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Technological Catch-up and Indigenous Institutional Infrastructures in Latecomer Natural Resource-related Industries:

An Exploration of the Role of EMBRAPA in Brazil's Soybean and Forestry-based Pulp and Paper Industries

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Abstract

This article reports the results of an exploratory study of the role of indigenous institutional infrastructures in the accumulation of world-leading innovative capabilities (technological catch-up) in natural resource-related industries in the context of developing/emerging economies. These issues are examined from the perspective of the Brazilian Corporation for Agricultural Research (EMBRAPA) and Brazil's soybean and forestry-based pulp and paper industries. The article suggests that: (1) EMBRAPA has been providing, in different ways, an effective contribution to the technological catch-up and international competitiveness of these two industries over the past decades; (2) one important aspect of EMBRAPA's effectiveness has been the orientation of its research towards specific local needs and demands; (3) however, the innovative process led by EMBRAPA is far from linear, being instead based on *systemic* interactions with diverse components of the indigenous institutional infrastructure and industry partners; (4) in the case of the soybean industry, there is a growing need for EMBRAPA to work on the basis of networked partnerships, especially with subsidiaries of multinational enterprises (MNEs); (5) innovative activities that have had a significant impact on productivity growth do not necessarily reflect only research and development efforts, but also effective *creative imitation* efforts; (6) negative and pessimistic views of the contribution of natural resource-related industries to industrial development can be challenged by demonstrating the benefits that can be achieved through efforts towards consistent innovative activities in these industries. The possibility of African developing/emerging economies emulating Brazil's success with innovation and competitiveness in the soybean and forestry-based industries will depend on the manner in which industry-level technological capabilities are developed through systemic institutional infrastructures.

Keywords
Technological capability, institutions, natural and agricultural resources, agricultural industry, developing economies

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Contents

1. INTRODUCTION

In a world with a population of seven billion – up from six billion in 1999 and expected to rise to 8.5 billion by 2030 – there has been an unprecedented demand for increased productivity and generation of resources such as materials, food, renewable energy, water and industrial inputs. In keeping with this, there has been a rising demand for agricultural products and natural resources. However, worldwide agricultural productivity growth has been slowing down; it is expected to grow only 1% annually over the next two decades, much slower than historical trends. Consequently, to meet the likely food, feed and fuel demand levels of 2030 would require around 175-220 million hectares of cropland up to 2030 (IIASA; FAO; Heck and Rogers, 2014). It has been estimated that by 2050 there will have been a 35% increase in food demand, stemming largely from the developing economies, particularly China, India, other Asian countries, and African countries (Bruinsma, 2009).

These facts and prospects amount to a major challenge for governments and businesses in general. But instead of simply suggesting a coming crisis of resource scarcity, this situation represents an opportunity to revitalize the world economy while meeting these demands (Heck and Rogers, 2014). Technological innovation in agriculture has been playing a very important role in tackling major challenges in food supply. The Green Revolution of the 1960s stimulated several developing economies to structure their research activities towards tackling food scarcity. The development of new seeds attracted large firms and encouraged large-scale farming, the development of input suppliers, mechanisation and the emergence of new agricultural techniques and management practices (Beintema and Stads, 2011). For instance, policy and institutional reforms and effective research efforts raised agricultural productivity in Brazil and China above the rest of the world during the 1980s (Chen et al., 2012). By 2008, public agricultural research and development (R&D) spending in China, India and Brazil (the three top-ranked countries in terms of public R&D spending) accounted for 25% of global public agricultural R&D spending and 50% of combined spending in the developing world (ASTI, 2012).

Therefore, to meet the challenge of growing demand for resources over the coming decades, it will be important, on the one hand, to expand and deepen innovation capabilities (or even create new ones) and institutional infrastructures built over the past decades, especially in developing economies, in order to deliver large scale and high productivity crops. On the other hand, the so-called next green revolution should move a step forward by bringing the benefits of agricultural innovation and, especially, research to the smallest and poorest farmers across the developing world (The Economist, 2014).

In a similar vein, planted forests are renewable resources. They are a source for important industrial inputs and products such as pulp and paper, and for industrialisation. Since the 1990s it has been recognized that trees that yield more cellulose generate gains across the entire production chain in the form of savings from tree harvesting and transportation, which minimizes the expansion of forests and reduces effluent waste (Grattapaglia, 2004). Having realized that the 'pulp factory' is actually the tree, pulp and paper firms have shifted their efforts from wood quantity to wood quality (Grattapaglia and Kirst, 2008). The objective is to reduce the cubic metres of wood necessary for the production of one ton of pulp. Through different types of biotechnological process, these forests have become an important source of biomass and function as a platform for new products such as fibre cement, biofuels, biochemicals, bio-plastic, bio-materials, and carbon fibres, in addition to services such as CO_2 sequestration (Bracelpa, 2012; www.wbcsd.com).

As such, natural resource-related industries in natural resource-endowed countries deserve the attention of researchers, investors and policymakers. However, despite their relevance for growth and despite the great opportunities they offer for countries, the importance of these industries tends to be downplayed by researchers and policymakers, especially in developing countries. Most policymakers conceive of them as mere 'commodities', in contrast to the so-called 'higher value' manufactured goods. In addition to existing debates relating to natural resources and industrialisation – e.g., over the 'resource curse' (Sachs and Warner, 2001; Auty, 2001), and the 'enclaved' nature of natural resource wealth (Humphreys et al., 2007) – in Latin American over the past several years there has been a predominantly negative view of natural resource-related industries. Such industries have been deemed a 'negative' consequence of the macro-level discontinuity of the 1990s and an obstacle to deepening innovative capabilities (e.g., Reinhardt & Peres, 2000; Cimoli and Katz, 2003).

Similarly, since the early 2000s the argument that natural resource-related industries are characterised by low knowledge content and low opportunity for innovation and learning has gained prominence (e.g. Cimoli and Correa, 2005; Castaldi et al, 2009). These industries are thereby reduced to the status of 'low-tech' sectors with low knowledge intensity. However, hidden behind their average 'low-medium tech' characteristics, such sectors include firms with considerable innovation capabilities undertaking new-to-market and new-to-world types of innovation (von Tunzelmann and Acha, 2005; Smith, 2005).

Indeed, there is considerable potential for accelerating technological dynamism in these sectors due to new technological opportunities associated with pervasive technologies and growing demand for diversified products (Perez, 2008; ECLAC, 2008). Consequently, a new 'window of opportunity' opens for developing economies to explore the technological and commercial opportunities opened up by *natural resource-related industries*. This would involve an intelligent combination between rich natural resource endowments and sophisticated innovation capability building. Additionally, natural resource-rich countries that underwent relevant industrial, economic and social development have built proper institutional infrastructures to support innovative activities in their natural resource-related industries (Mazzoleni and Nelson, 2007; Fagerberg et al, 2009; Arnold and Bell, 2007).

Therefore, natural resource-rich countries have the potential to address the aforementioned challenge of increased demand for resources. These countries may also take advantage of their natural resource endowments to achieve industrial progress and competitiveness and, consequently, to generate benefits for their own economies. This will depend on the way in which they develop their technological capabilities to implement innovative activities, and how they design institutional infrastructures to support, fund and stimulate these innovative activities. However, there is a scarcity of industry-level studies addressing this issue.

As such, the objective of this article is to explore the interaction between innovative activities, competitiveness and institutional infrastructures in the form of knowledge-related institutions and government policies in the context of a natural resource-rich country. The paper is organised around the following central question: What has been the role of the Brazilian Corporation for Agricultural Research (EMBRAPA), an important component of Brazil's agricultural system, and corresponding government policies in achieving innovative activity and competitiveness in the soybean and forestry-based pulp and paper industries in Brazil?

To address this research question, the argument is substantiated by long-term and qualitative evidence from industry- and organizational-level standpoints. The article is based on an exploratory empirical study focused on the experience of EMBRAPA and its implications for innovative activities in these two industries. The study is based on a qualitative design substantiated by industry-level primary and secondary empirical evidence. This evidence has been gathered through different sources and techniques (e.g. interviews, consultation of archival records, and published material from EMBRAPA and related organizations, the Brazilian government and other sources.

The article aims to shed new empirical light onto the academic and policy debates on how natural resource-rich countries may take advantage of their resource endowments to accumulate technological capabilities and achieve industrial development. It also offers some insights about the extent to which EMBRAPA's experience may be emulated by other natural resource-rich developing economies, such as certain developing and emerging economies in Africa. The remainder of the article is organised as follows. Section 2 provides theoretical background to the examination of latecomer firms' innovation capability accumulation and the role of institutional infrastructures. Section 3 outlines some aspects of Brazil's agricultural innovation system from the standpoint of EMBRAPA. Sections 4 and 5 explore the contribution of EMBRAPA to innovative activities in the soybean and forestry-based pulp and paper industries in Brazil. Section 6 contains the article's discussions and conclusions.

2. INNOVATIVE TECHNOLOGICAL ACTIVITIES AND INSTITUTIONAL INFRASTRUCTURES: THEORETICAL AND EMPIRICAL BACKGROUND

2.1 Latecomer organizations and technological catch-up

This section begins by clarifying some basic ideas that constitute the key components of the conceptual basis of this article and frame the argument adopted herein. These are the notions of 'latecomer firm', 'catch-up' and 'technological frontier'. Latecomer firms, unlike typical late entrants, are at a historically determined, rather than strategically chosen, position of late entrance (Mathews, 2002); they are typically characterized by a low level (or even an absence) of innovative capabilities and by being 'initially imitative', regardless of how ill-positioned they may be with respect to markets and technology sources and regardless of the speed at which they move towards more innovative patterns of behaviour (Bell and Figueiredo, 2012). Indeed, latecomer firms that aim at achieving a competitive position in global markets seek to achieve catch-up technologically with global leaders in advanced economies and to attain a position in the international innovation frontier.

However, the term 'catch-up' suggests a single pathway, with different firms distributed along it, towards a given and clearly defined 'innovation frontier'. Specifically, the notion of a frontier tends to be associated with that of all firms following the same specific technological path (towards the same end-point) as that previously followed by global technological leaders. In reality, however, the process of the technological development of latecomers cannot be represented using the analogy of a race along a fixed track (Perez and Soete, 1988), because of the possibility of successful overtaking by latecomers moving in new directions, and of the emergence of radical discontinuities that open up opportunities for them (Lim and Lee, 2001). Therefore, rather than conceiving the technological frontier as an end-point or even a moving target, it is taken here to be a fluid area or horizon to be explored.

Latecomers may undertake such exploration by accumulating innovative capabilities and pursuing significantly new innovation *directions* that depart from trajectories previously mapped by earlier innovators, thus opening up *qualitatively novel technological segments* in the international innovation frontier (Bell and Figueiredo, 2012) or initiating *path creation* (Lim and Lee, 2001). As suggested by Mazzoleni and Nelson (2007), there are fields in which latecomers necessarily have to engage in *path creating* catch-up. The reason for this, according to these authors, is because in certain fields, such as agriculture and medicine, developing countries cannot simply copy the technology from advanced economies at the international innovation frontier. In such cases, developing countries have to develop their own technology suitable to their own conditions – soil, climate, diseases, etc. – which tend to be different. In so doing, developing countries may end up creating new technological segments within the international technological frontier.

The achievement of this technological catch-up depends on the manner in which latecomer firms create and accumulate their innovative technological capabilities. These capabilities include a stock of resources that permit them to undertake *production* and *differing degrees* of innovation activities. Such capabilities involve both the nature of human capital (e.g., specialist professionals, knowledge bases and skills/talents that are formally and informally allocated within specific organisational units, projects and teams) and organisational aspects (firms' internal and external organisational arrangements, such as routines and procedures, and managerial systems (e.g., Bell and Pavitt, 1993; Leonard-Barton, 1995; Kim, 1997; Dutrénit, 2000; Teece, 2007).

In line with previous relevant studies (e.g., Bell and Pavitt, 1993, 1995; Choung et al., 2006), this paper distinguishes between *production-based* and *innovation* capabilities and focuses on the development of the latter kind of capability. The former refers to capabilities to *use* or *operate* current technologies and production systems with given levels of efficiency, while the latter refers to a firm's ability to assimilate, adapt and change current technologies, enabling the creation of new technologies and development of new products and processes (Kim, 1997; Choung et al., 2000; Dutrénit, 2000). This analytical distinction is important because latecomer firms generally begin as technology users and/or imitators, and the distinction helps determine whether their capabilities develop over time into more innovative aspects. Although this paper is concerned with innovative capabilities, the distinction between the two types of capabilities may be blurred in practice, and production capabilities may even contribute to the accumulation of innovative capabilities (Figueiredo, 2002; Bell and Figueiredo, 2012).

The article adopts a comprehensive approach to innovation as a process (Pavitt, 2005) which involves a spectrum of activities (Dosi, 1988) with differing degrees of novelty. We focus on distinctions in terms of the technological/market 'novelty' of an innovation; the extent to which it differs from existing technologies. This ranges from innovations that are close to being pure imitations to those that are fundamentally different from anything currently existing (Bell and Figueiredo, 2012). Thus, the building of capabilities for undertaking 'new-to-the-firm', 'new-to-market/economy' and 'new-to-world' innovative activities are all within our purview here. As above, in contrast to common views, this paper considers a technological frontier to be a fluid area or horizon to be explored, and the notion of catch-up to also encompass so-called 'overtaking' (Bell and Figueiredo, 2012). Innovation involves the recombination of existing knowledge (Kline and Rosenberg, 1994) and there is no distinction between innovation and diffusion and invention and imitation (Bell and Pavitt, 1993; Arnold and Bell, 2001).

Given the limitations of assessing innovation capabilities based mainly on quantitative measures such as R&D expenditures and/or patent grants (see Bell and Pavitt, 1993; Bell and Figueiredo, 2012), this article makes use of a comprehensive approach that has been the primary basis of research in this area since the earliest studies of the innovation capabilities of latecomer firms, i.e., using qualitative assessments at the scale of technological capability levels (Katz, 1987; Bell et al, 1982; Lall, 1992; Bell and Pavitt, 1993, 1995; Bell and Figueiredo, 2012). Such an approach has been operationalized through a typology of approaches based on 'revealed capability'. Rather than specifically identifying capability levels in terms of particular quantities and qualities of human resources, skills, knowledge bases, etc., such approaches have identified levels of increasing novelty and significance of innovative *activity* and then inferred that different capability levels underlie different types of innovative activities (Bell and Figueiredo, 2012).

2.2 Institutional infrastructures and latecomer firms' innovative capability accumulation

2.2.1 Defining institutional infrastructures

As noted by Nelson and Sampat (2001), the term 'institutions' means different things for different authors. By building on existing approaches, this section seeks to operationalise a definition consistent with the evidence examined in this study. Instead of taking the firm's institutional environment as 'given' – as 'background conditions' – the paper considers the manner in which certain components of the institutional environment interact with the firm's innovation efforts (Murmann, 2003).

According to North (1990), institutions 'consist of both informal constraints and formal rules'. Nelson and Sampat's (2001) notion of 'social technology' is in line with North's (1990) 'rules of the game' or 'institutional arrangements'. Although by definition 'institutions' denote stability, they are subject to change processes, both incremental and discontinuous (Scott, 2001). Institutional frameworks can be addressed from different perspectives such as broad policy regimes (e.g., North, 1990; Lall, 1992; Rodrik, 2004, 2006; Cimoli et al., 2009), industry-level frameworks (Murmann, 2003), networked policymaking (Evans, 2008; Hwang and Choung, 2013) and knowledge-related institutes and organisations (e.g., Malerba and Mani, 2009; Lundvall et al., 2009).

Building on these concepts and on insights from previous empirical research (e.g., Murmann, 2003; Evans, 1995) this paper defines an 'institutional framework' as a set of norms in the form of laws, policies, regulations, and incentive systems and knowledge-related bodies that shape and are shaped by firms' innovation-related strategic choices. By drawing on the above approaches, following Mazzeloni and Nelson (2007), Malerba and Mani (2009), Choung et al. (2014), and in line with Bell and Figueiredo (2012), this article operationalises the concept of institutional infrastructure on the basis of two dimensions.

The first involves institutions in the sense of Malerba and Mani (2009), and refers to knowledge-related institutes and organisations surrounding latecomer firms, such as those concerned with education, training, standards, research, and so forth. This dimension can be defined as *public and private training and research institutions*, and is referred to hereafter as '*knowledge-related institutions*'.

The second dimension refers to institutions in the sense explored by Nelson and Sampat (2001), and involves standardised patterns of interactions between social stakeholders including sets of laws, policies, incentives and industrial development policies, plans and programmes at the national level and also sector-level organisational structures and pressure groups (e.g. industry associations) acting to influence government policy. Aspects of political and bureaucratic public-private interactions related to specific industrial sectors underpinning particular kinds of policy regime. This dimension will be defined as '*government policy orientation'*.

2.2.2 Knowledge-related institutions and firms' capability building

Existing studies addressing this issue fall into at least three types. The first type draws on classical works on sectoral innovation systems, with their emphasis on the specific innovation patterns of industries (e.g., Malerba and Orsenigo, 1996; Malerba et al., 1997; Malerba, 2005) and focuses on sectoral innovation systems in developing and emerging economies (e.g. Malerba and Mani, 2009; Joseph, 2009; Perini, 2010). However, as pointed out by Bell and Figueiredo (2012), such work is still concerned with the basic task of seeking to understand the main characteristics of sectoral systems in these contexts and how they emerge and evolve over time. There is a scarcity of studies that explore how the nature of these innovation systems might affect the creation and accumulation of innovation capabilities by firms as the core actors in the systems.

The second type of study focuses on key features of technological regimes, such as technological opportunity, cumulativeness of innovation, appropriability and other features of the knowledge base (e.g., Lee and Lim, 2001; Kim and Lee, 2003; Park and Lee, 2006; Jung and Lee, 2010). By so doing, they seek to explain technological dimensions of catching up at the level of firms and industries in Korea and Taiwan between the 1980s and early 2000s. However, as again pointed out by Bell and Figueiredo (2012), this work tends to emphasise current levels of innovative capabilities while ignoring the previous processes of capabilities creation and accumulation found in those countries.

The third type of study is more concerned with the various kinds of interactions developed by firms of a particular sector with other organizations, such as public and private research institutes, to implement innovative activities. For instance, Brundenius et al. (2009) examine the growing importance of the varied roles of universities in contributing to the building of innovative capabilities in firms in developing economies. In a similar vein, Mazzoleni and Nelson (2007) emphasise that the role of indigenous universities and public research institutes in contributing to technological catch-up involves establishing and supporting research programmes to help solve problems and achieve technological advances oriented to a particular user-community of firms and industries. This third type of study is consistent with the approach adopted in this article.

2.2.3 Government policy and firms' innovative capability accumulation

During the 1990s, following the rise of East Asia, where the bulk of our recent understanding about technological catch-up has been generated, some studies sought to explore the important role played by macro-level institutions in the successful industrial innovation in that region (e.g., Amsden, 1989; Wade, 1990). For instance, Lall (1992) emphasises the role of the efforts undertaken by firms in investing in the development of technological capabilities. He argues that firm-level development of innovative capabilities for catching-up is influenced by external 'incentives' and 'institutions', while Lall and Teubal (1998) propose the concept of 'market-stimulating technology policies'. Evans (1995) extends this kind of approach, based on the 'public-private symbiosis', known as the 'embedded autonomy' approach. Although relevant, these approaches take the developmental state to be the main actor in the technological catch-up process and do not capture the wider array of stakeholders, beyond the state, that are involved. They are consequently somewhat narrow (Evans, 2008; Karo and Kattel, 2010).

More systemic approaches have emerged over the past several years. One of these has emphasised the role of national innovation systems in developing and emerging economies. Indeed, there has been a proliferation of studies of innovation systems as supportive of industrial technological development in developing economies (e.g. Intarakumnerd et al., 2002; Lundvall et al., 2006). However, these studies suffer from a lack of dynamism and tend to focus on the structure rather than the functioning of the systems they examine (Bell, 2006). There has also been a dissemination of networked innovation policy approaches to support the innovative activities of countries in a 'post-Washington consensus' stage (Radosevic, 2009) and whose industry is in large part operating around the international innovation frontier (Hwang and Choung, 2013). There also exist multi-level approaches to intra- and inter-policy coordination to support technological catch-up. However, these approaches lack an interaction with industry- and firm-level innovative activities. Other studies suggest a promising approach revolving around exploring the links of 'institutions' and 'innovation systems' with industry and organization-level innovative efforts (e.g. Murmann, 2003; Jiang and Murmann, 2011; Choung et al., 2014). This article draws on these approaches to examine empirically some of the implications of components of the indigenous institutional infrastructure – particularly EMBRAPA and the related policy framework – for the accumulation of innovative technological capabilities in the soybean and pulp and paper industries in Brazil.

2.2.4 Innovation and institutional infrastructures in agriculture

The Green Revolution of the 1960s emphasised the role of research institutions in providing knowledge to overcome problems in agriculture, particularly in developing countries. There was an emphasis on the role of scientific research in providing new technology to be transferred to society and agriculture. This reflects a perspective on based on a linear or transfer of technology model (World Bank, 2006). However, since the 1980s, as the perspectives on innovation have changed, so there have been new approaches to agricultural innovation. For instance, during the 1980s the *national agricultural research system* (NARS) initiative emphasised the importance of infrastructure, management and policy support at the national level for agricultural development (World Bank, 2006). In other words, there was an emphasis on the supply side of innovation to support agricultural development.

However, during the 1990s the agricultural knowledge and information system (AKIS) approach emphasised not only the supply of research infrastructures but also the interactions between research, education and extension to meet farmers' demands for new technological solutions. Since the early 2000s, probably also reflecting an intensification of the fragmentation of the innovation process, even greater emphasis has been given to the demand for research and technological solutions, and to innovation systems and the corresponding interactions of the innovation process (World Bank, 2006). Indeed, one of the notable features of the knowledge structure and technological development of the agricultural sector is its basis in the interaction between a large number of actors, including research institutes, farmers, non-governmental organizations, private sector (World Bank, 2006), and particularly multinational enterprises (MNEs) and their subsidiaries in developing economies (Arza and van Zwanenberg, 2013).

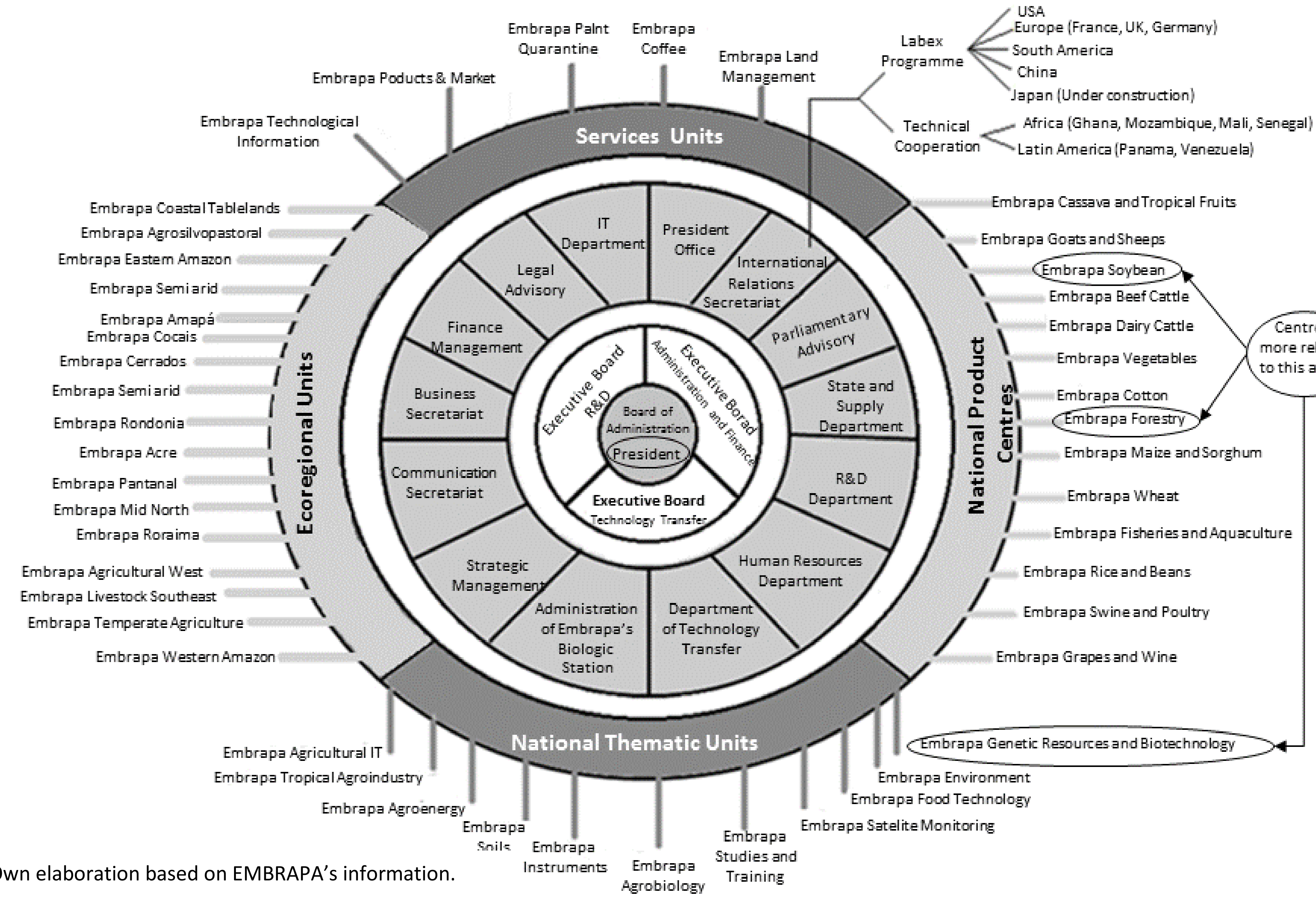
3. EVOLUTION OF BRAZIL'S INSTITUTIONAL INFRASTRUCUTURE FOR AGRICULTURAL INNOVATION: THE PLACE AND ROLE OF EMBRAPA

3.1 A brief overview of EMBRAPA

EMBRAPA was created in 1973, and since then has been under Brazil's Ministry of Agriculture, Livestock and Food Supply. EMBRAPA has a budget of approximately US$ 1 billion, most of which is provided by the federal government. Additional funding derives from the National Research Council for Scientific and Technological Development (CNPq), the Agency for Studies and Projects Funding (FINEP), and state-level research funding organizations. EMBRAPA has approximately 9,600 employees, of which around 25% (2,400) are researchers. More than 80% of EMBRAPA's researchers hold PhD degrees. EMBRAPA is headquartered in Brasília, and is organized on the basis of centralised units (e.g. finance management, IT), services units, national product centres, national thematic centres, and eco-regional units. Figure 1 illustrates EMBRAPA's current organizational structure. Figure 1 also points out the EMBRAPA centres that are most closely related to the focus of this paper.

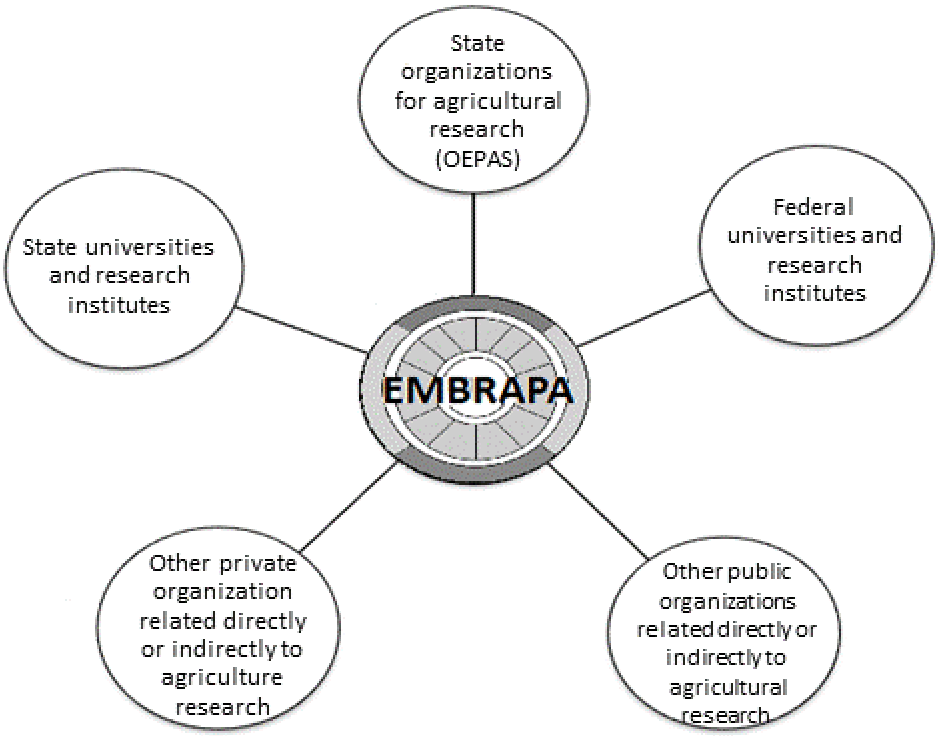
EMBRAPA also coordinates the National System of Agricultural Research (SNPA). The SNPA was created in 1991 (Law 8171, 17 Jan 1991). This system involves EMBRAPA and its units, nearly 20 state research organizations (OEPAs), state and federal universities and research institutes, as well as other public and private organizations related directly and indirectly to agricultural research. The idea was that, through the technical and financial support from EMBRAPA, these local institutions would work in closer contact with local needs (see illustration in Figure 2).

Figure 1. Current Organisational Structure of EMBRAPA



Source: Own elaboration based on EMBRAPA's information.

Figure 2. Brazil's National System of Agricultural Research



Source: Own elaboration based on EMBRAPA's information.

3.2 Some antecedents to the creation of EMBRAPA: 1960s

Systematic institutional research efforts on agriculture and natural resources in Brazil date back to the late 1890s and early 1900s when the foundations of today's important institutions were laid out, such as the Campinas Agronomic Institute (IAC) in 1891, and the Escola Superior de Agricultura Luiz Queiroz (ESALQ), in 1901. Also in the early 1900s came the creation of the Federal Universities of Vicoça (UFV), Lavras (UFLA), Paraná (UFPR) and Pelotas (UFPEL). The early 1930s saw the first attempt at coordinating agricultural research in Brazil through the creation of the General Directorate of Scientific Research at the Ministry of Agriculture, and the National Centre for Agricultural Education and Research (CNEP). During the 1940s the latter institution was re-organised to coordinate agricultural research across Brazil. Several other related institutions were created in Brazil such as the Institute for Forestry Research (IPEF), which proved essential to the early stages of technological capability development in the forestry-based pulp and paper industry in Brazil.

During the early 1960s the first national legislation for the seeds industry in Brazil was passed. This legislation set up rules exclusively related to the commercialization and organization of the production of seeds and seedlings. In 1967, the National Plan of Seeds (PLANASEM) laid out the main guiding principles of the governmental institutions' competencies for the productive sector. This was a preliminary milestone in the development of an organized system of seed production in Brazil. By the late 1960s, Brazil's seed industry underwent centralization of political decisions at the federal level as a result of the military regime (Wilkinson and Castelli, 2000). PLANASEM and the Governmental Support to the National Seed Plan (AGIPLAN), responsible for the development of research activities and the production of seeds, established cooperation with USAID and the Mississippi State University to train Brazilian seed specialists in American universities.

As a result, more than 50 Brazilians completed their MSc and Ph.D degrees in seed technology. In parallel, interactions between institutions such as ESALQ and UFPEL resulted in the training of 858 professionals involved in seed production, certification, research, and analysis (França-Neto and Oliveira, 1998). By the late 1960s, Brazil had accumulated an important research capability for agriculture in terms of human and organizational capital. However, despite its relative robustness, for a developing country, this institutional infrastructure did not meet Brazil's urgent need for increased production and productivity in agriculture.

3.3 The creation of EMBRAPA: 1970s

EMBRAPA was created in April 1973. Its creation was the consequence of internal needs in association with external institutional factors. During the early 1970s, the federal government commissioned a study to identify the causes of low agricultural productivity (low despite the existing government incentives). The study pointed to the following problems (Beaulieu, 2013): (i) a disconnection between the nature of research undertaken within public research institutes and universities and the real needs of producers; (ii) limited knowledge by public research institutes and universities about the technical and economic realities of land and farmers; (iii) scarce interaction between researchers and producers; (iv) organizational structures and decision making processes were extremely inadequate for rapid decision making and action related to agricultural productivity improvement; (v) acute scarcity of qualified human resources; (vi) absence of proper R&D management techniques; (vii) absence of proper mechanisms for financial resources management.

The need to address these problems spurred the creation of EMBRAPA. Its mission was to undertake research, development and innovation for the sustainability of agriculture and therefore the benefit of Brazilian society. However, its creation was not an isolated event. It can be considered both an evolution of previous indigenous institutional efforts, and also something motivated by external factors. In addition, there were pressures from the international institutional level, in the form of the 'Green Revolution' of the 1960s and 1970s. This movement involved a set of efforts and actions to increase food supply by enabling the increasing of agricultural productivity in developing countries (such as Brazil and India). This involved the intense use of advanced seeds (particularly hybrid seeds), use of agricultural inputs such as fertilizers and agro toxics, the mechanization of agricultural activities, and the reduction of management costs. The Green Revolution inaugurated important changes in agricultural technology such as the intensive use of herbicides, fertilizers, improved seeds, machinery, and irrigation equipment. At the institutional level, the challenge set by the Green Revolution was to create scientific and technological capabilities in order to produce technical changes in agriculture. As such, agricultural research had a key role to play (Fuck, 2009).

Following its creation, EMBRAPA began to take actions to form its organizational basis as well as gathering human capital. EMBRAPA secured funding from the Brazilian federal government, the World Bank and the Inter-American Development Bank (IDB). This funding allowed EMBRAPA to build research facilities and undertake extensive training programmes. By the mid-1970s, EMBRAPA had absorbed all technical and administrative personnel from AGIPLAN. EMBRAPA sought to differ from the existing agriculture research framework in Brazil by engendering an innovative application-oriented approach to agricultural research; one connected to locally-specific new problems and opportunities in the industry and economy.

EMBRAPA sought to impose a division of labour in Brazil's agricultural research system: the basic research would be undertaken by universities, while applied research would be conducted by EMBRAPA itself together with other indigenous institutions of the National Service of Agricultural Research (SNPA) (later renamed Cooperative System for Agricultural Research (SCPA)), which included the Cooperativa Central de Pesquisa Agropecuária (COODETEC), the Federation of Wheat and Soybean Cooperatives of Rio Grande do Sul (FECOTRIGO), and the Fundação Mato Grosso among others. This strategy resulted in a tense relationship with state level institutions and the weakening of their basic research capabilities. Additionally, due to the financial crisis generated by the tax concentration inflicted by the military government these state institutions started to be highly dependent on research funding and budgets that were centralized by EMBRAPA. On the other hand, EMBRAPA's focus on applied research enabled it to undertake extensive applied agricultural research for areas of national priority; this was achieved through the creation of EMBRAPA's own research centres and units and by the promotion of new state research agencies that were technically subordinated to EMBRAPA (EMBRAPA archival records).

3.4 Development of EMBRAPA: 1980s and 1990s

During the early 1980s, EMBRAPA introduced an organizational model based on research concentration. This model involved the creation of integrated centres of R&D with a focus on broad national issues, and marked a transition from supply-driven to demand-driven research. Agricultural technology was recognised as a means to reduce hunger and extreme poverty. From 1988 EMBRAPA adopted a strategic management approach which was materialised through EMBRAPA's Master Plans. The First Master Plan (1988-1992) sought to modernize EMBRAPA's management process, and led to the creation of EMBRAPA's Planning System. EMBRAPA's mission was conceived as generating and stimulating research to develop Brazil's agriculture, aiming social and economic well-being and a rational use of natural resources.

Through its planning system, EMBRAPA sought to include diverse areas in the definition of its research programmes. Priorities and the development of research were conducted by units that were decentralized, but which all adopted a National Research Plan, the aim of this being to replace the previous research model based on diffuse research. In addition to the implementation of research, in 1991 EMBRAPA became the coordinator of the National System of Agricultural Research, as mentioned earlier.

However, March 1990 marked the formal end of state-led industrialisation policy in Brazil. In line with measures adopted in other developing economies, the Collor administration implemented a substantial reduction of trade barriers, an abrupt opening-up of the economy to foreign competition with a greater attraction of FDI, de-regulation of the economy, and privatisation or shut-down of several state-owned companies. In the early 1990s the Brazilian Development Bank (BNDES) introduced the Industrial and Foreign Trade Policy (PICE), which sought to stimulate the development of industrial capabilities through the dissemination of new management and production organisation techniques and the creation and upgrading of organisations for manufacturing quality control. In parallel however, through the mid-1990s, reflecting the intensification of neoliberal policies, there was a severe financial and institutional weakening of public research institutes and universities. EMBRAPA and other agricultural research organisations suffered from a severe scarcity of funding and the discontinuation of some of their research programmes.

In the early 1990s, the Brazilian Corporation for Technical Assistance and Rural Extension (EMBRATER), responsible for the coordination of the Brazilian System of Technical Assistance and Rural Extension (SIBRATER), was shut down permanently. The activities of extension, technical assistance and technology transfer were intended to be taken over by the network of local organizations of the SNPA, and also by EMBRAPA's technology transfer unit. These changes created a void in EMBRAPA's extension programmes.

In the mid-1990s, EMBRAPA implemented its Second Master Plan (1994-1998). EMBRAPA's mission was reframed as being to generate, promote and transfer technology to develop the agricultural and forestry sectors to benefit Brazilian society. EMBRAPA now sought to balance demand-driven with supply-driven R&D. Also during this time, at the national level, Brazil took a great step forward in terms of intellectual property rights, with positive implications for Brazilian agriculture. In 1994 Brazil became subject to the Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement. This event was followed by the enactment of the Law of Patents (Law 9,279/1996) and the Law of Plant Cultivars Protection (LPC; Law 9,456/1997). In 1998, Brazil joined the International Union for the Protection of New Varieties of Plants (UPOV) of the World Intellectual Property Organization (WIPO).

The LPC established intellectual property rights for the varieties sector. The law is a protection mechanism that consists in the concession of a certificate that gives intellectual property rights to individuals or institutions which advance cultivars. The LPC guarantees to the certificate holder the right to commercialize in Brazilian territory, and prevents third parties from producing a cultivar for commercial objectives during the protection period (15 years), without the prior authorization of the cultivar owner. Under the LPC, small farmers may produce and commercialize seeds through donation or exchange with other small agriculturists. The LPC guarantees intellectual property of cultivars and obliges producers to pay royalties and taxes for using the technology.

Under the LPC the utilization of protected seeds requires the payment of royalties to their owners. Reflecting these changes, in 1998 EMBRAPA created the Intellectual Property Rights Unit (SPRI). The aim of this unit was to promote the transfer of technology and the value of the intellectual assets generated by EMBRAPA. A new model of cooperation was created between EMBRAPA and the foundations of seeds producers. This model differentiated between public and private partners and it established different rules. EMBRAPA required that partners involved in programs of genetic advance conducted by it cannot be involved in parallel research programs or work with organizations that have such programmes. The enactment of the LPC attracted various MNEs to the Brazilian seeds industry, including in the soy seeds market.

3.5 Development of EMBRAPA (2000-2007)

EMBRAPA's Third Master Plan (1999-2003) did not bring substantial change to its existing mission. However, this plan introduced a strategic management model based on the 'balanced score card' (BSC) in 2002. This new management approach replaced the former Planning System with EMBRAPA's Management System, based on performance indicators. This organisational model reflected a significant change in the scope and focus of the management and organization of research. The system encompasses the planning, execution, monitoring, assessment, feedback and time plan of funds releasing. The allocation of financial resources began to be made through Macro Programmes (MP), responsible for the management of a set of projects and processes in EMBRAPA to achieve institutional objectives and guarantee technical and scientific quality and the strategic value of the research programs.

During the early 2000s, EMBRAPA intensified its international scientific and technological cooperation. In 1998 EMBRAPA launched the Labex programme, which sought to set up virtual laboratories abroad. The idea was to share research facilities with partner institutions. The first virtual laboratory was set up in the US in 1998. In 2002, EMBRAPA created Labex Europe with Agropolis International in France. The first initiative in Asia began in 2009 in South Korea, in partnership with the Rural Development Administration (RDA). In 2012, Labex China was established in the Chinese Academy of Agricultural Sciences (CAAS). In the same year EMBRAPA signed an agreement with Japan's International Research Center for Agricultural Sciences (JIRCAS) for a Labex. There is also the 'inverted Labex' programme in which researchers from partner international institutions are set up at EMBRAPA's research centres to develop projects of mutual interest. Under this programme, EMBRAPA has received international researchers from, for instance, the Agricultural Research Service (ARS), linked to the United States Department of Agriculture (USDA), Rothamstead Research (UK), and from Rural Development Administration (RDA). This type of strategy has been used extensively by innovative organisations from other industries in developing/emerging economies. By setting up units or working groups near highly innovative counterpart organisations, the organisation may increase and improve the acquisition and assimilation of new codified and tacit knowledge to support innovative activities.

In relation to government policy changes, during the early 2000s there were further steps towards the liberalization of mechanisms of intellectual property protection. The Law of Seeds and Seedlings (Law 10,771), approved in 2001, led to the creation of the National System of Seeds and Seedlings (SNSM). Its purpose is to guarantee the quality and identity of the multiplication and reproduction material produced, commercialized and used in the entire country. In 2005, the Law of Bio Security (Law 11,105) regularized the research, production and commercialization of genetically modified (GM) products. This law allowed GM products to be introduced into the environment and human food without the necessary studies of the impact on the environment and on human health. This law also provided broad powers to the Bio Security Technical Committee (CTNBio) and the Bio Security Council for the commercial liberalization of GM products in Brazil. The official liberalization for planting GM soybeans in Brazil occurred in 2005 with the Law of Bio Security.

By the early 2000s, the Cardoso administration (1995-2002) had created 17 sector-level funds to complement the traditional financial resources to support industrial development (all managed by FINEP, except ICT). This set of innovation funds generated a new management model for innovation policies in Brazil emphasising the modernisation and expansion of the technological infrastructure, and the promotion of synergies between universities, research institutes and industry to strengthen competitiveness. A specific fund for agriculture (CT-Agro) was created, representing an additional source for research funding. The Lula administration strengthened the innovation funds created during the Cardoso government, and went further in implementing new policy instruments to promote innovation within firms and links with universities and research institutes based on funding and fiscal incentives (e.g., the Innovation Law (2004) and the Good Law (2005)).

EMBRAPA's Fourth Master Plan (2004-2007) sought to emphasise social inclusion, the reduction of inter-regional inequalities, and family agriculture. In parallel, greater emphasis was given to strengthening EMBRAPA's innovation capability. EMBRAPA also sought to build a more agile organizational model, with more autonomy for partner organizations, and to improve the functioning of its network to speed up innovation and the process of technology transfer. These changes reflected the federal government's move towrads South-South technical cooperation. In 2006 EMBRAPA started its first international office, EMBRAPA Africa.

According to EMBRAPA: '*the main purpose of EMBRAPA Africa is sharing of scientific and technological knowledge to contribute to social and economic development, to food security and to combat hunger across the region'* (EMBRAPA, 2012, p.2). In a recent talk with 30 African leaders in Johannesburg, EMBRAPA's president emphasised that EMBRAPA's relationship with African countries is not based on donation, but on partnership in relevant scientific and technological projects. EMBRAPA Africa's activities emphasise the specific demands of each partner country related to: (i) projects focused on agricultural development; (ii) technical assistance and training and development of human capital. These activities seek to cover areas such as agroenergy, tropical fruit production, cassava and vegetables, post-harvest technologies, animal beef/milk production, and forests.

In recent years, EMBRAPA has intensified the internationalization process, its operations in Africa perhaps being the most obvious aspect of this. There are four major programmes – in Senegal, Mozambique, Mali and Ghana – and research projects in other 18 countries. EMBRAPA also operates in other Latin American and Caribbean countries, and in East Timor. In Africa there are some promising results, such as with the cotton industry in the Cotton Four (Benin, Chad, Mali and Burkina Faso). Another initiative refers to the Nacala corridor project. It involves Mozambique and Japan in an area of 14 million hectares which are similar to Brazil's savannah (*cerrado*). However, recently EMBRAPA has decided to review and probably refocus its activities in Africa.

3.6 EMBRAPA and its 5th Master Plan (2008-2011-2023)

Since the mid-2000s there have been reports of tensions and bottlenecks in the functioning of SNPA (Figure 2). While some local research institutions for agricultural research are well equipped and receive strong support from local governments, other suffer from low support from their local governments and consequently scarce resources in terms of organization, physical systems, funding and human capital. Additional issues have been a lack of proper coordination between EMBRAPA and state-level organizations, and also complaints from local organizations that EMBRAPA has overrun and taken up tasks that should be implemented by local organizations, creating redundancies or disregarding the importance of such organisations (Mendes, 2006).

The structuring of the Department of Technology Transfer in 2010, resulting from the upgrading of the Executive Board of Technology Transfer (structured in 2003) has been one of the recent important organisational changes at EMBRAPA. This change sought to overcome some of the problems in the extension area (following the shut-down of EMBRATER) and the bottlenecks in the SNPA. The units of this department carry out strategies known as technology transfer, knowledge exchange and technical solutions. These strategies are implemented on the basis of 'strategic alliances' with several partners. Technology transfer is considered a component of EMBRAPA's innovation process. It involves the use of different communication and interactive strategies aimed at promoting production, market and institutional dynamism through the application of technical solutions in different contexts. Knowledge exchange involves an interactive process and dialogue that enables the adaptation of existing technical solutions to specific contexts, on the basis of the exchange of tacit knowledge

In this current organizational configuration, EMBRAPA emphasises its partnerships to undertake its innovative activities, with other research institutes, public and private, universities and firms, especially multinational enterprises (MNEs) and their subsidiaries. Such partnerships in the development of technologies have a significant role in the research activities of EMBRAPA. A worldwide network of partners develops technology together with EMBRAPA by bilateral cooperation agreements; this involves 55 countries, 555 research institutions and more than 250 R&D projects.

In its long-term master plan EMBRAPA seeks to (i) ensure the sustainability and competitiveness of Brazilian agriculture; (ii) achieve a new competitive and technological level in bioenergy biofuels; (iii) increase the development of technologies for sustainable use and productive integration of Brazil's regions; (iv) prospecting biodiversity to develop products differentiated and high value-added for any new market segments; (vi) contribute to the advancement of the knowledge frontier and incorporate emerging technologies.

However, EMBRAPA recognises its weaknesses and the challenges it will have to overcome to meet those goals: (i) embed a functioning institutional and organizational management model that is sufficiently flexible to allow autonomy for associations and partnerships; (ii) attract, develop and retain technical and managerial talent; (iii) expand operations in networks to increase synergy, capacity, and the speed of innovation and technology transfer; (iv) promote the management and protection of knowledge; (v) expand international action in support of the development of Brazilian agriculture and technology transfer; (vi) expand and diversify the sources of funding for PD & I; (vii) ensure the continuous updating of processes and infrastructure for PD &I; (vii) strengthen institutional and market communication to act strategically in the face of the challenges of the information society.

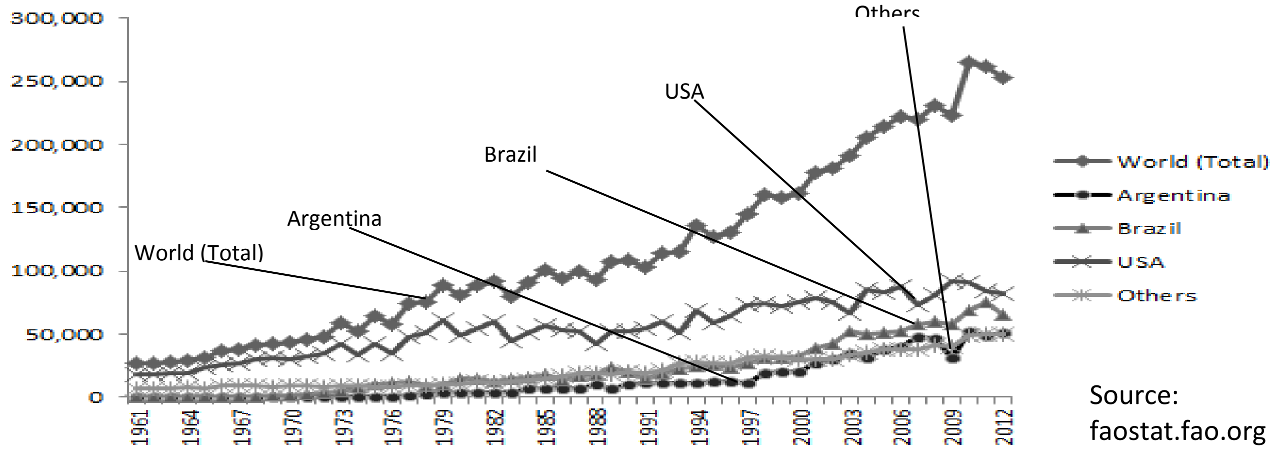
4. TECHNOLOGICAL CATCH-UP IN BRAZIL'S SOYBEAN INDUSTRY: THE ROLE OF EMBRAPA AND RELATED INSTITUTIONAL INFRASTRUCTURES

4.1 Brazil's soybean industry: a brief overview

Brazil produces a quarter of the world's soybean exports on just 6% of the country's arable land. Brazil is narrowly the world's second largest soybean producer, with gross production of 81.5 million tonnes in 2012/13; the US produced 82.1 million tonnes. Argentina, the world's third largest producer, harvested 53 million tonnes in the 2012/13 crop. Brazil's soybean production grew by 9.3% from the 2008/09 crop to the 2012/13 crop, while in the US production grew by 0.43% over the same period. By 2002, the overall average yield for soybean in Brazil (2.6 metric tons/hectare) surpassed the average yield in the United States (2.4 tons/hectare or about 36 bushels per acre). More significantly, the cost of producing soybean in Brazil fell to about $6.23 per 60 kilogram bag, just 50% of the US level of $11.72. Figures 3 to 5 show the evolution of soybean production, harvested area and yield for Brazil in comparison to other countries. According to the United States Department of Agriculture (USDA) and Brazil's Companhia Nacional de Abastecimento (CONAB), Brazil appears set to become the world's top producer.

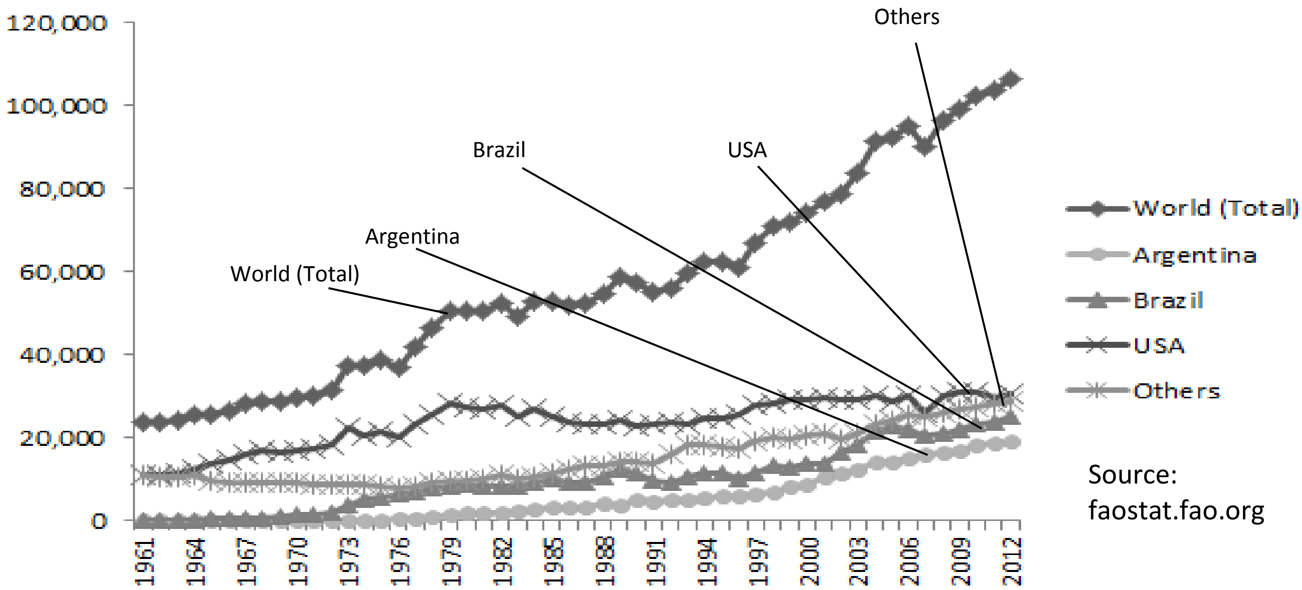
According to the USDA, Brazil's rapid export growth has been accompanied by changes in the composition of agricultural exports away from tropical products and towards processed products. Processed products now account for about three-fifths of agricultural exports, while primary bulk commodities account for about two-fifths. Brazil is now the second-largest exporter of soybeans, and of soybean meal. Over 90% of the increase in Brazilian agricultural output over the past three decades has been due to improvements in total factor productivity, with less than 10% attributable to increased use of land, labour, and capital. In other words, while farming just about everywhere else is experiencing falling returns, the returns to agriculture are rising in Brazil. That means that much of the achievements shown in Figures 3 to 5 derived from technological innovations.

Figure 3: Evolution of soybean production (millions of tonnes) across countries



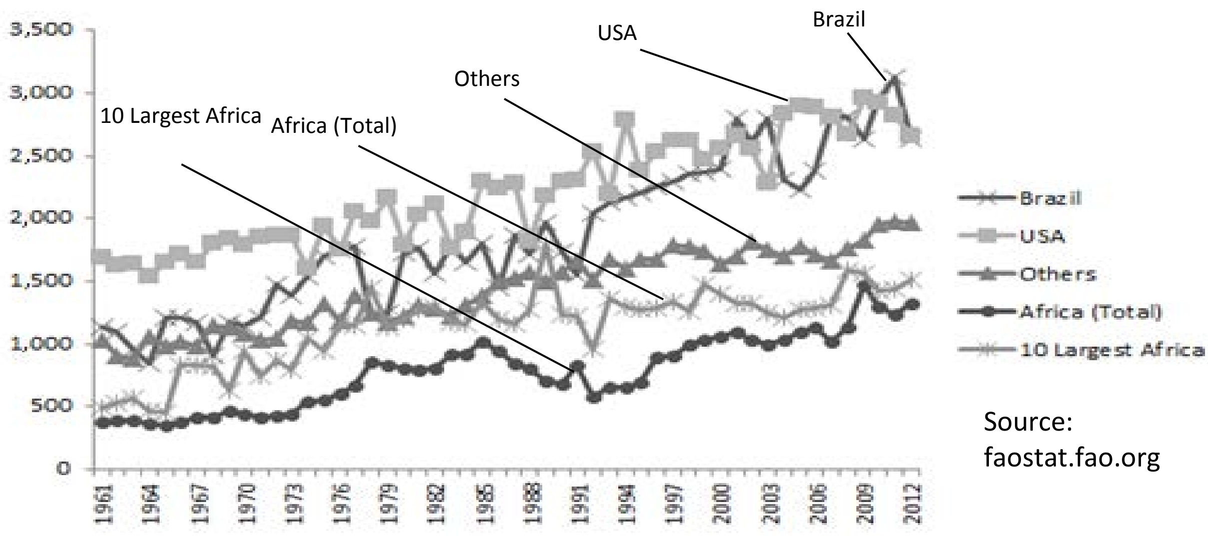
Source: faostat.fao.org

Figure 4: Evolution of soybean area harvested (Ha) across countries



Source: faostat.fao.org

Figure 5: Evolution of soybean yield (Kg/ha) across countries



Source: faostat.fao.org

4.2 Innovative activities in Brazil's soybean industry and the role of EMBRAPA and related institutional infrastructures

The high productivity and international competitiveness of Brazil's soybean industry is associated with technological innovation. A large part of this activity has been implemented by EMBRAPA and its network of partners. This section begins by outlining the relevance of the National Centre of Soybean Research (CNPSo), known as EMBRAPA Soybean.

4.2.1 The National Centre of Soybean Research (CNPSo) – EMBRAPA Soybean

EMBRAPA Soja was created in the early 1970s. The organization evolved from the Empresa Paranaense de Classificação de Produtos (Claspar) and especially the Instituto Agronômico do Paraná (IAPAR), both in the Paraná state in Southern Brazil, and by the late 1980s had built its own headquarters in Londrina (Paraná). By 2012, as a result of the federal government Programme for Acceleration and Strengthening of Growth – known as PAC EMBRAPA – the unit of EMBRAPA Soja had its Technological Nuclei of Seeds and Grains upgraded. It involves five laboratories (chemistry, molecular biology, after-harvesting of seeds of grains, seeds pathologies, and physiology and technology of seeds), acclimatised chambers, and training facilities. Since 2008 Embrapa Soja has involved around 300 employees, of whom 55 are researchers and 245 are technicians and support staff. During 2008-2013, EMBRAPA Soja developed technologies, products and processes, reflecting its innovative capabilities (Table 1).

Table 1: Development of technologies, products and processes at EMBRAPA Soja

	2008	2009	2010	2011	2012	2013	**Total**
Database	0	0	0	1	4		**6**
Biologic collection	1						**1**
Cultivar generated/launched	5	20	15	10	15	13	**78**
Cultivar tested/recommended	7	11	16	11	9	2	**56**
Agricultural feedstock	1	0	0	0	0	1	**2**
Scientific methodology	9	3	4	7	5	0	**28**
Monitoring		2	0	0	0	0	
Agricultural practice/process	5	1	9	4	2	0	**21**
Software	0	2	0	0	0	0	**2**
Total	**28**	**40**	**44**	**33**	**36**	**15**	**196**

Source: EMBRAPA Soja (2013)

Given its particular climate and land conditions, Brazil could not simply imitate global leaders such as the US, but rather had to develop its own technology, largely through EMBRAPA. During the late 1960s, Brazil experienced very low agricultural productivity and declining crops. These facts were worsened by the energy crisis of the 1970s. Being a largely closed economy, Brazil suffered a scarcity of foreign exchange and was an importer of food. Indeed, the process of innovative technological capability accumulation in the soybean industry in Brazil was largely led by EMBRAPA. Below are outlined two important innovative activities that have been fundamental to the productivity increase in Brazil's soybean industry: the adoption of the zero-tillage (ZT) technology for agricultural process, and the development of new soybean cultivars.

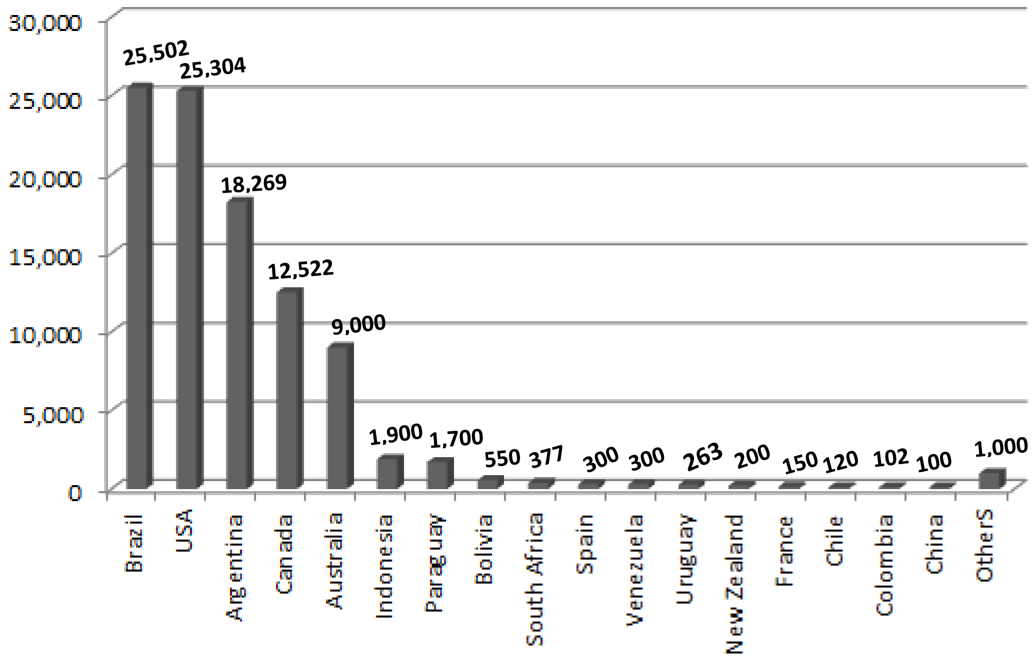
4.2.2 The adoption of ZT in Brazil's Cerrados

ZT means planting with minimum soil disturbance, coverage of soil with plants and plant residues, and rotation of crops. Through ZT, farmers can grow crops or pastures from year to year without ploughing or disturbing the soil at ground level through tillage. The no-till technique increases the amount of water that infiltrates into the soil and increases organic matter retention and cycling of nutrients in the soil. In many agricultural regions it can eliminate soil erosion. It increases the amount and variety of life in and on the soil, including disease-causing organisms and disease suppression organisms. The most powerful benefit of no-tillage is improvement in soil biological fertility, making soils more resilient. Farm operations are made much more efficient, particularly regarding improved sowing time and flexible farm operations.

ZT permits improved erosion control, improved soils, reduced turnaround times between crops, increased flexibility in operation times, and improved nutrient mobilization. ZT technology has been used since ancient times, but modern no-tillage technology emerged during the mid-1950s in the UK, and later spread across Europe and worldwide following the research of the British chemical firm ICI (Derpsch, 1998). Today's ZT is a sophisticated technology that involves the integration of different components such as seeds, agrochemicals, machinery, agricultural practices and different knowledge specialisations.

ZT is sensitive to ecological factors, and requires substantial adaptations to local conditions (Ekboir, 2003). As pointed out by Ekboir (2003), ZT is one of the most important agricultural technologies adopted in Brazil during the past 50 years; it reversed soil degradation, enabled the expansion of agriculture into marginal areas (especially the Cerrados), and boosted farmers' profitability and the competitiveness of Brazilian agriculture. During the early 1970s, the area based on ZT was negligible in Brazil (Ekboir, 2003); by 2008 Brazil was using a world record of more than 25 million ha (see Figures 6 and 7). As of 2010, Brazilian farmers were using no-till techniques for over 50 percent of their grain crops.

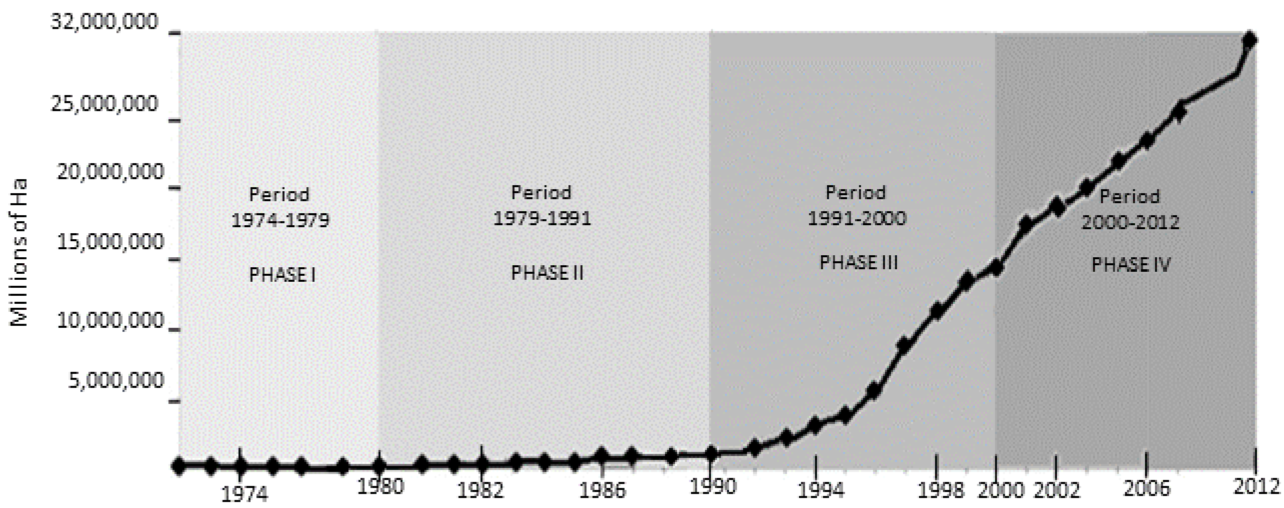
Figure 6: Zero Tillage Cultivated Area in Brazil Relative to Other Countries – 2008/2009



Source: EMBRAPA Soja (2013)

The adoption of ZT in Brazil's soybean industry can be divided into four phases (Ekboir, 2003; Mantovani et al, 2008; EMBRAPA, 2012), as illustrated in Figure 7. The first phase refers to the 1970s. During this period, government policy sought to reduce Brazil's dependence on food imports and its low agriculture productivity, and thereby to achieve food security for the country. Federal government sought to expand current agricultural production systems as a way of solving these problems. At the same time, ICI transferred its ZT research team to Brazil, following its policy of rotating its ZT research team internationally every two years. ICI developed its initial partners with local researchers and farmers, the Paraná Agronomic Institute (IAPAR) and EMBRAPA. By the late 1970s EMBRAPA, together with partners, had developed a ZT package adapted to the region's conditions. There was further dissemination around Southern Brazilian states.

Figure 7: Evolution of Zero Tillage Development Phases in Brazil (1974-2012)



Source: Adapted from EMBRAPA (2011); EMBRAPA Soja (2013)

The second phase, during the 1980s, referred to the dissemination of ZT technology into the mid-west and the Cerrados. In parallel, there were massive government investments to send researchers from EMBRAPA and other institutions to undertake overseas training, especially in the US, in agricultural technologies. There were also intense extension efforts made by local institutions together with input providers and farmers. The third phase, during the 1990s, was marked by the expansion of ZT to large scale commercial farms. The fourth phase, since the 2000s, relates to the expansion of ZT to both small scale and large scale commercial farms across new Cerrado areas, including the states of Tocantins, Bahia, and Mato Grosso. Additionally, the biological nitrogen fixation developed by EMBRAPA during the period helped increase the productivity of the ZT plantations (Pereira et al., 2012). The development of techniques for the integrated management of weeds and pests enabled significant reductions in the amount of pesticides used in their control. Studies on the nutrition of soybeans allowed better management of fertilization and liming, and the selection of efficient strains of Bradyrhizobium spp, enriched inoculants, completely replacing nitrogen fertilization. Micronutrient research indicated the need for their use, particularly in the *Cerrado*, to obtain maximum yields, as well as work on soil management and crop rotation, resulting in the almost complete replacement of conventional direct seeding, with positive impacts on the sustainability of production systems.

The successful adoption of ZT in the soybean industry in Brazil reflects an innovative process based on creative imitation and recombination of existing knowledge. Indeed, IAPAR and later EMBRAPA have played important roles in this creative imitation. However, the innovation process is far from being based on a linear model in which knowledge trickles down from R&D laboratories. Instead, it has involved a combination of different types of knowledge coming from diverse sources such as input suppliers, subsidiaries of MNEs, farmers, and research institutes, in terms of research in itself but also extension programmes.

Within the context of ZT technology, but also related to the development of new seed varieties, it is important to mention a significant technology developed by EMBRAPA, namely the inoculation of biological nitrogen fixers for soybean seeds before planting. This technology reduces the need for nitrogen-based fertilizers in crops, trimming usage by 52 million tons and affording a saving of US$ 1.5 billion annually. The inoculated seeds are resistant to multiple diseases and contribute to reducing the use of pesticides, generating gains of US$ 280 million to agricultural producers.

4.2.3 Development of new varieties of soybeans

Given that soya (*Glycine max L.*) is native to temperate climates of Asia (Japan and China), EMBRAPA could not simply replicate soya crops in Brazil. The first research program focussed on the soybean formed in the 1950s at the Agronomic Institute of Campinas (São Paulo). By the late 1960s, soybean research in Brazil was growing and focused in the southern region of the country. Research was based primarily on the adaptation of existing varieties from the US. Until the 1970s, the major concern of the Brazilian soybean research programs was productivity. There was some concern with adequate plant height for mechanical harvesting, lodging resistance and resistance to dehiscence of the pods.

During the 1980s, the issue of resistance to diseases such as Bacterial pustule, Wild Fire and stain-Eye Frog began to form in features necessary to recommend a new cultivar. Subsequently, major disease problems hd emerged, such as the Cancer Stem, the cyst nematode and powdery mildew, expanding the list of requirements for the recommendation of new cultivars. Until the 1970s, the commercial cultivation of soybeans was restricted globally to regions of temperate and subtropical climates, whose latitudes were near or above the 30 C. Brazilian researchers were able to break this barrier by developing germplasm adapted to tropical conditions. This achievement has enabled cultivation anywhere in the country. For example, in the *Cerrado* ecosystem, a potentially unproductive area, over 200 million hectares have become viable for the cultivation of soybean and other grains.

EMBRAPA Soja has played a decisive role in the advancement of soybean cultivars for the tropics. These advancements by EMBRAPA result from its partnership model, especially with seed growers associations, used in the breeding programmes. These partners have greatly increased EMBRAPA's ability to develop new cultivars, giving financial support and consequently speeding up the process. As a result of this model, EMBRAPA's cultivars account for over 50% of the national market of soybean seeds. The choice of cultivars was accompanied by incorporating both the 'old' as in new cultivars for resistance to major diseases attacking the crop in Brazil.

During the 1990s and 2000s, EMBRAPA engaged in capability development based on substantial R&D efforts at the frontier, supported by more advanced biotechnology techniques (genetic engineering, rDNA) and other advanced techniques (molecular biology and bioinformatics) to improve seeds. At the same time, EMBRAPA has managed to achieve concrete innovation outputs in association with these efforts, such as the patenting of soybean seeds resistant to imidazolinone herbicides. These innovations have enabled firms to gain the position of technology providers in the seed market. EMBRAPA has been actively involved in the development of tools and processes useful for conducting R&D and improving seeds, and in the opening up and supporting of different directions, besides transgenesis, for innovation in the seed sector. EMBRAPA has, among other things, engaged substantial resources to support research in non-GM soy bean seeds.

Most of these efforts were undertaken by EMBRAPA Soja together with other research institutions in Brazil engaged in researching new soybean cultivars (part of the OEPAs): Federal University of Viçosa (UFV), EPAMIG (Minas Gerais), EMGOPA (Goiás); EMBRAPA Cerrado (Brasília); Coodetec, Indusem and FT (Paraná); Fundacep, EMBRAPA Wheat and State Secretariat of Agriculture (Rio Grande do Sul), EMBRAPA Western Region Agriculture and EMPAER (Mato Grosso do Sul), and IAC (São Paulo). Additionally, and very importantly, following the Plant Variety Protection Law (1997), new private research programs were established in Brazil such as that of the Mato Grosso Foundation, and especially those undertaken by subsidiaries of MNEs such as Monsanto, Syngenta, Pioneer, Milenia and BASF. Table 2 shows some examples of soybean cultivars developed by EMBRAPA Soybean.

Table 2: Some examples of soybean cultivars developed by EMBRAPA Soybean

	1970s	1980s	1990s	2000s	2010s
Examples of cultivars	'Cristalina'	'Doko' and 'Cariru', 'Savana'	'Conquista'	BRS Nova Savana BRS Milena FT Abyara BR 83-147	BR/IAC-21 UFV-16 BR-9 Cultivance (with BASF)
Properties	(first variety suitable for Cerrados) Yield: 1,300Kg/ha	Yield: 2,000Kg/ha	Cycle: 110 days. Yield: 3,164Kg/ha	Cycle: 110- 115 days Yield: 3,300+Kg/ha	Cycle: 105-110 days Yield: 3,400+

Source: EMBRAPA Soja

In the context of EMBRAPA's partnerships it is important to highlight the technical and commercial cooperation it has with Monsanto for the development of 'Roundup Ready' (RR) soy seeds since the late 1990s, following the LPC. They have an agreement in which EMBRAPA has property of the cultivars that are produced and Monsanto have the rights over the gens incorporated in the seeds (the gens provide tolerance to glyphosate herbicide). Besides researching soy that is resistant to glyphosate, EMBRAPA has researched other varieties of transgenic soy. One of these varieties is researched through an agreement between EMBRAPA and BASF, a transnational German company, and such research is coordinated by EMBRAPA. The new soy seed is resistant to herbicides of the 'imidazolinonas' class (Cultivance, launched in 2010)

As can be seen, EMBRAPA's partnerships involve both public and private institutions. The partnerships with the private sector changed after the Plant Variety Protection Law. This law required EMBRAPA to change the partnerships rules, denying co-ownership of rights of materials in parallel advancement programs. The ownership of cultivars is solely EMBRAPA's, although partners can produce and commercialize cultivars with exclusivity during a certain period of time. The changes imposed by the LPC also affected the role of EMBRAPA in the seeds market: it started strategically considering its seeds portfolio as an asset, which is valued by charging royalties; at the same time, EMBRAPA established agreements and partnerships in order to preserve its public function and keep its assets (germplasm banks).

In relation to technology transfer, following the re-organisation of the Department of Technology Transfer in 2010 (previous subsection), the corresponding structure was implemented at EMBRAPA Soja in 2011. The new organisational unit involves the Technology Forecast and Evaluation Unit, the Technology Transfer Implementation Unit and the Local Committee of Intellectual Property. EMBRAPA Soja (and also other units) implements different types of mechanism to transfer technology and extension to farmers around Brazil. These mechanisms involve technical visits, training programmes, and different types of technical events. Among these mechanisms are the 'train and visit' (T&V) and the Field Days, which are well known. Table 3 below shows some evidence of Field Days, from 2008 to 2013, specific to soybean in Southern Brazil:

Table 3: Evolution of Field Days for Soybean in Southern Brazil

Crop	Field days	Total audience
2007/08	69	38,393
2008/09	65	30,774
2009/10	54	23,953
2010/11	53	21,018
2011/12	71	18,555
2012/13	74	18,935

Source: EMBRAPA Soja

The T&V mechanism reached its 50th edition in 2013. This mechanism reaches representatives of cooperatives, private firms of rural extension, professionals from local extension (part of SNPA). They share their problems during their soybean crop and receive training on specific technical themes. The participants then replicate this training within their original organizations, creating a cycle of knowledge dissemination.

5. TECHNOLOGICAL CATCH-UP IN BRAZIL'S EUCALYPTUS-BASED PULP AND PAPER INDUSTRY: THE ROLE OF EMBRAPA AND RELATED INSTITUTIONAL INFRASTRUCTURES

5.1 Brazil's forestry-based pulp and paper industry: a brief overview

Pulpmaking requires the separation of cellulose fibres from non-cellulose materials and impurities (e.g., lignin) to create woodpulp. Papermaking involves processes such as pulp refining and screening, the mixing of additives, sheet forming and drying. The pulp and paper industry is process-intensive and normally large-scale (Pavitt, 1984). Forestry is considered part of the pulp and paper industry because 90% of paper pulp is currently generated from wood, and pulp is increasingly manufactured in the same country in which the plantations are located; in addition, wood represents 55% of the average total cost of making pulp. To achieve and sustain a global competitive position in this industry—and to take advantage of these innovation opportunities—firms must master innovation capabilities at or near world-leading levels, particularly in planted forestry research that is focused on developing new genetic material.

In 2012, Brazil ranked as the world's fourth-largest pulp producer, the world's largest producer of hardwood pulp ('eucapulp'), and the ninth-largest paper producer. Of the pulp and paper produced in Brazil, 100% is derived from planted forests, which are renewable resources. Brazil has 2.2 million hectares of fully certified planted area for industrial use. In 2012, the revenue from Brazil's pulp and paper industry approached US$17 billion, yielding exports of US$ 7.2 billion and a trade balance of US$5.1 billion. In 2012, this industry generated 128,000 direct jobs, 575,000 indirect jobs in Brazil and US$1.75 billion in taxes. From 1970 to 2012, Brazil's output of pulp and paper grew by an average of 6.8% and 5.4% per year, respectively. During the same period, Brazil's pulp and paper exports increased annually by an average of 13.6% and 18.8% respectively. The value of such exports increased by an average of 17.3% (pulp) and 22.7% (paper). Although there are 220 firms engaged in this industry in Brazil, six large pulp makers were responsible for 85% of the pulp output in 2010; these firms have their own forests. The same six firms also represent 55% of the paper output. This high concentration of output from a small number of integrated firms is the result of the substantial investment involved in forestry and large-scale manufacturing activities (Bracelpa, 2012).

5.2 Technological catch-up and institutional infrastructures

Over the past 50 years, the forestry-based pulp and paper industry in Brazil has achieved a leading technological and commercial position in the global paper industry. In contrast to the soybean industry, most of its technological innovative activities have been undertaken by local large firms in association with local institutions such as IPEF, ESALQ, UFV, UFLA (especially 1970s to 1980s) and since the 1990s with international institutions. The involvement of EMBRAPA with the forestry-based pulp and paper industry in Brazil began as early as the late 1970s. EMBRAPA took up the responsibility for the National Programme of Forestry Research (PNPF), which led to the creation of the Centre for National Forestry Research or EMBRAPA Forestry. This unit resulted from an agreement signed with the Brazilian Institute for Forestry Development (IBDF), with the support from the Brazilian Society of Silviculture (SBS). In that agreement, IBDF delegated to EMBRAPA the coordination, implementation and support of the Brazilian forestry research, under the Ministry of Agriculture.

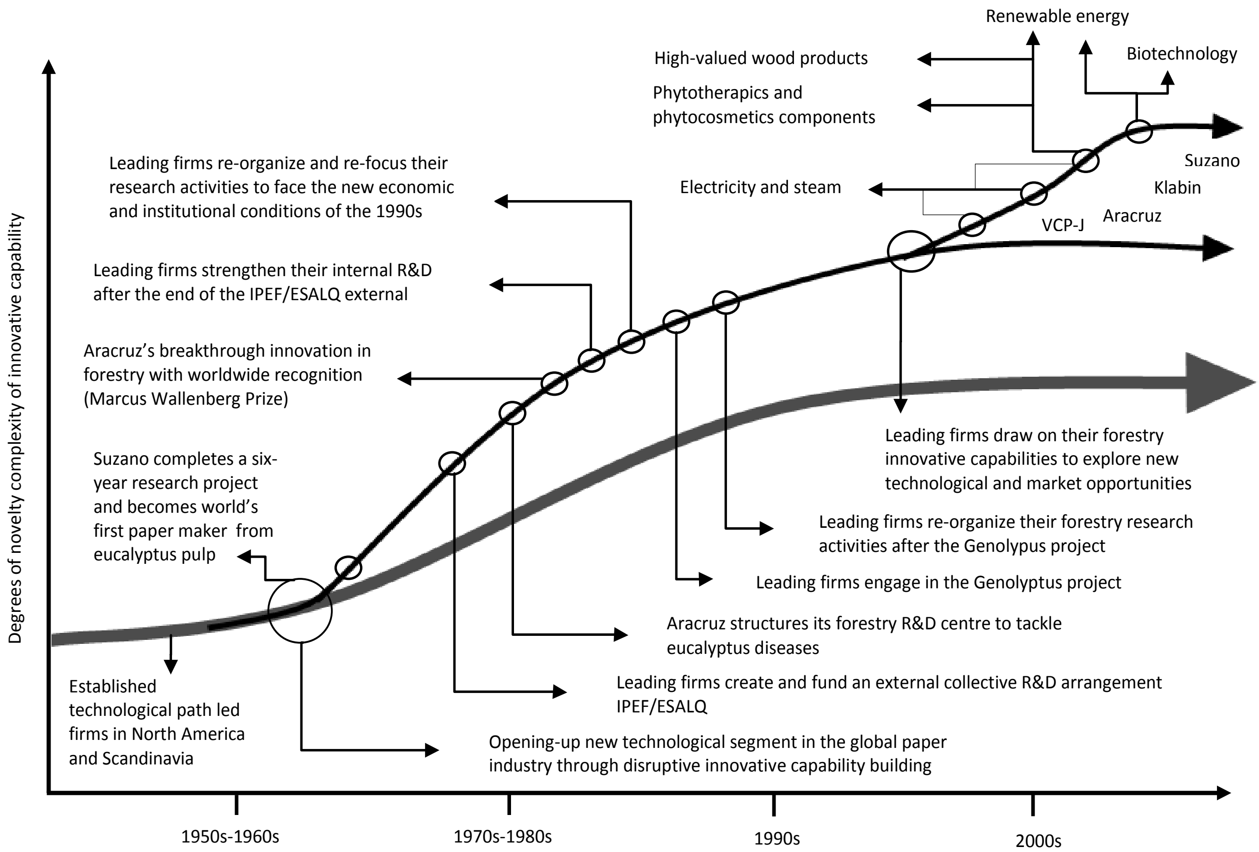
The creation of EMBRAPA Forestry also reflected a change in the division of labour related to the institutional framework for forestry research. While EMBRAPA took up the responsibility for the National Programme of Forestry Research, including genetic improvement, the Institute for Forestry Research (IPEF), which until then had been leading forestry research in Brazil together with the University of São Paulo's School of Agriculture (ESALQ), became dedicated to new research methods based on forestry handling and exploitation. IPEF/ESALQ and EMBRAPA set out the basis for research in molecular and genomic research. EMBRAPA Forestry represented approximately one third of the entire national effort, in terms of installed experimental network in the period 1977-1992. But it was during the 2000s, when leading firms of Brazil's forestry-based pulp and paper industry had already accumulated significant levels of innovative capabilities, that EMBRAPA, through EMBRAPA Forestry and EMBRAPA Genetic Resources and Biotechnology, played a very important role in contributing to deepening Brazil's capability in molecular research into eucalyptus for the pulp and paper industry.

As reported in Figueiredo (2010; 2014), since the 1950s leading firms from the forestry, pulp and paper industries in Brazil have engaged in a kind of 'path-creating' capability accumulation. By the late 1940s Brazil was a small producer of paper based on fully imported pine pulp from North America and Scandinavia (the so-called 'Norscan countries'). Pulp supply became even less stable by the late 1940s because of WW2 and the Korean War. At the same time, there was growing domestic demand for paper as Brazil began to industrialise; lack of pulp was a hurdle to industrialization and economic growth. In this context of necessity but also opportunity, Brazilian firms recognised that alternate raw material was a way of overcoming this hurdle. After several years of research and experimentation, eucalyptus proved a feasible new raw material for paper making.

Thus firms began to make pulp and paper from eucalyptus trees, and to engage in activities that firms in the Norscan countries were not engaged in. This meant that from a relatively early stage, firms could not simply copy the recognised global leaders but were instead forced to develop technologies more suited to their own somewhat different operations; they could not simply *imitate,* because they were developing along a different trajectory. This involved the use of different raw materials (eucapulp), and to develop an effective means to do this, firms had to innovate in their downstream pulp and papermaking processes because of innovations developed upstream in forestry. Specifically, firms began to diverge from the existing technological trajectory at an *early stage* of the development of their innovation capabilities. The firms took a *different direction* of technological development from those already pursued by the global industry leaders. By so doing, they opened up a qualitatively different segment at the international technological frontier: that of eucalyptus pulp (or 'eucapulp' technological segment, hereafter). This path and its main phases are represented in Figure 8.

Within that new industrial segment some firms achieved world-leading innovative capability levels: e.g., Suzano, Aracruz, Klabin and VCP, examined herein. From this technological position, these firms are able to expand the international innovation frontier by developing innovation capabilities at world-leading levels; they have been able to undertake innovative activities with a 'new-to-the-world' degree of novelty. The evidence indicates that firms that achieved world-leading levels also accumulated other types of capabilities which were important for undertaking a multiplicity of innovative activities (for details, see Figueiredo 2014).

Figure 8: Path of innovative capability development in Brazil's forestry-based pulp and paper industry

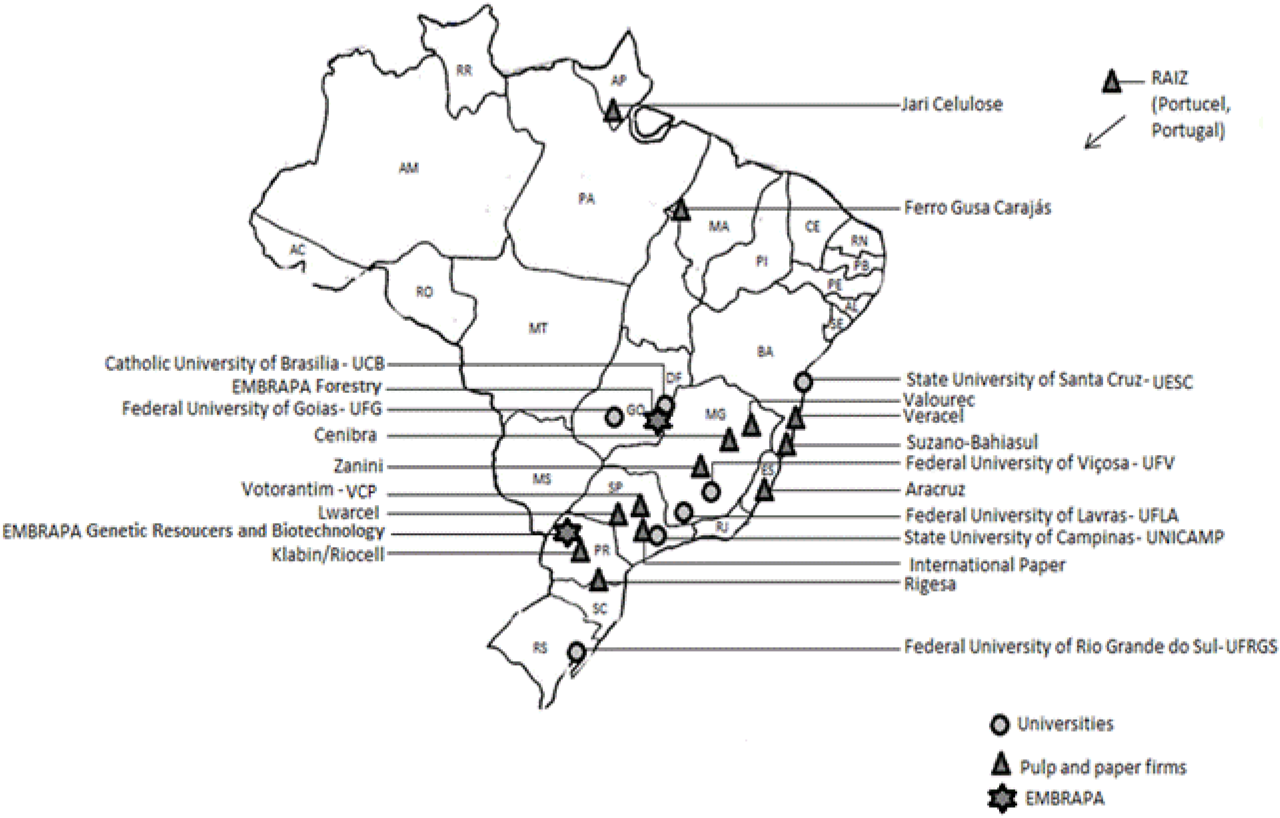


Source: own elaboration based on the empirical study.

During the early 2000s, EMBRAPA Forestry and EMBRAPA Genetic Resources and Biotechnology led a remarkable nationwide research project on the eucalyptus genome. Indeed, by the late 1990s, Brazil had consolidated its world-leading technological position in the eucalyptus-derived pulp and paper industry. During the early 2000s, Brazil engaged in innovative capabilities as leading firms also engaged in an embryonic diversification of their technological capabilities. Leading firms such as Aracruz, Suzano, VCP, and Klabin, among others, engaged in a network of research to deepen their capabilities in gene technology. From 2002 to 2008, along with other firms and universities under the coordination of EMBRAPA, these firms engaged in a nation-wide project called Genolyptus (the Brazilian Network of Eucalyptus Genomics Research). Funded by the Ministry of Science and

Technology through FINEP, this project involved 13 firms from the forestry, pulp and paper industries (among them Aracruz, Suzano, Klabin and VCP) and seven universities (among them UFV, UFLA, ESALQ, UFPR, IPEF, the Society for Forestry Investigation, and others) – see Figure 9. The project involved the creation of a specific organizational arrangement under which nine projects were implemented (Figure 10).

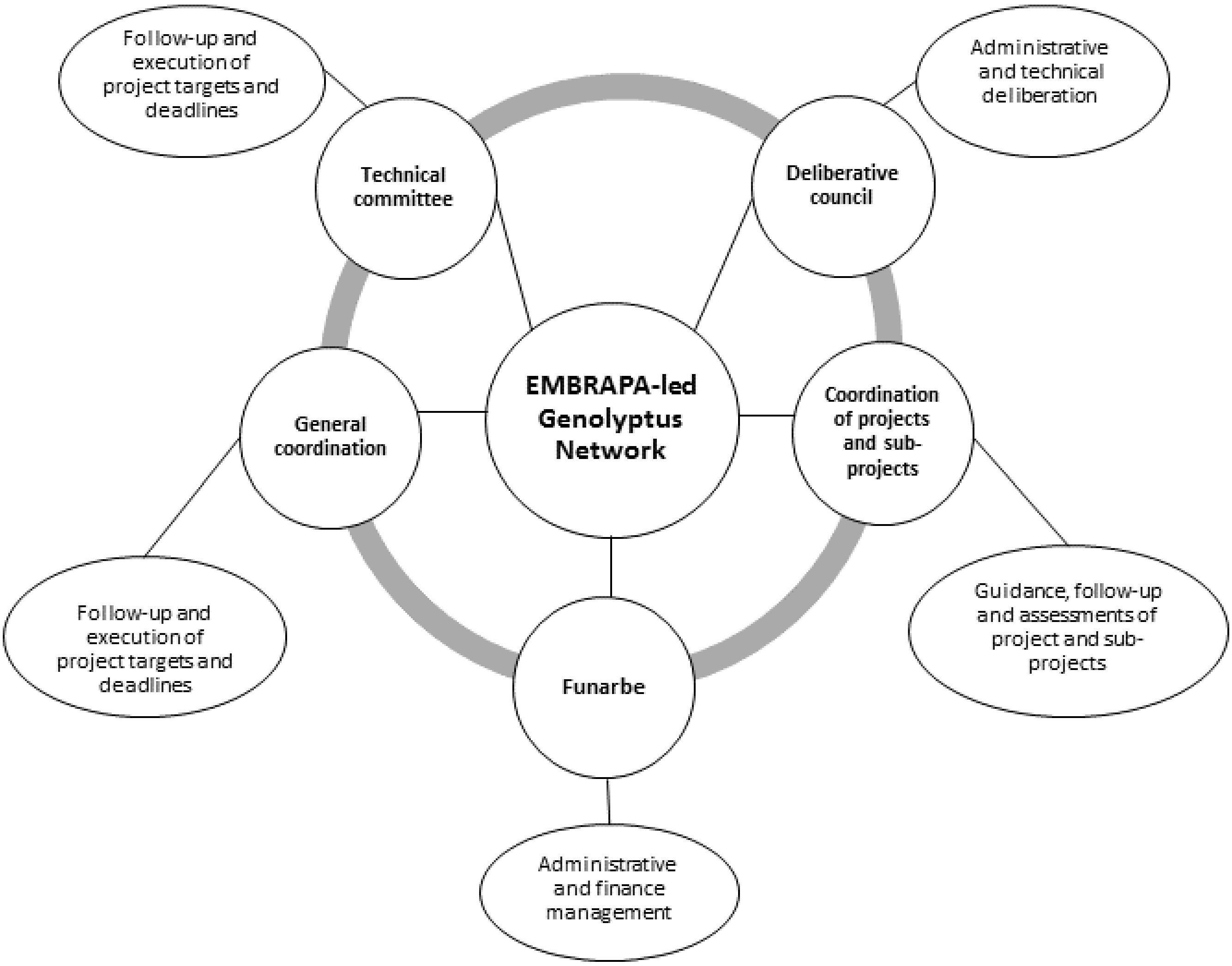
Figure 9: The Genolyptus' project network sources



Source: Adapted from Grattapaglia (2010).

This project characterized the complete phenotypes required to study the functions of the genes in question and employed a multidisciplinary approach involving researchers in genetics, biochemistry, molecular biology, breeding, phyto-pathology, wood technology and industrial process engineering. Specifically, the Genolyptus network was structured around nine subprojects. Each subproject corresponded to a specific theme: (i) installation and continued evaluation of a field experimental network; (ii) internalization of high performance technologies for assessing wood quality; (iii) genetic basis and identification of genes that confer resistance to Eucalyptus-affecting diseases; (iv) construction of genetic maps and mapping of QTLs (Quantitative Trait Loci); (v) Construction of physical maps located in the *Eucalyptus* genome; (vi) sequencing of the Eucalyptus transcriptome; (vii) analysis of gene expression (microarrays); (viii) bioinformatics for analysis, integration and availability of genomic data; (ix) statistical genetics and development of analytical tools.

Figure 10: Organizational arrangement of the EMBRAPA-led Genolyptus research network



Source: Own elaboration based on the study.

By 2004, the Genolyptus network had achieved a collection of over 150,000 DNA sequences generated from genes and genomes of four species of Eucalyptus (*E. grandis*, *E. globulus*, *E. pellita* and *E. urophylla*). In addition to these achieved and related scientific outputs, Genolyptus also generated: (i) important learning through experiments undertaken by firms and universities and research institutes, (ii) development of new human capital (e.g. MSc and PhD), development of new techniques for assisted molecular breeding, (iii) development of new techniques for wood quality improvement and (iv) new techniques for physical wood analysis. One concrete example of a learning outcome generated by this project for firms is the upgrade in Suzano's capability for genomic research. The deepening of this capability permitted Suzano to collaborate actively with partners in advanced economies. For example, Suzano collaborated with the genome project led by the Joint Genome Institute (JGI) in the US by donating a germplasm base (designated as BRASUZ1) for the complete genomic sequencing of eucalyptus (Grattapaglia, 2011). Another important output is the accumulated learning and experience in creating and running an organizational arrangement to implement a world-leading project of this type and scope.

During the 2000s, these firms began to draw on their world-leading innovative capability in forestry to diversify into new activities, which gave rise to *new business lines.* For example, by acquiring FuturaGene (with operations in the US, Israel, China and Southeast Asia), Suzano was able to engage firmly in the international commercialization of modified genes and develop trees that require less land, water consumption and fewer fertilizers, that produce less lignin (and fewer chemicals during the pulping processes) and generate higher carbon sequestration, thereby achieving stronger competitiveness in its forestry and pulp and paper businesses. The creation of Suzano Renewable Energy may allow Suzano to move into the new forestry segment of planted 'energy forests' by producing genetically modified trees with short cut-off times and calorific properties. By drawing on its world-leading innovative capabilities in forestry, Klabin intensified its business in medicinal plants, phytotherapy and phytocosmetics.

6. DISCUSSION AND IMPLICATIONS

6.1 Discussion of the evidence and some implications for EMBRAPA and policymaking

This article has sought to explore some aspects of the role of indigenous institutional infrastructures in the accumulation of innovative capabilities at world-leading levels or technological catch-up. Indigenous institutional infrastructures were examined on the basis of knowledge-related institutions and government policies. The article explored this issue through an examination of the contribution of EMBRAPA to the accumulation of innovative technological capabilities in the soybean and eucalyptus-based pulp and paper industries in Brazil. The article suggests that:

(i) In the soybean industry, EMBRAPA has been playing a significant role in the achievement of increasingly novel and sophisticated innovative activities since the early stages of the innovative capability building process or technological catch-up. In the case of the forestry-based pulp and paper industry, EMBRAPA's role became more significant when leading firms had already accumulated world-leading levels of innovative capability, especially in forestry. In this industry, EMBRAPA has played an important role in deepening firms' research capability in molecular research. This has allowed firms to draw on these capabilities to diversify into new business lines from their forestry basis.

(ii) An important aspect of the positive impact of EMBRAPA's role in these two industries is its emphasis on research oriented to the specific demands of these industries. This article thus supports the findings of Mazzoleni and Nelson (2007) in relation to the role of public research institutes in supporting industrial technological catch-up through the development of an application-oriented approach to research, linked with industry's needs and problems.

(iii) However, the article does not suggest any linearity in this innovation process, in which innovative activities would trickle down from research laboratories to industry (the linear model of innovation). Instead, EMBRAPA's innovative activity has been characterised by a 'system' involving extensive partnerships with other components of the institutional infrastructure, such as public and private research institutes and universities and firms. Consequently, EMBRAPA does not operate in isolation, but on the basis of an intricate network of partners. In the case of soybean research in particular, there has been increasing interaction with MNEs and their subsidiaries, which is an important aspect of innovation in the seeds industry (Arza and Zwanenberg, 2013).

(iv) The article indicates that innovative activities that generate a significant impact on productivity do not necessarily reflect only R&D efforts. There are other types of innovative non-R&D activities which are also relevant. The implementation of the ZT technology in soybeans represents an effective *creative imitation*. At the same time, there are still inventive activities involved in the process of adaptation to local soil and climate conditions. This evidence supports previous studies' emphasis on the importance of non-R&D innovative activities to technological catch-up and competitive performance. The evidence has implications for the emulation of Brazil's experience by other developing economies; policymakers should adopt a comprehensive perspective on innovation based on a spectrum of activities ranging from simple copying and duplicative and creative imitation to progressive levels of change and novelty. Even R&D should be understood in terms of degrees along a spectrum.

(v) The article suggests that, in addition to EMBRAPA's efforts and those of related knowledge-based institutions, government policies have played an important role, especially in the soybean industry. One of the most important policies has been the 1970s-onwards approach of supporting agricultural expansion in Brazil; another relates to intellectual property rights. There are also other types of more implicit government policies. For instance, the opening-up of the economy in the early 1990s brought competition into the Brazilian economy favouring more innovative efforts in both the soybean and forestry-based pulp and paper industries. Additionally, the absence of direct agricultural subsidies could be considered a kind of implicit policy that has been stimulating innovative activities, especially in the soybean industry.

(vi) More specifically, there are factors beyond EMBRAPA and related institutions and government policy that have stimulated the search for and efforts towards innovative activities in both industries. In the case of soybeans, most of them relate to aspects of demand and resource-scarcity (e.g. high prices of grain in the international market during the 1970s and 1980s and subsequent higher demand for grain; the substitution of animal fat for healthier vegetable fat). In the case of the forestry-based pulp and paper industry, demand for deeper knowledge on tree genomics to improve forestry productivity also contributed to the implementation of the Genolyptus project. This evidence has important implications for policymakers in developing economies as they tend to allocate funding to inventive and innovative activities that are disconnected from specific and concrete needs and demands from the industry and the economy.

(vii) The article challenges common generalisations that have tended to encapsulate natural resource-related industries in one single category characterised by 'low knowledge content' and 'absence of technological learning' (see for example Castaldi et al., 2009). Instead, by drawing on evidence of the technological and commercial success of Brazil's soybean and forestry-based pulp and paper industries, this article demonstrates a wide range of opportunities for technological innovation and international competitiveness that can be achieved within natural resource-related industries.

(viii) Finally, the article supports studies that emphasise the role of institutional infrastructures in industrial innovation in developing economies (e.g., Rodrik, 2004, 2006; Nelson, 1996; Nelson and Sampat, 2001; Choung et al., 2014). However, it goes further by demonstrating that although well-designed institutional frameworks are obviously necessary for the achievement of industrial innovation and leadership, a large part of achieving them will depend on the nature and dynamics of the industry's own strategic choices and related innovation efforts. Although this appears to be well known, the role of industry-level innovation efforts seems to be ignored or underestimated in the design and implementation of industrial innovation policies.

6.2 Some implications for Africa

This article suggests a number of implications for the extent to which aspects of EMBRAPA's capabilities could be emulated by other resource-rich developing economies, such as some African countries. The emulation of the EMBRAPA model in the developing and emerging economies of Africa would perhaps depend on at least two factors. The first relates to building indigenous technological capabilities to absorb external knowledge and also to implementing local production-based and innovative activities. In relation to the development of technological capabilities two components deserve careful attention: the formation of a human capital basis and the formation of an organizational basis. The building of these capabilities involves deliberate and effective efforts by government, cooperatives, farmers and other private firms, rural extension organisations and other stakeholders. The building of technological capabilities does not depend only on availability of funding but mainly on the effectiveness of learning mechanisms. The second aspect relates to the building of and/or improvement of components of the institutional framework, involving supporting knowledge-related institutions to provide human capital but also to support innovative activities. They would also be involved in the design of specific government policies.

Finally, one aspect of EMBRAPA's experience would appear to have particular relevance to the context of sub-Saharan Africa. This is the experience of achieving centralised or large-scale coordination and 'critical mass' in application-oriented research, while at the same time fostering a decentralised engagement with producers to understand the diversity of problems faced by farmers in different areas. There is some evidence that African governments are attempting to achieve bigger markets and a pooling of technical resources, through the formation of regional trading areas. These include: SADC (Southern African Development Community), EAC (East African Community) and ECOWAS (Economic Community of West African States). A consideration of some of the aspects of the functioning of EMBRAPA, as well as its problems and challenges, could perhaps shed some light on how these regional bodies might tackle the technical aspects of natural resource management and policy to strengthen agricultural research in Africa.

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