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Reinventing industrial policy at the frontier: catalysing learning and innovation in Brazil

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Our argument revalidates and advances the idea of learning that is central to literatures on economic development, innovation and industrial policy. Global shifts where developing countries are advancing and innovating at the technological frontier challenge the conventional view of learning that focused on adapting existing technologies from advanced economies to build domestic firms' capabilities. Our research contributes to capture new dynamics of innovation, emerging technologies and government industrial policy, crucial in the learning perspective. Our field study of Brazilian government programmes in the bio-based industry illustrates how industrial policy is reinvented to catalyse firm innovation at the technological frontier.

Keywords: bio-based industry, Brazil, economic development, industrial policy, innovation, Latin America, learning
JEL Classification: O1 Economic Development, O25 Industrial policy and development, O31 Innovation, O38 Innovation and government policy

Introduction

The notion of learning as a central process underlying economic development is a prominent idea (Amsden, 1989, 2001, 2008). Learning builds knowledge and increases know-how (Lundvall and Johnson, 1994; Malerba and Nelson, 2011). Firms in developing economies must learn to produce new products and processes to build their assets, enhancing their competitiveness beyond raw labour power and low wages. The prevalent view focuses on learning foreign practices and borrowing already existing technologies, that is "catching up" to established industries and technologies invented by multinationals in advanced economies (Kim, 1999; Lall, 2000; Malerba and Nelson, 2011). As learning results in new knowledge for the developing country, this is seen as innovation tied to a process of local adaptation, modification and incremental improvement, leading to products and processes that are new locally but not to the world (Lall, 2000; Altenburg et al., 2008; Nelson, 2011). While this learning view is crucial for understanding development dynamics, it is limited in capturing a changing global context where innovation in developing countries is advancing and, in some cases, approaching or even occupying the technological frontier.

Some developing economies are pursuing learning in emerging technologies where the frontier is in the making, instead of only producing and adapting based on what exists already in advanced economies (Kraemer-Mbula and Wamae, 2010; Lema et al., 2015b). Understanding this dynamic is a challenge, particularly for analysing the role of government and its industrial policy. The learning perspective emphasises the developmental role of government, and the building of the domestic firms' capabilities in the technology acquisition process (Amsden, 1989, 2009). Creating capacity for knowledge-building requires government to support learning through policies that enhance the ability of firms in developing countries to close the knowledge gaps with advanced countries' companies (Malerba and Nelson, 2011; Nelson, 2011). Since the 2000s, following the success of the East Asian tigers and China, and after the 2008 financial crisis, there is a growing focus on industrial policy that creates the conditions for learning and innovation to build long-term capacities (Cimoli et al., 2009; Stiglitz et al., 2013; Stiglitz and Greenwald, 2014). Moreover, local problems such as oil dependence and air pollution often drive demand for policies that foster innovation to address them. The current view on industrial policy is not about "whether," but "how."

Renewed interest in industrial policy revalidates Alice Amsden's notion of learning. Specifically, the idea that economic development is a process of continuous technological innovation, upgrading and diversification, where government actions facilitate domestic firms' innovative capacities. However, significant changes in the role of developing countries in new technological frontiers challenge some tenets of the existing learning literature. Due to the global shifts in innovation patterns and problems connected to climate change and sustainable development, industrial policy in developing economies can be viewed from the perspective of their role as innovators, rather than as mere imitators.

This article explores how industrial policy is being reinvented at the frontier. We argue that the conventional view of learning in developing countries, focused on copying what already exists, and producing existing products following defined ways of doing things based on catching-up, does not capture the new innovation dynamics of emerging technologies and global shifts in the world economy. New technological challenges addressing local problems moves developing country governments to catalyse innovation. The government engages in both learning and creating conditions for firms to learn in a different way than for known or mature technology and products being transferred or adapted. Fostering innovation becomes a central aspect of new industrial policies today, as illustrated in the Brazilian example we present. The focus of "new" industrial policy is on more innovation, or innovation enhancing.

Placing learning as the centre theme, our analysis begins by presenting the theoretical discussion about learning, innovation and industrial policy, while reviewing Amsden's ideas, based on her historical perspective of what developing countries' governments of the 1970s and 1980s did to address knowledge gaps and lack of assets. Then, we discuss the new innovation dynamics that challenge conventional thinking about how to foster knowledge building through industrial policies. The discussion then builds on a study about how Brazilian government policies promote a learning economy, organising programmes to catalyse local firms' efforts and investments to innovate new technologies. Conceptually, the article builds on Brazil's efforts to advance innovation in the bio-based industry, which includes biofuels, biochemicals and biopolymers derived from renewable feedstock (in the case of Brazil, sugarcane). Situated in the biotechnology field, where new technologies are emerging in agriculture, industrial processing, health and energy, it is an unlikely arena for innovation based on established technologies. Empirically, the article presents our

study of the programme called "Joint Plan to Support Industrial Technological Innovation in the Sugar-Based Energy and Chemical Sectors from Sugar" (PAISS), led by the Brazilian National Development Bank (BNDES) and the Agency for Funding Studies and Projects (FINEP). Brazilian efforts illustrate the policy experiments to foster learning and innovation in a new direction during an ongoing international technological race. Brazil's history of productive development policies, a paradigmatic case for conventional industrial policy, gives a vantage point from which to explore the movement towards new policies.

Learning, innovation and industrial policy

Learning is a central concept of discussions in different literatures on economic development, innovation and industrial policy. Specifically, the economic development literature highlights the challenge facing developing economies to build their knowledge, to improve and innovate products and processes, and develop skills, namely learning (Amsden, 1989, 2001; Sabel, 1994). For Amsden, firms in developing countries (or late developers) need to move beyond the low-labour cost advantage that could not compete with the technological and managerial knowledge of more advanced economies. For example, in the 1960s, even with low wages, South Korea and Taiwan could not compete against the Japanese textile industry on market price or production cost (Amsden, 1989). Therefore, this perspective emphasises the efforts of domestic firms to build capabilities: organisational, managerial and technical know-how (Amsden, 1989, 2009).

The idea of learning by firms is also central in the literature on innovation systems and catching-up (Malerba and Nelson, 2011; Nelson, 2011). Economic development is seen as a deliberate effort to catch up, using the technological practices of advanced economies as models. This does not mean exact copying, but rather an indigenous process of adapting foreign technology to local conditions, doing them differently, and tailoring practices to developing country contexts (Malerba and Nelson, 2011). Typically, different stages of capability development begin with duplicative imitation progressing to creative imitation, then to innovation, mainly focusing on production capabilities (Kim, 1999; Kim and Nelson, 2000). For instance, large-scale electronics firms in Taiwan combined production engineering and design (Amsden and Chu, 2003). Learning involves all the knowledge building and experience gained through trial and error, using and improving existing technologies, which are not straightforward tasks (Lall, 2000; Malerba and Nelson, 2011). This catching-up is tied to industrialisation, involving a move from agriculture to manufactured goods production (Kim, 1999).

The existing literature establishes a strong connection between learning and innovation, but with qualifications for developing countries. New knowledge is created and acquired through learning (Lundvall and Johnson, 1994). Learning increases know-how, including new combinations, methods and products. Innovation combines new knowledge that results from learning (Lundvall and Johnson, 1994). As the catching-up process is a break from traditional ways of doing things, it is seen as innovation (Malerba and Nelson, 2011; Nelson, 2011). In this view, technologies originate in advanced economies; therefore, the innovation occurring in developing countries refers to a practice or product new to the region or the firms catching up, but not "new to the world" (Malerba and Nelson, 2011). Therefore, innovation in developing countries is not the technological advancement at the frontier; rather it is bringing in and mastering ways of doing things that may have been used for some time in advanced economies (Lall, 2000; Malerba and Nelson, 2012).

In general, this idea that advanced economies create technologies and then developing economies adapt existing products is also common in development studies (Lema

and Lema, 2012). For example, research on the automobile industry shows that Chinese companies are global players with strong production capabilities, but not cutting-edge innovators compared to Europe and the USA (Altenburg et al., 2008). Likewise, research on the Argentinean auto sector shows suppliers to foreign multinationals upgrading production by importing advanced foreign knowledge (Corredoira and McDermott, 2014). Similarly, in the electronics sector, a study shows India has outstanding indigenous capabilities, but it is not seen as a cutting-edge innovator (Altenburg et al., 2008). These studies emphasise the building of production capabilities and adaptive innovation while learning from developed countries.

Another perspective on learning in development processes emphasises upgrading, shifting from lower to higher value added activities through constant improvements in products and processes, in the context of clusters and network forms of organisation. This literature highlights mechanisms and routines that induce ongoing learning (Sabel, 1994; Perez-Aleman, 2005; Herrigel et al., 2013). In addition, the role of varied knowledge resources and international standards in coordinating organisational changes that facilitate upgrading of firms' capabilities contributes an institutional perspective on collective learning in clusters (Perez-Aleman, 2005, 2011). These studies show how firms build know-how when there are large gaps with the technological frontier. Firms in clusters learn to improve their products and processes by accessing diverse knowledge through joint exploration and creation of resources, while public and private organisations play a crucial role (Corredoira and McDermott, 2014).

A relevant dimension in the learning, innovation and development literature is the role of multiple actors who create conditions for firms to learn, specifically governments. What firms do, through their efforts on the shop floor and in interaction with others, builds their know-how (Amsden, 1989; Kim, 1999; Lall, 2000). As important, there is an emphasis on the role of non-market institutions such as government policy. This institutional perspective is justified, not in terms of market failure, but rather by the expected social returns and the dynamics of catching-up (Nelson, 2011). As firms incorporate and master new ways of doing things, there are considerable risks of failure. Moreover, the concern for enabling many enterprises, not just one, puts the emphasis on widespread national skill building and technological development. Active government policy stimulates and supports the learning processes and promotes the capability building of firms.

For Amsden, developing countries addressed the knowledge gaps by creating developmental institutions, such as the developmental state. Governments in the 1950s and 1960s began to promote more skill-intensive industries, through industrialisation plans designed to bolster manufacturing activity. In response to hard currency shortages (foreign exchange scarcity), governments in developing countries created new agencies to pursue industrial policy. Rather than let wages fall, as the free market view would prescribe, the states began to pursue import-substitution industrialisation (ISI) to deal with their balance of payments crises. ISI provided a roadmap for local entrepreneurs of what products were in demand locally and therefore what to produce. Under ISI, tariffs and cheap financing created conditions to make ISI investments feasible. This ushered an era of industrial transformation and fast growth rates in developing countries, particularly Brazil, Chile, China, India, Malaysia, Mexico, Taiwan, Thailand and others (Amsden, 2001).

In this model, manufacturing is at the centre, seen as the route to build skills and pay higher wages. With this argument, Amsden shared Raúl Prebisch's idea on the tendency for the terms of trade to fall against primary products relative to manufacturing (Prebisch, 1950). Asian countries, for example diversified their

economies and used exporting of manufactured products as a growth engine, rather than relying solely on natural resources (Amsden, 1989, 2001). In the Asian case, ISI was also behind the rise of exports, as the governments created and used export processing zones, local content policies, tariffs and subsidised credit. The idea is that manufacturing activities generate higher learning opportunities and capacity building potential. Moreover, technological development supports the diversification of productive activities and exports.

Industrial policy is central to help indigenous firms build their assets, foster increases in productivity, dynamic efficiency and growth through learning (Amsden 1989, 2008, 2009). Industrial policy refers to selective government intervention to promote specific sectors, affecting the structure of the economy to stimulate economic development, industrialisation and employment generation (Cimoli et al., 2009, Stiglitz et al., 2013). The government makes investments and uses policy tools such as subsidies, incentives, tax reduction, new regulations and infrastructure investments. It can include infant industry policies, but also trade policies, foreign direct investment, export promotion, price regulations, financing and infrastructure (Cimoli et al., 2009). The goal is to alter the structure of production in favour of sectors that offer better prospects for economic growth (Amsden, 1989, 2001). The government actively directs resources to firms, encouraging them to upgrade and improve competitiveness. The role of industrial policies in transforming economies, capable of learning how to implement and generate new ways of producing and new products, became part of the literature that linked development, learning and innovation in the catching-up process (Kim and Nelson, 2000; Amsden, 2001; Cimoli et al., 2009).

In practice, industrial policies focused on creating an environment for developing economies to move from subsistence agriculture to manufacturing, including growth of new industries, expansion of production output, and becoming a competitive producer of such goods as textiles, apparel, footwear, automobiles, ships, steel, consumer electronics and heavy industries such as petroleum refining (Dahlman and Frischtak, 1993; Kim, 1999; Amsden, 2008). Compared to foreign companies from advanced countries, late industrialisers had an initial disadvantage in producing the mature products and technologies on which their industrialisation strategy was based. Policies supporting import-substitution and export promotion of such mature products "violated" static comparative advantages and oriented resources toward activities with higher learning opportunities (Amsden, 1989). For example, South Korea combined a protectionist trade regime with export promotion policies, where the government used high-quality performance standards and monitoring to foster technological upgrading and internationally competitive locally owned firms (Amsden, 1989, 2009; Kim, 1999). In Asia and Latin America, governments created development banks for financing private and public investments (Di Maio, 2009). Since developing countries imported foreign technology, however, industrial policies focused on technology transfer, capital goods imports and direct foreign investment (Dahlman and Frischtak, 1993).

Separate innovation policies attempted to foster technological development. While industrial policies supported the growth of the manufacturing industry, distinct initiatives supported the creation of public research agencies, laboratories, university research programmes and national research councils (Di Maio, 2009). In Brazil, for example the creation of the Aerospace Technology Center and the Brazilian Agricultural Research Enterprise were part of attempts to establish a science and technology infrastructure (Koeller and Cassiolato, 2009). There were also funds for training specialised technical personnel (Di Maio, 2009). In Latin America, as industrial policies characteristically focused on setting and establishing

import-substituting industries and new industrial investments, they did not fund research and development in firms (Koeller and Cassiolato, 2009). In East Asia, governments fostered the development of indigenous capabilities to reduce dependence on foreign technology, putting more emphasis on domestic R&D (Amsden, 1989).

The learning view focused on encouraging dynamic efficiency in the 1980s and 1990s, when the Washington Consensus policies predicated that markets are efficient and stood against government intervention (Amsden, 2001, 2008). Building on the successful performance of East Asian countries that followed policies fostering technological development and indigenous capabilities, innovation theory diverged from the neoliberal perspective (Kim and Nelson, 2000; Cimoli et al., 2009; Nelson, 2011), while also influencing policy rethinking in Latin America, after slow growth in this period. Also, the renewed emphasis on industrial policies increased after the financial crisis of 2008, which challenged the notion that free markets are efficient and ensure growth (Stiglitz and Greenwald, 2014). Similarly, in this view, learning how to do things better, learning how to learn, closing knowledge gaps and increasing innovation are fundamental to economic development and prosperity. If increases in productivity and innovation are the result of learning, then increasing learning in the economy should be a focal point of government policy (Stiglitz and Greenwald, 2014). This argument for industrial policy is similar to Amsden's emphasis on learning among private domestic firms in developing countries as the reason for government intervention in the economy, and differs from the view of others that emphasise market failures as justification (for example Rodrik, 2004).

Current challenges to the prevalent view on innovation in developing countries

While revalidating ideas that emphasise learning, innovation and the role of industrial policy, several changes challenge some aspects of the learning perspective discussed above. First, new technological challenges for which the frontier is unknown or in the making defy the assumption that industrial policies in developing countries follow what advanced countries are doing on a defined path, because technologies and products come from advanced economies and are then produced in developing countries (that is, local manufacturing of cars whose R&D was done elsewhere). Second, global shifts in the world economy are changing the role of developing countries as innovators. Third, the idea that industrial policy focuses on manufacturing, where learning possibilities are highest, is challenged by advances in other sectors that reveal potential for learning and innovation. We develop these points next.

First, today there are new challenges for which the technological frontier is unknown, or in the making, and developing countries are participating in this frontier innovation. For example the bio-based industry, which encompasses biofuels, biochemical, and bioproducts produced from renewable feedstock, can be considered an emerging industry (Bomtempo and Alves, 2014), meaning that there is not yet a defined industrial structure or established competitors. Product and process innovation occurs intensively, with a diversity of players. New knowledge and technologies are being developed without the existence of technological frontiers or leaders. There is a wide diversity of firms with innovative projects developing different strategies to participate in this emerging industry, with intense innovation activity. Similarly, in green technologies to mitigate climate change, research shows that rather than transferring "ready-made," the global challenge is how to generate low carbon technology innovation (Lema et al., 2015a).

In this context, the challenge for developing countries like Brazil is to create policy instruments that could allow them to enter the technology race in this new industry. Policies need to introduce new perspectives focused on

ways to organise and foster knowledge building at the frontier of innovation. Just like bio-based production technologies, the frontier is unknown in many areas related to current social and environmental challenges, such as neglected diseases, clean energy and other green technologies. In these complex and rapid changing technological contexts, industrial and innovation policies cannot rely on, or be shaped by, the catching-up model of innovation.

Second, with the integration of developing countries into the global economy, their roles have shifted. Developing countries are no longer dependent when they move beyond apprenticeship from advanced economies, even in manufacturing sectors like automobiles. For example, in China firms initially learned from foreign multinationals; however, currently both foreign and local firms learn from one another in a multi-directional or two-way learning process (Herrigel et al., 2013). There are new competition and innovation dynamics where developing countries seek to develop novel technologies and products that go beyond what exists at home, or what foreign multinationals can offer. In addition to new forms of South-South integration and flows of trade and investment, there is growing South-South innovation to solve local development challenges and meet the demands for low-income economy products and processes (Kraemer-Mbula and Wamae, 2010). The sources of innovation around the world are emerging in varied locations such as Brazil, Chile, China, Kenya, India, South Africa and others (Harvey and McMeekin, 2005; Kraemer-Mbula and Wamae, 2010; Giuliani, 2011; Lema et al., 2015b). Notions like "reverse innovation" capture this unconventional phenomenon: innovation takes place in developing countries or emerging markets and is brought back into developed countries (Govindarajan and Immelt, 2009).

With the reorganisation of innovation and production in Europe and the USA, new opportunities opened up to build both production capabilities and innovation capacities (Lema et al., 2015b). For example, foreign subsidiaries and local suppliers engage in advanced innovation in the auto industry in Brazil and software in India (Lema et al., 2015b). Subsidiaries assume more design and engineering capacity to develop new products and processes in developing countries. As important, suppliers of products and services create and design new products and contribute to process engineering for local and global markets (Lema et al., 2015b). Local firms in developing countries engage in innovation activities. Similarly, in green technologies such as wind power and solar photovoltaic, Chinese and Indian firms engage in substantive local innovation, either through in-house R&D or collaborations (Lema and Lema, 2012). These findings challenge the view that technologies are only developed in advanced economies, that developing countries only import knowledge, or that there is a given technological path. In the search for new technologies to meet a variety of environmental and social challenges, developing economies may be pushing the frontier in new directions (Lema and Lema, 2012).

Third, another change is the innovation through different trajectories and diverse strategies in agriculture and natural resource-based sectors in developing countries. Innovation in the wine sector (Giuliani et al., 2011), forestry, pulp and paper (Figueiredo, 2010, 2014) and genomics (Harvey and McMeekin, 2005) shows how Latin American and African countries pursue new pathways in which invention, science and research play a prominent role. Often, these innovations are connected to cluster forms of organisation that characterise export growth successes (Perez-Aleman, 2005; Sabel et al., 2012). The existing studies reveal investments in knowledge-intensive activities in non-manufacturing sectors that achieve innovation capabilities leading to technological frontiers of global significance. Such experiences transform the view of agriculture as low-tech and low skill, to one that combines many new skills with new technological innovations.

While these changes revalidate the literature's emphasis on learning to foster economic development processes, they also highlight the limits of the catching-up view about innovation in developing countries, with implications for the design of current industrial and innovation policies. To start, neither the path nor the technological frontier are a given, as current views emphasise uncertainty, non-linearity and the distributed nature of innovation (Chesbrough, 2003). A key issue for industrial policies is how they respond to this uncertainty through collective experimentation. The means to stimulate knowledge creation and entrepreneurship will differ from efforts to adapt existing technologies. While the conventional view highlights learning, how this takes place in government and among firms is different than for known technology and products being transferred or adapted (given assumptions of copying what exists already). Today, as industrial policies attempt to create conditions for innovation, policymakers contend with the inherent uncertainty in innovation that expresses itself in many ways: complexity of technology, timeframes, changing economic conditions and varying government policy priorities and resource allocation (Coutinho, 2014).

Moreover, developing countries no longer focus only on building production capacity, but also on creating new routes and technological frontiers grounded in their local context while having global significance. Conventional industrial policy has implicitly a linear notion of innovation, as it is about producing a product that someone else discovered elsewhere and that developing countries import through technology transfer (Lema and Lema, 2012). Yet innovation has many dimensions (not just product, but also process), and constantly engages different actors along the way to commercialisation. As innovation is also distributed and open, where diverse actors have and develop knowledge, this challenges the policy conceptions based only on the catching-up model of learning.

Furthermore, there is growing recognition that governments foster learning and new industries connected to local problems, not only in manufacturing, but also in agriculture and in services like health, information technology and finance, as other sectors hold innovation potential (Kraemer-Mbula, 2010; Stiglitz et al., 2013). Finally, collaboration and new entrants matter, as innovation is taking place in forms of organisations such as clusters and networks. Beyond supporting an individual firm, industrial policy supports learning in varied forms of organisation that foster connections between firms in the value chain and that foster the creation of networks of innovators.

These changes, that challenge the conventional view about innovation in developing countries, raise questions addressed in our study: how are industrial policies fostering conditions for learning, not as catching-up, but as innovators in areas where the technological frontier is unknown or in the making; how is the government, a key actor in the literature on learning and innovation, supporting indigenous capacity building to open new frontiers or advances at the leading edge?

Research methods

The Brazil context

This study explores technological innovation in developing countries, looking at sectors and technologies where developing countries are not seen as innovators in fields of rapid technological change. This led the research into biotechnology enabling advances in health, agriculture and industrial processing. Our initial exploration uncovered policy initiatives in Brazil to foster the development of biotechnology. The study followed with questions about what Brazil was doing to build new innovative capabilities. Using archival sources and interviews with Brazilian firms and government we uncovered firms and networks working in second-generation biofuels. Second-generation biofuels, made from ligno-cellulosic biomass, or agricultural residues and waste, currently

present technological challenges, compared to the first-generation biofuels, which afford easy extraction with conventional technologies. Brazil is well known for its National Alcohol Programme (PROALCOOL) to produce ethanol from sugarcane, a first-generation biofuel (Gee and McMeekin, 2011; Mingo and Khanna, 2013). This study, however, concentrates on a currently novel technology in biofuel, different from the PROALCOOL programme and its first-generation product. This initial phase then led us to focus on the actions of the government in supporting and financing second-generation biofuel development, a crucial actor in the learning and innovation framework.

At the same time, Brazil is often cited as a paradigmatic case for import-substituting industrialisation (ISI) strategies. Industrial policy in Brazil aimed at substituting imports in specific sectors began in the 1940s and continued until the 1970s (Koeller and Cassiolato, 2009; Kupfer et al., 2013; Doctor, 2015). As other developing countries did in the post-1929 global economic crisis, Brazil intended to shift from agricultural exports to import substitution, structuring new sectors, such as petrochemicals, pulp and paper, aeronautics and others that were mature elsewhere. In the 1960s–1980s, exports resulted from manufacturing that firms learned during the ISI period, specifically automobiles (Amsden, 2001, 2008).

Parallel to the ISI policies, some important investments concerning science and technology (S&T) occurred during this period, particularly after the 1950s. At the federal level, there was the creation of the National Council for Scientific and Technological Development and the Coordination Committee for the Further Training of Personnel with Higher Education, both established in 1951 to organise and fund research and graduate studies (Koeller and Cassiolato, 2009). Other important steps in the late 1960s were the creation of FINEP, and postgraduate programmes that strengthened research in all scientific fields. Until the late 1990s and early 2000s, however, innovation policies remained separate and restricted to the Ministry of Science and Technology, emphasised research projects, and lacked funding and coordination between agencies limiting their impact (Koeller and Cassiolato, 2009).

By the 2000s in Brazil, industrial policy started again, with a focus on increasing technological innovation and overcoming the separation and lack of coordination between industrial and innovation policies that characterised the previous decades, when innovation policy was restricted to the Ministry of Science and Technology (Koeller and Cassiolato, 2009). From 2004 to 2014, three industrial policies were developed: the Industrial, Technological and Foreign Trade Policy (PITCE) from 2004 to 2007, the Productive Development Policy (PDP) from 2008 to 2010, and the Brasil Maior Plan (PBM) from 2011 to 2014 (Kupfer et al., 2013). These industrial policies encompassed technology-intensive sectors, and since 2008, innovation became a central tenet in the PDP, and even more in the PBM. For example, the PDP aimed to expand Brazilian supply capacity, as well as to increase innovation and competitiveness of Brazilian firms in sectors such as health and biotechnology selected as strategic areas, and aeronautics, bioethanol and cellulose targeted as areas to expand leadership by innovating (Koeller and Cassiolato, 2009; Kupfer et al., 2013). Both the PDP and the PBM emphasised coordination of the actions of various ministries. These attempts to connect innovation policy and industrial policy became relevant for our study, as we discuss in the following sections.

Case selection

This study examines a new model to support innovation through a joint initiative from two distinct Brazilian government institutions, BNDES and FINEP, that launched the PAISS programme creating a learning environment enticing firms to develop technologies in the specific field of second-generation biofuels and biochemicals from sugarcane. We selected

this case for several reasons. First, historically, an important domain of industrial policy includes targeted lending to specific sectors by development banks (Amsden, 2001). BNDES is a pivotal federal government institution in industrial policy implementation in Brazil, and the main financing agent for development, compared to India, South Korea and Mexico (Amsden, 2001). Since the 1950s, BNDES has fostered social and economic development, offering support for large-scale industrial and infrastructure projects; machinery and equipment commercialisation; exports of engineering-intensive goods and services; assistance for micro and small companies; and capital market support (Alem, 2010). Among the largest development banks in the world (Ferraz et al., 2013), it provides credit, equity investments, project finance and grants. Its long-term financing is a main source for companies to finance priority investments for Brazil. Since 2006, BNDES has stimulated growth in Brazil by targeting efforts to address three challenges: increasing innovation capacity, expanding industrial production capacity and increasing exports (Ferraz et al., 2013). These BNDES efforts are tied to the industrial policies pursued since the mid-2000s, as discussed in the previous section. PAISS was among the programmes launched to support technological development, given the concern of the Brazilian government for promoting innovation (Ferraz et al., 2013).

Second, this PAISS case is representative of the programmes created in the recent decade to finance productive development and innovation in Brazil (Ferraz et al., 2013). Since 2008, as Brazil attempted to overcome the historical separation between industrial and innovation policies, it encouraged the coordination and joint efforts between government agencies (Koeller and Cassiolato, 2009). In the case of PAISS, BNDES joined efforts with FINEP, the public organisation linked to the Brazilian Ministry of Science, Technology and Innovation, which provides funding for scientific and technological research, courses in Brazilian universities and research institutions, as well as supporting firms' innovation activities. FINEP provides support through grants, from resources derived from the National Fund for Scientific and Technological Development (FNDCT), or through reimbursable funding from the Science and Technology Sectorial Funds (created in 1999) (de Melo, 2009).

Third, PAISS focuses on leadership at the technological frontier. By the time they launched the PAISS programme, there were only six pilot plants of second generation ethanol in the world (Nyko et al., 2010) and no commercial facility, showing that the technologies were not yet developed, while active efforts aimed to achieve economic feasibility with successful processes. PAISS was the first experience using the approach described in the next subsections, and can be considered successful (Nyko et al., 2013), despite being recent. It represented a shift in the way BNDES and FINEP foster innovation and became a model for subsequent programmes, directed to other economic sectors such as PAISS Agrícola (agriculture), Inova Petro (oil), InovaEnergia (energy), Inova Telecom (telecommunication), PADIQ (chemical industry) and others (Nyko et al., 2013). As it was replicated, it is important to understand it in detail.

Given the government actors involved, the integration of innovation into industrial policy, and the focus on new technologies and products, PAISS is an ideal case for exploring how the government fosters learning and innovation at a technological frontier. It is an ideal window to better understand innovation efforts and the shifting roles of developing countries. The analysis of PAISS is based on original empirical research that includes interviews conducted during 2012 and 2015 with Brazilian government officials and private companies directly involved with PAISS. In addition, participation in related biofuels and biotechnology industry meetings, some led by firms and others by the Brazilian government, contributed relevant technological and industry information.

These are complemented with data collected from government reports and secondary sources.

Case presentation: PAISS

The bioethanol context: leveraging the past and the gestation of new ideas

Brazil's efforts to become a leader in second generation biofuels originated in a context where first generation bioethanol was well established. By 2004, Brazil was the largest ethanol producer in the world, and is currently second after the USA (Gee and McMeekin, 2011). The second generation is more environmentally friendly than the first generation, as it uses the residues, contributing to less waste and an improved carbon footprint. The same plant can generate up to 50% more fuel using lignocellulosic residues. Biotechnology innovation is relevant for addressing current challenges in the conversion process (pre-treatment, enzyme hydrolysis, fermentation).

Historically, Brazilian government actions contributed significantly in the achievements of first generation ethanol production. Although public policies related to ethanol existed since the 1930s, only after the 1970's oil crisis was the Brazilian PROALCOOL established (Gee and McMeekin, 2011; Andersen, 2015). PROALCOOL, launched in 1975, is considered a successful policy that achieved positive economic results, with energy security improvement and foreign exchange savings, and socially, with local employment generation, as well as being environmentally positive with a reduction of CO_2 emissions (La Rovere et al., 2011). The federal government established PROALCOOL policy to encourage ethanol production and achieve energy security while reducing the trade deficit (Mingo and Khanna, 2013). Regional influences existed, mainly from São Paulo state, which had the majority of sugar producers, sugarcane research institutions and equipment suppliers (Andersen, 2015), pressuring the federal government because of low international sugar prices (Puppim de Oliveira, 2002). In this context, the PROALCOOL policy resulted from varied interests: state governments; military groups; the alcohol industry; sugarcane agricultural producers; researchers; and the key one, the federal government. This industry would not have developed without the industrial policies implemented from 1975 to 1985 (Mingo and Khanna, 2013).

Since 2009, however, many challenges have confronted the ethanol industry, apart from economic ones: new technological developments in second generation ethanol; new environmental regulations aimed at reducing carbon dioxide emission levels; new competitive players; and an expanded view of the sector, including new products such as chemicals and biopolymers. Brazil promoted innovation to maintain its competitive position and to expand its participation in bio-based technologies. The country has advantages in biomass choices. Their availability and distribution, apart from technical questions, are decisive for the economic feasibility of a conversion technology. Since Brazil has a consolidated sugarcane industry, the bagasse and crop residues are sufficiently available as raw materials (Nyko et al., 2010).

In the context of the PDP policy, BNDES' goal was to expand the number of innovative companies, particularly in areas where Brazil has or can build competitive advantages, as in the case of ethanol. Its PAISS programme focused on the development, production and commercialisation of new industrial technologies for the processing of biomass derived from sugarcane. The PDP has a close connection with PAISS, as its "Programmes to Consolidate and Expand Leadership" includes sectors with an international projection and competitive capacity, such as bioethanol (Kupfer et al., 2013). The subsequent PBM policy selected bioethanol among strategic sectors to be developed. BNDES does not formulate policies, rather it executes them. Its financial support for ethanol capacity improvement was crucial in the past, and its organisational structure, divided by economic sectors, led to a high level of sectorial

knowledge by its technical officers. BNDES and FINEP decided to stimulate innovation in new technologies, and strengthen the bioethanol production chain, turning attention to the second generation ethanol produced from lignocellulosic residues, rather than the traditional raw material, sugarcane juice. This new technology was not available then, and is an ongoing technology race in developed countries.

The beginning: diagnosing and exploring possibilities

As innovation became an important part of Brazilian industrial policy in the 2000s (Kupfer et al., 2013), it was also included in the BNDES priority agenda (Ferraz et al., 2013). In 2010, the BNDES board invited the BNDES Biofuels Department to investigate Brazil's position in second generation ethanol, considering it a key technology. As it was a new technology, still under development, BNDES joined FINEP, the Brazilian agency responsible for financing research and innovation, to create a sectoral diagnosis of biofuels and analyse what projects they were supporting. Traditionally, FINEP focused on innovation policies, and BNDES was not involved in this issue. The new interaction between both agencies was crucial for creating PAISS, and its future development. Jointly, they would unify the gateway for project requests, avoiding dispersion while increasing coordination among firms in the sector. This would be a new approach to the way they worked with their financing tools, compared to the past. This increased coordination between two government agencies that previously worked in parallel at a distance constituted an experiment for exploration, learning and innovation within the government.

BNDES and FINEP determined existing government incentives focused on first generation biofuel, and decided to change direction to advance second generation biofuel, a more ecological and innovative approach. First, the diagnosis[1] concluded Brazilian public investment for second generation RD&I was small compared to USA or Europe (Nyko et al., 2010). Until 2010, the total amount invested in new bioenergy technologies until then was around US$550 million while the USA spent four times more from 2000 to 2009, reaching US$2.1 billion (U$250 million per year), and the EU invested US$2.5 billion from 2007 to 2013 ($400 million per year) for biofuel RD&I (Nyko et al., 2010). Second, the financial support from the Brazilian federal funding agencies was concentrated in projects related to more mature chains of the sugarcane industry, agriculture and first generation, overlooking second generation technologies. Third, innovation efforts were small, dispersed and disconnected with each other. Fourth, the focus of existing second generation research was very academic and theoretical, with limited links or participation by the companies affected. Finally, there was lack of coordination among supporting institutions.

As the diagnosis showed the need to create a new arrangement to support innovation in second generation technologies, BNDES and FINEP coordinated together the design and implementation of a programme focused on this goal. They fostered participation of traditional and new producers, as well as biotech and chemical companies to learn about the challenges and how to design the PAISS programme. They also met with relevant sector organisations, such as the National Bioethanol Science and Technology Lab, the Sugarcane Technology Center and the Agronomic Institute. With a common understanding concerning key innovation challenges, the technical officers identified main bottlenecks, constructed new goals and designed the programme, with a totally new conception to both institutions. The technical teams led, setting the budget, elaborating diagnoses and presenting to the board initial programme proposals, guiding its direction through an interactive process (Nyko et al., 2013).

Launching PAISS: coordinating and integrating diverse actors

In March 2011, FINEP and BNDES launched PAISS,[2] with the goal of financing business

plans related to the development, production and commercialisation of new industrial technologies for processing lignocellulosic biomass from sugarcane. This was the first coordinated integration of financial instruments from BNDES and FINEP, and introduced a new model: diagnosis followed by the launch of a funding programme. The initial budget was R$1 billion, equivalent to US$256 million,[3] focusing on second generation ethanol, new products from sugarcane biomass, and gasification.

New forms of interaction between the government agencies and other actors, such as firms and universities, were invented, overcoming the traditional way of separating industrial and innovation policies. As the two independent federal funding agencies developed a new programme with a novel framework jointly, and there was a change in coordination. They did not develop new financing instruments or changed rules for PAISS; each institution continued to follow its own rules of financing. Traditionally, firms aiming to get financing from BNDES or FINEP prepare a project and apply for a specific financing instrument, according to the project characteristics. This "on demand" mechanism hinders a broad understanding of what is being financed by each agency and can, for new technology developments, lead to dispersion of resources and innovation efforts. The two agencies identified that the key issue was coordination of efforts, rather than the investment amount.

The eligibility criteria were "firms whose corporate objective comprise research, technological development and innovation related to the technologies under this Plan and which are interested to undertake production activities and/or marketing of final products from these technologies" (BNDES, 2011). Therefore, any firm established in Brazil could participate, not only Brazilian ones. This could be interpreted as an understanding of the knowledge complexity of this field, and an openness to foreign firms that could enhance knowledge creation. Also, the programme did not restrict support to specific business groups or national firms, showing an extended effort to bring in new entrants. PAISS participants included different firm profiles from different countries, as startups and companies from diverse industries, such as agribusiness, chemicals, oil, biotechnology and biofuels. This high diversity reflects the effort to attract innovative capacity to the country. Also, PAISS stimulated partnerships among local and foreign firms and different arrangements for technology developments. The programme also established as evaluation criteria the amount of R&D and knowledge that foreign firms were willing to develop in Brazil. Concern over the proprietary knowledge gains for Brazil was present since PAISS conception and coincides with the idea of creating local learning within and between firms.

With innovation as the programme's goal, it also pursued a new approach: firms had to create a business plan. Instead of an isolated project approach as in the past, a business plan fostered thinking about future problems. The purpose was to encourage firms to think about the technological problems, discuss them with the agencies, and find partners in order to achieve eventual commercial success and sustainable innovation. As important, this business plan requirement reduced bureaucracy and increased external collaboration. From the agency's perspective, the business plan approach was fundamental because it allowed a broad view of the technologies involved along the second generation value chain, with considerable learning for the team and the organisations. They mapped out the entire technological scenario and compared the different approaches taken by the firms. From the firm's perspective, this new approach changed its decision scope. It was not necessary, a priori, to define which public financial instrument the firm would apply for; it should focus on developing partnerships to be able to create a business plan that could face different technological challenges, considering the entire value chain and which partners would join. The decision about the most suitable

financial instruments was postponed for a later step in the process, after working together with the agencies, to support the business plan.

The process: bringing dispersed and diverse knowledge together

The involvement and engagement of private companies and other relevant organisations was at stake in the new interactions BNDES and FINEP fostered. The government wanted to engage as many independent disconnected firms as possible and then foster collaborations. The whole PAISS process was a sequence of four steps. It started with a letter of expression of interest from each firm willing to participate. In the letter, the firm had to choose the thematic lines and present, briefly, the following topics: innovation strategy, entrepreneurial capacity, technical training, institutional cooperation and necessary support. A total of 57 firms expressed interest in joining PAISS.

The second step had two parts: a pre-selection, based on the analysis of the letter of interest, followed by a proposal presentation to the BNDES/FINEP team. At this point, the agencies started to signal the need for technology integration among firms, promoting partnerships to achieve the goals. Once again, the agencies were aware that coordination among the firms did not exist, and there was a concentration in some parts of the second generation ethanol process, fermentation and pre-treatment, for example, which was not desired since the purpose was to develop the technology for a commercial end, not a proprietary approach. In this case, the need for covering the whole process, without the concentration of many firms in the same technological challenge, remained as a guideline since the beginning. Partnership was not forced, but strongly recommended. As second generation ethanol involves more steps and companies, it was challenging to create the consortia in practice. For new sugarcane products, the consortium was usually simpler, one biotech company and one feedstock supplier. Promotion events facilitated the interactions among the participant firms as only business plans encompassing the whole technology would be funded. The agencies and firms developed closer and improved relations during the process. Some firms were not able to articulate partnerships. From the 57 initial firms, only 39 reached the second phase.

The second phase required that companies formulate a detailed business plan and its analysis by BNDES/FINEP. Forty-four business plans were submitted and 35 selected, for a total of 25 firms involved. BNDES and FINEP needed to be convinced that the business plans were well constructed, and interviewed the firms and consortiums, asking many questions about the plans presented. The government's selection criteria included degree of innovation, degree of technological risk (for example, a pilot plant is riskier so would earn more points), externalities (how much R&D is done in Brazil, which could spread knowledge to other mills), and degree of technology nationalisation.

The final step consisted of structuring a joint support plan to indicate the most appropriate existing financial instrument for each project within the business plans. Again, the model allowed coordination of financial instruments. The 35 approved business plans requested R$3.1 billion, more than initially expected. Each institution followed its own usual procedures, while bundling BNDES and FINEP's respective instruments. Although the programme is still ongoing, some important results can already be identified.

Results: new networks of innovators

In terms of results, it is possible to use quantitative and qualitative indicators. Projects contracted until February 2015 total R$2.8 billion, with R$1.2 billion from FINEP and R$1.6 billion from BNDES (Table 1). The number of industrial projects, 5–6, is very representative considering that before PAISS there were none (Table 1). Firms located in Brazil because of the PAISS Programme, such as Amyris and Solazyme, important players in this emerging industry. PAISS was able to negotiate with these

Table 1. *PAISS results: second generation situation before and after PAISS.*

Results	Before PAISS (2010)	After PAISS (2013)
Disbursements related to 2G ethanol[a]	FINEP: R$60.2 million BNDES: R$53.9 million	FINEP: R$1.2 billion BNDES: R$1.6 billion
Number of pilot facilities[b]	2	7
Number of demo facilities[b]	0	5
Number of commercial facilities[b]	0	5
Expected 2G ethanol production[b]	0	168 million litres
Consortia[b]	0	7
New firm-university partnership[b]	—	10

[a]Personal communication.
[b]Nyko et al. (2013).

firms to bring their R&D to Brazil. This created more opportunities for increased knowledge sharing inside the country. Some partnerships already existed, but seven new firm partnerships (consortia) were created during the process. A new Brazilian firm, Granbio, was also funded and initiated its commercial 2G ethanol facility operation in 2014. Although it was not an initial focus, the cooperation between firms and research institutes and universities became stronger, with 10 new firm-university partnerships, although more are expected (Table 1). More than R$3 billion were approved, far more than the initial prevision, indicating both strong firm interest and commitment from the funding agencies to achieve the PAISS goals. Compared to the period before PAISS, when no demo or commercial facilities existed in Brazil, after PAISS five demo and five commercial facilities were built and also seven pilot plants (Table 1).

The PAISS initiative both fostered innovation and also encouraged companies to collaborate. From the firm's side, the programme created a collaborative learning environment. Even firms that did not use financial resources from PAISS recognised the benefits of an environment that attracted more companies to work on technological development. PAISS attracted 21 firms that never had previous innovation project financing by BNDES, allowing new relationships to be formed (Nyko et al., 2013). In this perspective, not only biofuels but also other high value products resulted from the learning environment created by PAISS, which also involved universities, expanding the profile of actors participating in this collective experimentation.

After PAISS, the same model was applied in other sectors, as InnovaPetro and InnovaEnergia (Nyko et al., 2013), and even in the sugarcane productive chain focusing on the agricultural part, called PAISS Agrícola (BNDES, 2014). More time is needed to determine if the model will be successful in different sectors, and like any innovation process it faces ongoing challenges, but the positive effects of its development for institutions are visible. Institutional learning, more collaborative work within each institution and with firms and research organisations can be attributed to the PAISS development strategy. Moreover, PAISS fostered communication and partnerships among firms and between them and research organisations to address technological challenges. Established and new firms in the biofuel industry became part of new innovation networks and became willing to develop new technologies to address the challenges of creating new processes and products for second generation production.

New industrial policy and innovation in developing countries

The PAISS case raises five points that follow, corroborating the learning view ideas, and revising some understanding about innovation in

developing countries. First, a core idea of the learning perspective is that economic development requires building knowledge to improve and innovate products and processes and develop skills. The PAISS case clearly highlights the goal of national skill building and technological development, pushing Brazil to build capacities to create new technologies and products. It stimulated diverse firms to apply to the programme and experiment in an emerging technology. PAISS created a learning environment and attracted multiple actors. This framework also highlights the government's key role in fostering innovation. With PAISS, the government searches for ways to overcome limits to past policies and move companies to innovate and go beyond producing their traditional products. We observe the government fostering the moves forward into the rapidly changing technological development in biotechnology and energy frontiers.

Second, learning was explicitly at the centre of PAISS design and implementation in two different ways. The literature emphasises the importance of building domestic firms' capabilities, which has continued relevance. Learning by firms participating in the programme was central for PAISS success. It was important even for firms not applying to the programme but which later demonstrated interest in the bio-based industry. The meetings, the stimulus to collaborate, the search for technological breakthroughs, and new commercial plants in second generation technologies and bio-based products are evidence of learning by firms as a key element in the programme. As important, learning occurred within and among the government agencies responsible for the programme. The existing literature has not emphasised learning on the part of governments, as it focuses on firms' capabilities while assuming the government supports existing technologies. The PAISS case, however, points to bringing in this dimension, as the government policies and programmes are also changing. The way the PAISS programme came about, its design, implementation and evolution, emerged as a new design for industrial policy in Brazil. The technical officers' interactions with multiple actors (such as universities, firms and industry associations), and an enhanced understanding of how innovation could be fostered for sugarcane-based products, promoted an intense learning process. This knowledge creation could be used not just to replicate the PAISS model, but to improve on new programmes, such as in the chemical industry (BNDES, 2016). PAISS reveals the importance of learning for the involved government institutions, as they reconfigure their ways of supporting innovation and production.

Third, the PAISS case suggests a different model of industrial policy that breaks away from the catching-up and linear model of innovation assumed in the current literature on learning in developing countries, where developing countries transfer technologies from advanced economies. This is only one possible model, as the PAISS case reveals another. We identify PAISS as a new industrial policy strategy, aiming to foster innovation. Following the conventional model, industrial policy focused on production, capital goods imports and infrastructure, while separately innovation policies focused on R&D or training or university research (Koeller and Cassiolato, 2009). A different approach compared to previous practice is visible, however, in the planning and coordination among agencies. Moreover, in the past there was a separation between industrial policy and innovation policy, and now there are proactive efforts to connect them, as the frontier is in the making. PAISS encompasses from one side knowledge creation, which is the aim of innovation policies, and on the other side, production and competitiveness, which was the focus of traditional industrial policies. PAISS success depends on collective learning but also on achieving competitiveness. Production capacity and innovating at the frontier were not usually connected in previous policies as they are in PAISS.

Fourth, the government's effort to foster innovation through PAISS is fundamentally different than the conventional view based on the

catching-up model of adapting and assimilating mature technologies in mature industries, particularly manufacturing. Instead, it pushes firms to innovate in emerging technologies. While catching-up innovation remains relevant, in the advanced biofuels case, Brazil is not a latecomer. It is engaged in the race to develop new bio-based inputs and processes at the frontier, which is in the making locally and globally. That the programme was looking for business plans instead of a research project, the usual requirement, shows that the emphasis was not in R&D only, but in innovation, since a broad view of productive chain and integrated technologies was necessary. This requirement also fostered interaction of firms from the beginning of the development process, showing a new approach in the way they innovate, with more collaboration and not after the technology is established and adopted in developing countries. In this sense, no catching-up existed, showing a great difference in the way developing countries usually implement their policies (Kim, 1999). The success of PAISS is promoting the development of new technologies, not the adaptation of old ones.

Finally, the PAISS case reveals the possibilities for learning and innovation in diverse sectors, established and emerging. The literature on global value chains driven by multinationals from advanced economies captures relevant innovation dynamics, but assumes a model of adaptation and incremental innovation of existing technologies. Moreover, the literature privileges manufacturing, and foreign MNCs are the leading actors. The PAISS case reveals that learning and innovation in developing countries is occurring in diverse sectors, including agriculture, energy, biotechnology, genomics, forestry and bioinformatics, where they are participating in ongoing frontier innovation efforts.

There are other examples of innovation at the frontier in the Brazilian context. Capability building of firms in natural resource-processing industries presents some similarities with our case. Brazilian firms search for their own path of capability development from early stages (Figueiredo, 2010, 2014). As they confront natural resources that had local characteristics, existing foreign knowledge was not enough for their development and they had to build their own capabilities early, meaning the traditional catch-up mechanism was insufficient. This innovation capability building allowed some firms to become world leaders (Figueiredo, 2014), reflecting their successful learning process. Also, as in the PAISS case, government played a key role designing policies to stimulate the technological development of forestry, pulp and paper firms (Figueiredo, 2010).

Another example that shows a different concurrent trajectory and diverse strategies for innovating at the frontier is in genomics and bioinformatics (Harvey and McMeekin, 2005). Brazil's network of laboratories financed by the São Paulo government developed genomics capacity related to Brazilian crops, such as sugar, citrus and eucalyptus, as well as achieving a world leading position for bacterial genomics of plant pathogens. Its biotech companies are now engaged in transnational innovation networks. Brazilian frontier innovations on agricultural genomics and crop protection technologies have achieved global applications. While these examples focus on Brazil, the point is that attention to emerging technologies reveals a different view of how developing countries are innovating. Others identify similar patterns in the context of low-carbon technologies in other developing economies (Lema and Lema, 2012; Lema et al., 2015a). More research in emerging fields and technologies will help to uncover additional examples.

Conclusions

Alice Amsden's ideas on the roles of learning and the government in creating learning conditions are timely today, as current discussions in economic theorising put the learning

economy as central for improving living standards and fostering prosperity. It is a relevant view from which to think about industrial policy in developing countries. However, today developing countries are engaged in efforts to innovate at the technological frontier, and the industrial policy of the past focused on supporting imitation of existing products seems limited. Catching up and innovating at the frontier are not mutually exclusive, but the latter is neglected in existing studies. Innovation is occurring in unexpected locations, as changing global patterns and emerging technologies open new options for explorations in developing countries. At the frontier, governments are reinventing industrial policy as they foster local innovation of global significance.

Reinventing industrial policy today requires integrating production and innovation and experimenting with new models. We observe in Brazil's PAISS a two-way interaction between the government diagnosis and the firms' engagement in design and goal setting. Also, learning processes occurred inside both government agencies and firms. There are limits to what the government knows initially, and a great part of its effort is figuring how to catalyse innovation in specific sectors. BNDES and FINEP experiment and learn what works for developing advanced biofuels and biochemicals. Understanding the technological complexity and the innovation dynamics was crucial to achieve results. Currently, as industrial policies strive to develop new technologies, PAISS supports more joint inquiry and experimentation within and between the institutions and private firms. There was an understanding that the programme was designed to foster innovation in an emerging industry, where new technologies and new products were under development, meaning that innovation was necessary. Policies based only on the catching-up model miss an opportunity to promote diverse innovation possibilities.

Moreover, overcoming coordination failures by bringing different firms together that hold different parts of the value chain to form new networks is also part of the new policy. A broad view of technology development in Brazil uncovers very dispersed innovation efforts. To be successful, the programme catalysed interaction among different actors, each one involved on a specific part of technology development. There was an effort to bring in new entrants; the focus was on the sector, not on specific firms. PAISS had as a goal to bring new firms into the bio-based industry and created a favourable context to product and process innovation, and it saw as one measure of success how many of the private firms selected for PAISS support were new customers of BNDES. In this respect, the government also sought to structure new forms of organising among firms, by fostering alliances, networks and consortia that would bring together firms with knowledge in different parts of the value chain, with the goal of generating more knowledge spillovers between firms, in an approach that fostered both competition and collaboration. The key issue is not *if* government should or should not have an active role through industrial policies, it is *how* to do this with current social and environmental challenges. PAISS is an example of reinventing to catalyse learning and innovation to keep opening possibilities, and revalidates Amsden's core idea about the importance of learning for development.

Endnotes

[1] For a discussion about the PAISS diagnosis step, see Nyko et al. (2013).

[2] The complete description of PAISS can be found at BNDES (2012).

[3] Considering dollar quotation on 19 September 2015: US$1 = R$3.902.

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Appendix 1
Online links

Brazilian Industrial Policy http://www.abdi.com.br/Paginas/politica_industrial.aspx

Report "From the Sugar Platform to biofuels and biochemicals" https://ec.europa.eu/energy/sites/ener/files/documents/EC%20Sugar%20Platform%20final%20report.pdf

Brazilian Development Bank http://www.bndes.gov.br/SiteBNDES/bndes/bndes_en/

Synopsis of National Strategies on Bioeconomy around the World http://biooekonomierat.de/en/publications/?tx_rsmpublications_pi1%5Bpublication%5D=96&tx_rsmpublications_pi1%5Baction%5D=show&tx_rsmpublications_pi1%5Bcontroller%5D=Publication&cHash=07878beb63c751a3ae88953bb33e6d37

Biochemical enzymatic hydrolysis video https://www.youtube.com/watch?v=iljM5UP2gEQ