper’s underlying idea is that technical progress is embodied in specific products and processes. It should also be clear that it is something far from spontaneous; technological advances are stimulated by policies that combine effective demand with instruments that support scientific and technological development. Attention must be drawn to the fact that “advanced manufacturing” experiences were originated in developed countries as part of their strategies for the next decades. These strategies have not yet been fully implemented and cover areas to be developed in at least 15-20 years.

The next sections cover the two main ongoing initiatives for implementing advanced manufacturing. From our perspective, it is important to understand the theoretical features that led them to “rediscover” the importance of manufacturing (and industrial and technological policies).

3. We need to talk about industrial policy

According to O’Sullivan *et al.* (2013, p. 432), “there is renewed interest in ‘industrial policy,’” especially in the aftermath of the 2008 crisis. This renewal reflects changes in the global nature of manufacturing, such as the declining share of manufacturing activity in many developed countries, the growing competition from emerging economies and the accelerating pace of technological change. Besides national peculiarities, an essential dynamic shaping current industrial policy is the growing fragmentation of production (Milberg and Winkler, 2013).

Many analysts advocate that the world has entered a postindustrial phase in which selling services and becoming a “knowledge economy” is better than making “stuff”[2]. Others, like Chang (2009), challenge this pseudo-consensual view and argue that the manufacturing companies are responsible for the relevant sources of demand for services.

Indeed, historically there have been several attempts to foster industrial development, given its centrality to economic development traditional arguments in favor of manufacturing are encapsulated in Kaldor’s laws, which highlight its relevance for economic growth and the benefits on productivity and employment (Kaldor, 1981). Rosenberg (1963) argues that manufacturing – more specifically, the capital goods segment – is a major diffuser of technological innovations. Besides, manufacturing drives demand for high productivity activities in others sectors and is also fundamental for the relief of external constraints, mitigating balance of payments crisis.

Less highlighted, though, are the synergies enhanced by the proximity of shop floor activities to others such as engineering. Some authors conclude that when several firms offshore their activities, it contributes to weakening the country’s overall economic position (Pisano and Shih, 2009). Splitting certain activities ends up undermining national innovative capacity.

Technological development is strongly related to production, and the proximity of R&D teams to the shop floor is extremely important for innovation. The authors refer to these collective capabilities as industrial commons, which may include the know-how related to R&D, engineering and other skills related to specific technologies.

This finding has been raised while discussing development strategies and public policies have been redesigned under denominations like advanced or digital manufacturing. As mentioned by Andreoni and Gregory (2013, p. 35): “The crisis situation has led many analysts to ask: ‘Has off-shoring gone too far?’ and, more importantly, ‘Does manufacturing still matter for the wealth of advanced nations?’”

4. Main international experiences

From our perception it is fundamental to investigate which policies the leading countries are pursuing. Indeed, the experiences here alluded were mainly motivated by political wills to

retake industrial leadership. This perspective brings up interesting issues, such as the recognition that technological developments do not consist of “exogenous” trends. Quite the contrary, they benefit from specific actions established by countries that seek to stimulate industrial development.

4.1 US' advanced manufacturing

4.1.1 *A bird's eye view.* Throughout the American history, it is clear that the federal government plays a substantial role in regard to industrial policy (Andreoni, 2016, pp. 14-15). The USA has always used a broad spectrum of policies and is particularly recognized for its support on the military industrial complex. Also there exists a strong institutional structure to stimulate technological innovations. This institutional structure combines support to R&D with several other measures, including trade policies, local content requirements and public procurement. The US National System of Innovation (NSI), often singled out as a major contributor to the country's industrial strength, was traditionally articulated around a wide network of universities and laboratories, as well as public agencies and federal departments.

However, in recent decades, manufacturing as a share of GDP and employment has declined in both low and high-tech industries. The fall in employment is not only related to production; there are also concerns on losing the lead in R&D-related employment. More recently, academic papers and governmental white papers reveal many concerns with the implications of American deindustrialization.

Many of them suggest that US leadership is threatened and even draw attention to the country's current account[3]. The trade balance in high-tech manufacturing products currently shows a deficit, shifting from a surplus in the 1990s to a circa US\$100 billion deficit in 2011. Also, by now the USA has already been surpassed by Germany and China as world's largest exporter (President's Council of Advisers on Science and Technology (PCAST, 2011). In addition, the USA is losing to foreign countries some R&D activities related to manufacturing. For years, American firms' expenditures in R&D outside the USA have grown three times higher than domestic spending (see Tasse, 2010).

In this sense, Pisano and Shih (2009) draw attention to the fact that relevant activities were relocated to other countries. This is an important finding, contrary to the conventional wisdom that usually states that possible harms are restricted to lower value-added tasks, as assembly[4].

Offshoring harms not only the firms that offshored their activities but also the capabilities of other firms, so it is important to be geographically close to the commons. According to Tasse (2010), examples can be found in the personal computers industry, semiconductors, electronic displays and others. As emphasized by PCAST (2011, pp. 11-12): “[w]hen different aspects of manufacturing [...] are located in the same region, they breed efficiencies in knowledge transfer that allow new technologies to develop and businesses to innovate.”

Furthermore, Pisano and Shih (2009) deconstruct the myth that the relocation of certain (mature) industries is part of a natural process, allowing resources to be reallocated to higher value-added activities. One should not ignore that modern products can depend on the commons of mature industries, as the authors' example of the semiconductor foundries and the capabilities related to thin-film-deposition.

Hence the separation between production and innovation is far from simple. Indeed, there is a blurry boundary between these activities and separating them can negatively impact the feedback interactions of the innovation process.

4.1.2 *The American approach.* As already mentioned, the USA aims at reconquering their fading industrial leadership. In this context, a set of white papers emphasizes the

synergies between different activities and the importance of cutting-edge enabling technologies. As stated by PCAST (2011), “[...] technology innovation is closely tied to manufacturing knowledge. We cannot remain the world’s engine of innovation without manufacturing.”

Following PCAST (2011), the crucial part of the American strategy is an initiative for supporting research related to new and generally applicable enabling technologies. Their key recommendation is that the federal government launches the advanced manufacturing initiative, combining several institutions, notably the commerce, defense and energy departments (see also National Science and Technology Council, 2012 and President’s Council of Advisers on Science and Technology, 2012, 2014).

Thus, as precondition to boost advanced manufacturing, massive investments are needed both to ensure that new technologies are developed nationally and to create infrastructures to support technology-intensive firms[5]. Such investments involve strong support for applied research programs whose impacts are potentially transformative. Such an effort would be complemented by parallel academia and industry initiatives.

What’s more, investments in shared infrastructure help a number of companies. PCAST (2011) reasonably assume that smaller companies will not (individually) invest in the entire infrastructure needed to promote advanced manufacturing.

The recommendations gave birth to the National Network for Manufacturing Innovation (NNMI), formed by regional research institutes called Innovative Manufacturing Institutes (IMI). Inspired by the German Fraunhofer, the NNMI is a network of research institutes that accelerates the development and deployment of advanced manufacturing technologies. They all have common goals, such as develop advanced manufacturing technologies, as well as undertake research activities and stimulate the supply of skilled workers.

Despite common goals, each institute has a specific focus, functioning as a regional hub. Each institute operates through public-private partnerships between the triple helix. In addition to the participation of several universities, it is worth mentioning the joint participation of several companies (e.g. GE, Lockheed Martin, Boeing, IBM, etc.). The vast majority is US-owned with strong global insertion and commanding robust supply chains.

Currently, 45 institutes are planned for a period of ten years. Created in 2012, the pilot IMI is called National Additive Manufacturing Innovation Institute (NAMII). To enable the NAMII, five government agencies (DOD, DOE, DOC, NASA and NSF) were brought together and a consortium was selected to co-invest the necessary resources. With the establishment of the first seven IMIs[6], the federal government invested up to US\$500 million whilst other parties amounted up to US\$1 billion (see www.whitehouse.gov/the-press-office/2015/08/28/fact-sheet-obama-administration-announces-new-flexible-hybrid).

Though analyzing each institute would be out of scope, we should sum up some common features: federal agencies play a key role (as well as US-owned firms); they all deal with enabling technologies; and they contribute to future reduction in the costs of acquiring technologies, energy consumption, etc.

4.1.3 Conclusion. By now we must emphasize some valuable aspects. Also they may be relevant for comparing USA and Germany, and to point out preliminary recommendations for Brazil.

It is worth mentioning that the American white papers assign an explicit role to the government in boosting the development of advanced manufacturing. In particular, the defense, energy and health departments work together with the institutes to provide effective demand, enabling the IMIs.

Clearly the Department of Defense has a major role. Currently, the DOD accounts for half of the federal spending on R&D and operates through major programs and agencies. Obviously, the USA has huge concerns with national security and it permeates several

initiatives (advanced manufacturing being one of them). Given their unique implications, DARPA and DOD are strategic to the success of the advanced manufacturing initiative:

Historically, Federal technology investment [...] has been crucial to the creation of many technologies that have created new industries in the United States. Such investments, commonly supported by the Department of Defense, Department of Energy, National Institutes of Health, NASA, and National Science Foundation, have helped spawn entire industries. (PCAST, 2011, p. 17)

In light of this it is difficult to argue against the proposals to increase the funding of several departments and agencies as they intend to support solutions to the challenges imposed by the advanced manufacturing initiative. Complementary measures include incentives for private R&D, financial incentives, and support for education/training. We may also note that the US' ability to succeed is enhanced by a strong industrial base and the strengthening of high-tech segments. Certainly, already having national (large and mid-sized) companies paves the way.

In analyzing the American approach, one must note that, besides ensuring stable effective demand, the government also plays a particular role in coordinating and mobilizing agents and resources. One can also identify many measures toward a mission-oriented problem solving approach, stimulating specific projects that benefit the American industrial sector.

4.2 *Germany and industrie 4.0*

4.2.1 *A bird's eye view.* It is well known that for almost two decades after the Second World War, the German economic growth was carried by massive investment in strategic industries. O'Sullivan *et al.* (2013) recall that the German manufacturing sector accounts for more than a fifth of the country's total value added. More recently, Germany also emerged as a leader in new technologies.

As Andreoni (2016) recalls, some renowned companies are world leaders in various segments, but there is also a dense network of relatively smaller companies which is extremely relevant to the economy. In fact, many *Mittelstand* companies are technology-intensive and market leaders in their niche, although they remain completely unknown to the general public[7].

Historically, German industrial development has benefited from some key elements. Following Chang *et al.* (2013) and O'Sullivan *et al.* (2013), the industrial sector is traditionally backed by a highly organized institutional infrastructure. Many of them have historical roots and are actively supported by public resources. Among others, one can point out the wide network for R&D support, initiatives for improving technical capabilities, access to credit, the vocational system and the role of foreign trade agencies.

Andreoni (2016) highlights the special role of Fraunhofer, a post-war network of institutes, being one of the major pillars of German industrial policy. The institutes are widely known for addressing relevant technological challenges for the industrial system. A second pillar consists of the financial infrastructure composed of public banks focused on financing the industrial sector. This network is not only made by federal actors – *länder* also play a relevant role – and is essential to the *Mittelstand*. Finally, the author highlights some regulations on the industrial relations (Hancké and Coulter, 2013).

Although these traditional elements have been present for a fairly long time, German capitalism underwent relevant changes since the 1990s. Until the beginning of the 2000s, the country was considered the “sickman of Europe” but then became a successful model. As stated by Bastasin (2013, p. 2):

[...] the entire German production system had to and was able to strengthen its export orientation, while facing the major geopolitical changes that have directly involved the country; the German reunification, the European monetary unification, Eastern Europe opening to international trade and, finally, the entrance into the markets of large areas of the world up to the full development phase of globalization.

There is a rather long debate about the reasons for the German success, from market reforms to technological superiority coupled with outstanding export performance. According to Cesaratto (2010), there are a number of reasons for the recent external performance. Among others, we must name the European macroeconomic environment and Germany's integration with the peripheral countries of Eastern Europe. Exports, especially within Europe, appear as the most dynamic component of demand. These are essential aspects, especially considering the restrictions on fiscal policy (Maastricht Treaty) and the low dynamism of domestic consumption (wage compression and growing inequality).

Indeed, wage compression and also the fact that the German exchange rate (since the implementation of the Euro) is devalued *vis-à-vis* other European countries make German exports more competitive than their European competitors. Nonetheless, Storm and Naastepad (2014) and Dauderstädt (2012) argue that the products with the best export performance are those whose competitiveness is not mainly related to prices.

In this sense, Germany's industrial capacity guarantees the exports' competitiveness, especially within Europe, which happens to be its major market. According to Bastasin (2013, p. 5):

German competitiveness derives from the acquisition of comparative advantages in a rather large number of specialized categories of products. In capital goods, durable consumer goods and pharmaceutical products, German firms hold large shares of the world markets. Germany has thus increased exports to the rest of Europe, maintaining its traditional European subcontracting chains, especially in non-euro Visegrad countries.

As mentioned above, Germany's leading position is a result of various elements, especially since the formation of the European Union. The legislation on the European single market imposed unique standards for products and services exported under the common market. What used to be "only" a non-tariff barrier has become a huge advantage for exports because of its technological superiority and the ever since strengthened ability to set standards.

Another important structural change was the transformation of German companies into large global groups. Since the 1990s many companies started to acquire facilities and firms in the neighboring countries, setting up their "European value chains" – as opposed to the so called "global" value chains. Taking advantage of its central position in Europe, its excellent infrastructure of ports/airports and its tradition on trade promotion, the country has turned itself into an intra-European hub. Large companies began to import more intermediate goods, concentrating the assembly's final steps in Germany and exporting final goods with strong technological content.

Another relevant factor was how Germany benefited from changes in the patterns of global demand. Originated basically from the ongoing process of income concentration, both in Europe and globally, these changes favored the German industrial structure, also encouraging the demand for "luxury" consumer goods.

Dauderstädt (2012) argues that the pursuit for international competitiveness is almost an "obsession" for Germany. Nevertheless, it is worth emphasizing that the economic policies do not add up as a deliberate and coherent strategy. There is not precisely a strategic actor, but instead a common effort of the state, companies and unions[8].

Therefore, to comprehend the "new" industrial strategy, one must first understand Germany's overall context. It is in this context that the German strategy takes place, and aims to deepen the country's leading industrial position – by stimulating and expanding the technological competitiveness of its firms and by strengthening its non-price competitiveness.

4.2.2 The German approach. In light of the above, there are ongoing initiatives aiming at Germany's industrial future. The background for the German initiative is composed of a series of general concerns translated into the ambition to reinforce global (primarily European) leadership.

Andreoni (2016) points out that the German economy underwent some transformation cycles. The first recent cycle occurred in the early 2000s and emphasized environmental issues, energy efficiency and stimulus to renewable sources. Since mid-2000s, Germany underwent three major cycles, whose guidelines can be found in the High-Tech Strategy. The translation of this general plan into specific measures encompasses the federal government, länders and European institutions in several levels.

Bundesministerium für Bildung und Forschung (BMBF, 2010, 2014) states that the High-Tech Strategy was built on a national consensus sharing a common vision on the innovation process and the need to create new technologies, consolidating global leadership and opening new possibilities for the industrial sector. The initiative is coordinated by the government and has the participation of important companies (e.g. Siemens, Volkswagen, Bosch, etc.), mainly German-owned.

The strategy aims to solve challenges posed by globalization (“Germany cannot compete on cost”, as Andreoni, 2016, pp. 23-24 recalls) and is designed to explore opportunities posed by specific segments and cross-technologies. The High-Tech Strategy emphasizes the need to secure new markets through a mix of mission-oriented projects and export promotion initiatives.

Germany intends to present itself as a solution provider for many global challenges – either opening/creating markets or deepening the existing/dynamic ones. Several actions are derived from major themes (fields of action), and both the development of enabling (key) technologies and measures to improve the “general conditions” for innovation are encouraged[9].

Figure 3 illustrates the proposed framework.

Currently, the priorities are: digital economy and society; sustainable economy and energy; health living; intelligent mobility; and civil security. As summarized by Figure 3, both key technologies and the general conditions are cross-cutting issues that span all fields of action. A central issue of the strategy is to direct research and innovation policies to solve specific “missions.” To this end, specific (forward-looking) projects are associated with the major themes.

Of course, there are many specific examples, but whether achieving or not the targets, BMBF (2014) highlights that each of them looks for “systematic solutions that enhance our quality of life, protect our bases for life and give our industry competitive advantages in important lead markets” (BMBF, 2014, p. 50). Figure 4 illustrates some projects.

Let us now turn briefly to the topic of the digital economy, which deals with the integration of digital technologies with industrial applications. Such integration is seen as a decisive factor for the competitiveness of the German economy. Only underneath this broad topic we find the industrie 4.0.

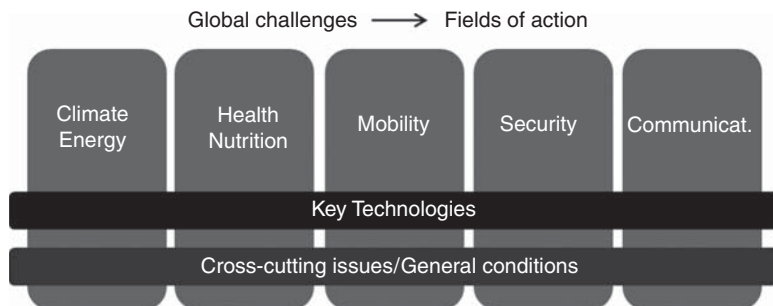


Figure 3.
The High-Tech
Strategy fields
of action

Source: Adapted from BMBF (2010)

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Source: Adapted from BMBF (2014)

Figure 4.
Ten forward-looking
projects

Acatech (2013) recognizes that Germany's industrial strength derives from its specialization in innovative technologies. The document states that the accumulated capabilities in engineering, manufacturing and information technologies allow the country to be a leader in the manufacturing engineering industry. Generally speaking, Acatech (2013, p. 5) emphasizes cyber physical systems which, in the manufacturing environment, comprise smart machines, sensors, storage systems and facilities capable of autonomously exchanging information and triggering other actions. Among other things, industrie 4.0 is associated with the resolution of important problems and aims to increase productivity at the firm level.

A key element of the strategy is the adoption of a "dual" strategy by Germany (Acatech, 2013, p. 29). Dual in the sense that: the utilization of cyber physical systems brings efficiency to domestic production and the development of cyber physical technologies represent an opportunity for companies to export. Therefore, the country can benefit from its strong industrial base and excellent research environment.

Rather than understanding each and every detail, it is important to understand the general framework as well as its mission-oriented feature. BMBF (2014, p. 36) underlines the relevance of key technologies "due to the economic leverage they can develop" (BMBF, 2014, p. 36) and include the digital technologies as critical. Also, BMBF (2014) makes explicit reference to the relationship between these key technologies and the maintenance of the German leading position as the factory of the world.

4.2.3 Conclusion. Within the conceptual and institutional frameworks, the initiatives are materialized in the forward-looking projects, of which industrie 4.0 is "merely" one of them. Similar to the American case, such projects can be seen as mission-oriented, and the development of key technologies are "the drivers of innovation and the basis for new products, processes and services" (BMBF, 2010, p. 9).

At first glance, one could argue that the proliferation of "smart" factories and the adoption of these technologies would be driven by the domestic industry itself. Indeed, embracing new technologies can bring efficiency gains and Germany has numerous modern companies that may be able to absorb new technologies. However, the German economy does not show exuberant growth and traditionally relies on exports. The latter is the component of effective demand that can truly enable and scale up the German strategy. This interpretation appears to be in line with the country's excellent export performance and its link with European value chains. In addition, it is directly related to the aforementioned explicit orientation of seeking new markets, even in emerging countries.

Moreover, a possible new feature is that Germany will not only place itself as a product and technology exporter, but also as a “producer” (or EPC contractor) of smart factories. EPC contractors commonly have a special role defining from which companies will be demanded the equipments/solutions. We can recall Simon (2009, p. 108) as: “(w)e often hear that China will become the “factory of the world,” an assertion that will probably come true. But hardly anyone asks the ensuing question, ‘Who builds this factory of the world?’”.

Although Germany’s federal government does not act exactly like its American counterpart, it still plays a prominent role. This is a fact both with regard to the coordination of a diversity of agents and the provision of effective demand. In fact, the High-Tech Strategy launched in 2006 committed itself to about €4 billion per year for the development of enabling technologies; the revised 2010 High-Tech Strategy allocated more than €8 billion for the recent period of 2012-2015 (see www.gtai.de/GTAI/Navigation/EN/Invest/Industries/Smarter-business/smart-solutions-changing-world,t=hightech-strategy-2020-action-plan,did=575914.html).

In addition, the German innovation ecosystem strengthens the industrial sector with numerous supports for R&D, skilled labor and highly ranked research institutes. Similarly to the USA, Germany benefits from its robust industrial base, the current international insertion and the ability to set standards, securing markets and establishing barriers.

5. Final remarks

5.1 What’s really new? Is there anything old?

Away from the prevailing views, the present paper brings a different approach. Definitely, it would be a misconception to view the advanced manufacturing debate as a global strategy jointly undertaken in a coordinated manner. In fact, it is precisely the opposite of the latter (naïve) position: they consist of national policies aiming at industrial leadership – which, after all, intend to maintain the global preponderance of those countries.

By means of our interpretation, it is clear that there is no “exogenous” tendency for technological evolution, neither autonomous nor unavoidable. Instead, we find deliberate policies to create new markets and build the future by incorporating enabling technologies. Thus, the non-spontaneous nature of the technological progress is emphasized.

Having addressed the general motivations and two particular experiences, we can list some similarities between the USA and German initiatives. Table I summarizes the main points.

Generally speaking, the initiatives consist in a set of policies that brings innovation in its core. As already mentioned, they support and stimulate the emergence of new enabling (key) technologies, a crucial element of both strategies. These technologies are at the basis of

Main common features	USA	Germany
Drivers	Government	Exports
Enabling (key) technologies	Additive manufacturing, nano and biomanufacturing, composite and lightweight materials, wide-bandgap semiconductors, photonics, next generation electronics, etc.	(Reinforce) Institutes like Fraunhofer
Innovation infrastructure	(Create) Innovative manufacturing institutes	
Fields of action	Defense (dual), energy, health, etc.	Renewables, health, mobility, security and communication, etc.
Industrial base	GE, Boeing, Lockheed Martin, IBM, Honeywell, etc.	Siemens, VW, Kuka, Bosch, Festo, etc.

Table I.
Common features
(USA x Germany)

Source: Elaborated by the authors

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similar initiatives from several mature economies. These technologies may enable new economic activities or revitalize traditional ones.

Loural (2014) associates these technologies with platforms, “technologies on which other technologies, processes and products can be developed” (Loural, 2014, p. 12, our translation). Following Tassey’s (2008) concept of generic technologies, which provide “a knowledge base from which particular sets of applications and other technologies can be developed” (Loural, 2014, p. 14, our translation).

Secondly, it is clear that there are massive investments involved, especially by the federal government – though to a greater degree in the USA. These initiatives call for a special role for specialized institutes dedicated to the development of enabling (key) technologies and stimulate the industrial commons.

Moreover, the institutional structure related to the innovation ecosystem strengthens the industrial sector. This structure is supported by federal and local authorities and provides an excellent research environment, skilled labor and various forms of R&D support.

Among many things, the federal government plays a particular role in terms of coordinating and mobilizing agents and resources. With regard to the provision of an effective demand that allows the development of key technologies, the US agencies’ role is an unequivocal example. The German federal government also plays a prominent role (together with *länder*s), although reinforcing Germany’s exporting feature is crucial. As already emphasized, one may note that many measures are directed toward problem solving, starting from a mission-oriented approach.

In both cases we can benefit from PCAST’s (2011, p. 9) definition and state that both countries’ efforts aim at developing a “family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology.”

In addition, it is worth noting that both countries benefit from their international insertion and industrial base – particularly from their national and hidden champions. The capacity to develop high-tech capabilities is boosted by the existence of (large and mid-sized) companies coupled with a strong industrial base – where national ownership is more of a rule rather than the exception.

We can, thus, emphasize once more that the identification and development of enabling technologies acquire a relevant role. Relevant, also, as part of the strategy to create and/or command new markets.

Let us now consider on what can be truly new. In this sense, what could distinguish the current period of technological progress is the convergence/combination of enabling (key) technologies to generate new products and processes that could lead to more disruptive changes.

Nevertheless: is there anything “old”? In light of the current global competition and changes in the nature of production, several countries adopted repositioning strategies. In this sense, we are once more facing another manifestation of the old debate on industrial policy – now revisited in order to stimulate reshoring. Clearly, mature economies themselves have rehabilitated industrial policy bringing together: a mission-oriented view; emphasis on the combination of enabling technologies; and strengthening of collective capabilities.

Indeed, given the dynamics stressed in this paper, the idea of a “new” revolution deserves a skeptical view. One may admit that it is premature to categorically claim for a (fourth industrial) revolution. Obviously, the future is full of uncertainties and it is difficult to predict the maturity of this or that approach. It is clear, however, that there is still a long transition and that the future is under construction. Although we recognize that significant changes are on the way, it is possible that they represent a new step of a long process already in progress – made possible by information technologies. Thus, it may be wiser to interpret this as part of

an evolutionary process, full of incremental innovations and characterized by a combination of technologies. Actually, many of them are already known or, as OECD (2015, p. 10) puts it, “have been around for a while”[10]. Many technologies will coexist in a hybrid form, coupling new and traditional products/processes and mature and emerging technologies. Some of these hybrid technologies themselves are still close to their infancy.

5.2 *Some preliminary recommendations for Brazil*

The present study focused on exploring the main international experiences. By exploring these cases we may also gain perspective for a future Brazilian strategy. Considering the elements summarized in Table I, we now list analytical questions that could guide a possible incursion. Only general questions will be elaborated, in order not to escape from the original scope. Evidently, future work may further explore these questions.

First, it is critical to identify which enabling technologies are the most relevant to Brazil. Though acknowledging that several technologies are naturally transversal and may span the whole economy, we must consider that the opportunities may be greater in some “niches” than in others. In this way, which sectors or activities could anchor a Brazilian strategy? What are the specific forward-looking problems that could be responsible for boosting demand?

Briefly, and not exhausting the topic, it should be noted that Brazil is particularly well positioned in the oil and gas sector and has a huge potential when it comes to pre-salt oil reserves. Similarly, the country has a “natural” vocation for agriculture and also owns a unique asset such as the Amazon biome. Renewable energies can turn the country to new technologies and markets. As is well known, Brazil has huge social deficits in, e.g. health and mobility and these are also issues that could guide national challenges.

Second, where would the effective demand come from? In the USA, public procurement is crucial and the domestic market may assume an important role. In Germany, crucial is its export orientation associated with its role within Europe. Clearly, the Brazilian international insertion is different, but it is somewhat basic to analyze the regional role that it can assume and has assumed – in some cases a global role could also be feasible. In addition, it is worth asking: is it necessary to structure a medium/long-term procurement policy that stands behind the challenges to be addressed? In the long term, would there be an economic “will” for this? Most important, would there be political cohesion to sustain the necessary actions (and effective demand) in the long term?

It is worth recalling that something has been done in the recent past, e.g. with *Inova Empresa* and with the *Programa Nacional de Plataformas do Conhecimento – PNPC*. The first involved public calls for supporting priority sectors and technologies. The second had among its goals to create knowledge platforms in selected areas, using public procurement and strengthening research institutions.

On the latter, one must compare what ideally could be done *vis-à-vis* how the country can benefit from the existing structure. In light of what has been explored by now, we can encourage the creation and strengthening of commons in Brazil. As example, we should highlight the ongoing initiative consisting of the creation of a series of regional institutes with specific focus – the Senai Institutes of Innovation (ISI) and the Senai Institutes of Technology (IST). Conceptually, we could argue that initiatives such as PNPC and ISIs/ISTs are “baby steps” measures willing to place Brazil at a level similar to that of the mature economies. In addition, Brazil has a variety of traditionally important institutions and instruments, such as Embrapa, Cenesp/Petrobras, ITA, Finep, etc.

In any case, stimulating the development of enabling (key) technologies involves mapping the relevant institutions and companies. In this respect, the role of the local entrepreneurial base should also be examined, considering its fragility and heterogeneity. In particular, given that foreign multinational firms accounts for a significant part in

Brazilian industrialization, it should be asked whether this puts Brazil in a different position from Germany or the USA. Whatever the answer, one cannot but question: do the characteristics of our industrial base matter in any particular way?

Of course a Brazilian strategy would be a deliberate effort, which obviously could go right or wrong; there are many cases where industrial policies have failed. Part of its success depends on political support for essential measures. As Chang (2009) recalls, without it, little progress will be made in regard to effectively promote the industrial sector. Furthermore, the relationship between classes and institutions is relevant, but one must be careful about the risk of being “captured” by the interests of specific groups. In this line, Chang, Andreoni and Kuan (2013) rescue Peter Evans’ famous notion of embedded autonomy, warning about the risks of the government becoming just an executive committee of the bourgeoisie.

Finally, it remains to be seen if this will be one of those situations in which the industrially most developed nation only shows the least developed image of its own future and if, paraphrasing Chang (2004), mature economies will kick away the ladder of the others.

Notes

1. This view prevails, even though there is a long-standing controversy in the economic literature about the relationship between technology and employment. Recently, Frey and Osborne (2013) highlighted that computerisation may affect many jobs.
2. As Larry Summers’ statement in Gertner (2011).
3. It is worth noting that permanent deficits are not a major macroeconomic problem for the USA, as it can finance deficits in its own currency (see Serrano, 2008).
4. Take the software industry, for example, many companies outsourced simple tasks to India in order to reduce the costs of software development; but then Indian companies have developed skills related to software engineering and now can handle much more complex tasks.
5. To say the least, PCAST (2011)’s “business environment” is a vague expression, but they understand that tax incentives will be needed to attract investments in innovation. Another related topic is the quality enhancement of the workforce.
6. For existing IMIs: www.manufacturing.gov/. For related initiatives: www.manufacturing.gov/federal-initiatives/
7. See Simon (2009) for an interesting incursion on the hidden champions.
8. As the author points out, German industrial policy finds external and internal limits. The former refer to restrictions imposed by the European treaties (limiting subsidies, tariffs and non-tariff barriers) and the latter being a strong ideological opposition to state intervention.
9. We may also note that the strategy was explicitly built “with the aim of tapping emerging markets” (BMBF, 2010, p. 5).
10. For a similar interpretation, see Loural (2014) and Kupfer (2016).

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