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INDUSTRIAL POLICY, INNOVATION CAPABILITY ACCUMULATION AND DISCONTINUITIES

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This paper examines a path-creating innovation capability accumulation trajectory in latecomer natural resource-processing industries across discontinuous policy regimes. Drawing on multiple-case and first-hand evidence from 13 forestry, pulp and paper firms in Brazil (1950-2007) it was found that: (1) Firms innovation capability accumulation paths involved a qualitative departure from the established technological trajectory at the early stage of their capability development: (2) As firms moved along the new technological segment, over discontinuous policy regimes, there was a high degree of variability across and within firms in terms of depths and speeds of capability accumulation: (3) Firms that reached advanced and world-leading capability levels exhibited a combination between pro-active innovation strategies, entrepreneurial management and synergetic, and relatively informal, relationships with industrial policy-making, other than protectionism: (4) Such combination proved essential for such innovators to thrive along the new technological segment and cross discontinuous industrial policy regimes with progressively higher innovative performance. By adopting an approach that captures types, stages and dynamics of firms innovation capability building, the paper contributes to expanding our understanding of technological catch-up . It also sheds light on the role of firms innovation strategies and government policy in achieving international leadership in natural resource-processing industries from latecomer natural resource-endowed contexts.

JEL - codes: M10, O32, M1

Industrial Policy, Innovation Capability Accumulation and Discontinuities:

Findings from Forestry, Pulp and Paper Firms in Brazil[1]

Abstract
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Key words: Technological catch-up; innovation capability; latecomer firms; natural resources processing industries; multiple case-study; Brazil.

JEL code: M1, O3, Q

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1. Introduction

Drawing on approaches to technological catch-up (Kim, 1980; Dahlman et al., 1987; Perez and Soete, 1988), numerous studies from the late 1980s have sought to examine how firms and industries in newly industrialized Asian countries narrowed their capability gap with world leading firms (see Amsden, 1989; Hobday, 1995; Kim, 1997; Mathews, 1997; Mathews and Cho, 1989). Building on these studies, a significant body of empirical work emerged from the late 1990s to scrutinize the catch-up paths in various industries from Asian countries like semiconductors (Choung et al., 2000), TDX telephone switching and CDMA mobile phone (Lim and Lee, 2001; Choung et al., 2006), electronics goods and components, capital goods for electronics and telecom services (Mathews, 2002; Amsden and Chu, 2003; Hobday et al., 2004), digital TV and telephone switch and handsets (Mu and Lee, 2005; Lee et al., 2005). Feng and Ling, 2007) revealed the process by which Chinese firms moved towards high capability levels for architectural innovation in DVD players without even having the capabilities to produce them, while Zheng and Williamson (2007) examined "cost innovation" paths which involved the use of process and product innovation capabilities to create new kinds of products and unique market positions.

Such kind of studies gave rise to frameworks to interpret catch-up processes in the Asian context in different assembled-products industries like the sequence from manufacturers of third-party design to own-design and own-brand-manufacturers (Hobday, 1995) and Linsu Kim's *Imitation to Innovation* (Kim, 1997). Building on these frameworks and other Korean studies, Lim and Lee (2001) developed a typology that identifies three catch-up modes: *path-following* (when latecomer firms follow the same path as taken by the forerunners, although in a shorter period of time); *stage-skipping* (when latecomer firms follow the path to an extent but skip some stage, and thus, save time) and *path-creating* catch-up, when:

> … latecomer firms explore their own path of technological development. This kind of catching can happen when the latecomers turn to a new path *after* having followed the path of the forerunners, and thereby, create a new path (p. 465, my italics).

This body of empirical research and typologies such as Lim and Lee's (2001) have provided us with illuminating evidence and analyses relative to latecomer firms' technological catch-up. Lim and Lee's (2001) study, in particular, has opened up our perspective on catch-up and also instigate new investigation on different kinds of catch-up experiences. However, there are some issues and contexts that have received scant attention from researchers over the past few years.

First, there is a predominance of studies examining catch-up processes as a *cumulative continuity* based on trajectory-following innovation, mainly for product design and development (see Hobday, 1995; Kim, 1997; Ariffin and Bell, 1999; Ariffin and Figueiredo, 2004; Marcelle, 2004; Iammarino et al., 2008). The issue of discontinuity (either in terms of new trajectories or truncation) involved in firm-level catch-up has received less attention, although there are a few exceptions. For instance, Dutrénit (2000) explored elements of *truncation* in catch-up associated with the firm's limited innovation strategy. In Viotti (2002), however, such truncation is deemed as an "inherent" difficulty of Latin American firms in moving from incremental to sophisticated innovation levels. Other studies have sought to tackle the problems involved in latecomers' *transition* into leading innovation like Amsden and Tschang (2003) and Hobday et al. (2004). But none of these two latter studies have scrutinised *qualitative discontinuities* in firms' capability building paths. Neither did they examine how firms negotiated such discontinuities and how they differed in doing that.

Second, catch-up processes have been examined under relatively *continuous* policy contexts. For instance, despite the Asian crisis in 1997 there is plenty of evidence showing that soon after that event, several Korean industries were returning to their "catch-up" development mode (see Kim, 1998) and/or to recovering and restructuring paths as a result of industrial policy measures and firms' innovative efforts (see Woo and Sul, 2000; Choi and Kang, 2000). More rare are studies that bring together different catch-up paths taken by firms' and examine them *over time* and under discontinuous (macro-level) industrial policy contexts [e.g. the abrupt and structural changes from the import substitution industrialisation (ISI) into the open economy and global competition regime in Latin America].

Third, most of the recent catch-up studies have focused on assembled-product industries, especially in the Asian contexts. Much less attention has been paid to technological catch-up modes in the natural resource-processing industries from natural resource-rich countries. As pointed out in Cimoli and Katz (2003), following the structural reforms of the 1990s in Latin America natural resource-processing industries (e.g. pulp and paper, iron and steel, vegetable oil) have "forged ahead" in Argentina, Brazil and Chile. Thus, "in these activities [...] we can talk about Latin American countries partially 'closing up' the relative productivity gap with more mature industrial economies" (Cimoli and Katz, 2003, p. 398). But this seems to refer to catch-up in terms of *production* capabilities and not *innovative* capabilities.[2] As far as innovative capability accumulation in these industries in Latin America is concerned, there are at least two kinds of views.

For some (e.g. Reihardt and Peres, 2000; Ocampo, 2001; Cimoli and Katz, 2003), the growing relevance of such industries in Argentina, Chile and Brazil is deemed as a "negative" consequence of the macro-level imposed discontinuity in the industrial policy regime from the early 1990s and a kind of obstacle to deepening innovative capabilities. For others an intelligent

[2] In production-based catch-up the technology-using firm incorporates in its products and production processes the technical methods, design specifications and performance features that are progressively closer to most sophisticated at the international *production* (process and product) frontier. This catch-up in terms of technologies *used* by firms may not be associated with their capabilities to undertake differing degrees of innovative activities.

combination between natural resources and innovation capability building is viewed as new "window of opportunity" for Latin America to improve its competitive position in relation to Asia (see Perez, 2008; ECLAC, 2008). Yet, there is scanty empirical analysis of the nature and extent of firm-level innovation capability building paths and catch-up in these industries in Latin America.

Fourth, it has been pointed out that considerable "time" is involved in moving through different innovation capability stages (Dahlman et al. 1987), that catch-up also involves running in new directions (Perez and Soete, 1988) and that "the speed of progress on the track has been uneven, with some catching-up rapidly and others lagging behind" (Lee, 2005, p. 98). However, as noted in Bell (2006), most of the recent studies of latecomer firms' capability building have given a limited treatment to the issue of timing and rate (speed) at which firms move – or fail to move – from basic to advanced and/or frontier innovation levels.

This paper seeks to address some of these neglected issues. The study reported here examined a catch-up mode in which firms from natural resource-processing industries like forestry, pulp and paper in Brazil began to drive away from the existing technological trajectory in the *early stage* of the development of their innovation capabilities. Just after World War II, these firms began to make pulp and paper from eucalyptus trees, and do other things that firms in North American and Scandinavian (Norscan) countries were not doing. This means that, relatively early in the game, they could not simply copy what the recognised industry leaders were doing. They had to develop technologies suitable to their own somewhat different operations. Both drawing on and creating different raw materials and developing effective ways to do that were innovations in any meaningful sense of the term. They could not simply *imitate* because they were moving along a somewhat different trajectory.[3]

[3] I thank Richard Nelson for commenting on this finding and for advising me to bring it to the front of the paper.

The process involved a *qualitative departure* from the trajectory already mapped out by earlier innovators, so opening up a qualitatively different segment of the international technological frontier. Yet, firms' paths in that "variant" technological trajectory was far from wholly successful, but marked by a high degree of *variability* in the "depths" and speeds of innovation capability building – from world-leading to innovation followers and laggards – across *discontinuous* policy regimes. Such capability accumulation process is slightly different from Lim and Lee's (2001) *path-creating catch-up mode*, which occurs only *after* considerable trajectory-following innovation has already taken place.

Previous research has indicated that Brazil's forestry, pulp and paper industries offer a rich empirical setting to examine this kind of innovation capability building path. For instance, Scott-Kemmis's (1988) pioneer study examined firm-level capability development in these industries in Brazil (1940-1970) and captured some embryonic research and development (R&D) activities to shift for eucalyptus-based pulp. Later, Dalcomuni (1997) found that five large Brazilian pulp exporters achieved internationally recognised environmental performance involving research into bleaching technologies for pulp production processes and research linked to the upstream forestry activities. However, there are scarce studies about whether, the extent and speed at which firms from these industries in Brazil (forestry, pulp and paper) have caught up with the innovation frontier.

One should expect to find variability in catch-up processes in these industries. For instance, examining the pulp and paper industries in Indonesia, Bell and van Dijk (2003) and van Dijk and Bell (2007) found that some firms were able, quite rapidly, to narrow the gap between their *production* capabilities and those of other firms at the international production frontier, but most of them did not move towards significant levels of *innovation* capabilities. And Jonker et al. (2006) found variations in firms' capabilities supporting performance improvement in paper firms in West Java. However, there is a shortage of studies that scrutinise the manner and speed of firm-level capability accumulation processes and innovative performance, beyond the path-following mode, across discontinuous industrial policy regimes in Latin American forestry and pulp and paper industries.

Thus this paper has been structured to address two questions. First, *what have been the nature and speed of the innovation capability accumulation paths taken by main firms of the forestry, pulp and paper industries in Brazil across different industrial policy regimes from 1950 to 2007?* Second, *what have been the implications of these capability building paths for these firms' innovative performance over that period?*

These questions are addressed here on the basis of a multiple-case research design drawing on first-hand empirical evidence gathered through extensive fieldwork. The remainder of the paper is structured as follows. Section 2 outlines the paper's analytical background and framework, while Sections 3 and 4 contains the empirical setting and research methods, respectively. Section 5 presents the empirical analysis and discussions. Section 6 lays out the paper's conclusions.

2. Analytical framework

This paper examines firms' nature and speed of innovation capability building paths (technological "catch-up") and its implications for innovative performance across different industrial policy contexts. This section provides the analytical basis to examine this relationship.

2.1 Catch-up, capability building paths and innovative performance

Catch-up in this paper is understood as the process by which latecomer firms and industries narrow their capability gaps with that of leading firms and industries that operate at the international technological frontier. Therefore, this paper is concerned with *technological* and not economic catch-up. Firms' capabilities involve a stock of resources that permit them to undertake *production* and *differing degrees* of innovation activities, involving the following core dimensions: human capital (specialised professionals, knowledge bases and skills/talents that are formally and informally allocated in specific organisational units, projects, teams) and 'organisational' (the firm's internal and external organisational arrangements like routines and procedures, linkages, managerial systems). These two dimensions not only co-exist within the firm and its network of partners, but are symbiotically *intertwined* (see Bell and Pavitt, 1993; Leonard-Barton, 1995; Kim, 1997; Dutrénit, 2000). Capabilities also encompass the firm's values, norms and beliefs that are reflected in the firm's management style and behaviour in the form, for example, of entrepreneurial firm's management and ambitious innovation strategies. However, such norms and values may also have a reverse feature (Leonard-Barton, 1995; Kim, 1997; 1998)

Following Bell and Pavitt (1993), this paper distinguishes between *production-based* and *innovation* capabilities. *Production* capability is the resource to use existing technologies to undertake process, products and organisational related activities at given levels of efficiency and given input requirements. '*Innovation'* capability, the focus here, is change-generating resource to create, change or improve products, processes and production organization, or equipment. The notion of 'catch-up' emphasised in this paper is about narrowing the gap in terms of capability to undertake *innovative* activities, in order words, closing the gap with the innovation "frontier".

However, the catch-up parlance seems to connote a single path, with firms arrayed along it, and a well defined "frontier" (Nelson, 2008, personal communication). Specifically, the "frontier" tends to be associated with following the same specific technological path (or end-point) as previously followed by world technological leaders (Bell, 2008, personal communication). However, it is crucial to consider that latecomers' technological development process is not a race along a fixed track as there are successful overtaking in a new direction and the emergence of radical discontinuities that open up opportunities for latecomers (see Perez and Soete, 1988; Lim and Lee, 2001). Specifically, latecomer firms may accumulate capabilities to pursue significantly new *directions* of innovation that depart from the trajectories already mapped out by earlier innovators, so opening up *qualitatively different segments* of the international innovation frontier (Bell, 2008, personal communication). Therefore in this paper the notion of "catch-up" also encompasses "overtaking".

Firms' paths of innovation capability building may proceed at differing rates (speeds) over time (Dahlman et al. 1987; Bell and Pavitt, 1993; Bell, 2006) although catching up is not merely a matter of relative speed (Perez and Soete, 1988). Concrete notions of firms' speed of capability accumulation is important to expand our understanding about the reality of the dynamics of catch-up as such areas as strategic management in firms, the management of public programmes to support technological development, or the formulation of longer term government policy and strategy concerned with learning and the technological basis for industrial growth (Bell, 2006). Scarce previous research has suggested a high degree of variability across and within firms in terms of speed of innovation capability building (see Ariffin, 2000; Figueiredo, 2003).

The manner and rate (speed) at which firms' capability building paths proceed over tome determine the types and levels of innovative activities that firms are able to undertake, that is, the firm's *innovative performance*. This is understood here by the actual activities, with differing and increasing *degrees* or *levels* of novelty and complexity that firms are able to undertake over time in terms of processes, products and organisation.

As far as the measurement of capabilities is concerned, traditional innovation indicators derived from surveys (e.g. R&D expenditures and personnel and patenting statistics) are not suitable to capture latecomer firms' paths of innovative capability building in a country like Brazil (see Lall, 1992; Bell and Pavitt, 1993; Bell, 2006), especially in pulp and paper industries (see Laestadius, 1998). Consequently, this paper draws on a modified version of the Lall/Bell and Pavitt typology. It identifies "levels" of innovative capabilities running from basic to world leading. Such kind of typology has been used successfully in empirical studies, with slightly variations in terminology (see Figueiredo, 2003; Ariffin and Figueiredo, 2004; Hobday et al., 2004; Tsekouras, 2006; Dantas and Bell, 2006; Iammarino et al., 2008). Rather than specifically identifying capabilities in terms of specific resources, they have identified levels of innovative *activity*, and then inferred that different levels of capability lie behind the patterns of *innovative performance*.

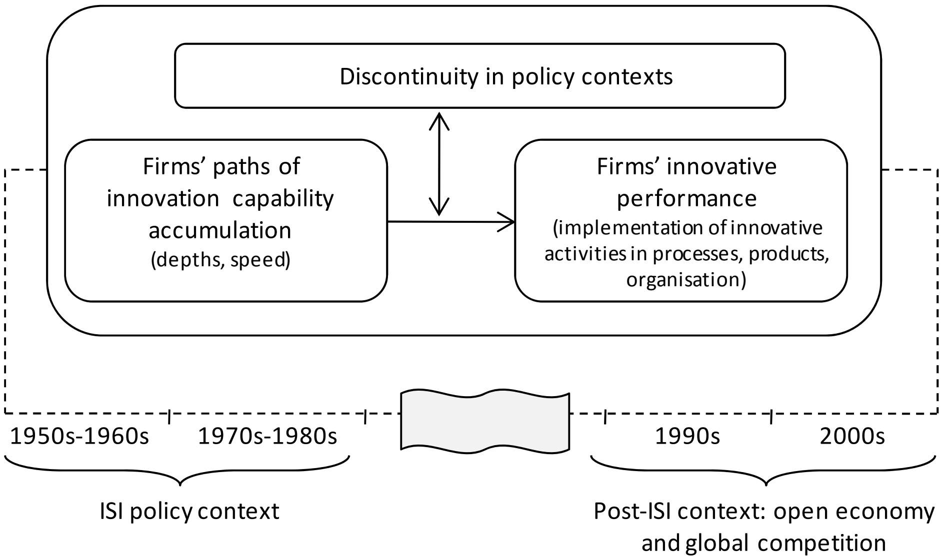
The Appendix Table presents a compacted version of the adapted framework for assessing firms' capabilities in this paper. It distinguishes between four levels of innovation capability, running from "Basic", to "Intermediate/Incremental", "Advanced" and 'World Leading'. Although this framework emphasises capabilities that are internal to the firm, it also recognises that a substantial part of a firm's capability to innovate lies in other organisations(e.g. consulting firms, research institutes, universities). Consequently, the building of innovation capability is not necessarily confined to firm's boundaries, but may involve several interdependencies. However, in order for the firm to develop such interactions, it has to build up substantial in-house expertise (Mowery, 1983) or absorptive capacity (Cohen and Levinthal, 1990), and demand for local R&D outputs (Bell, 1993). Preferably both collaborating sides (firms are other organisations) have to engage in significant innovation. Such approach is particularly relevant when latecomer firms engage in sophisticated innovation activities at the early stage of their technological accumulation process, as the cases studied here.

2.2 Technological catch-up and changes in industrial policy contexts

Numerous studies point to the role of industrial policy in influencing the capability building process at the level of firms and industries (Lall, 1987, 1992; 2003; Kim, 1980, 1998; Bell et al, 1982; Katz, 1987; Dahlman et al., 1987; Amsden, 1989; Amsden and Tschang, 2003). As pointed out in Bell et al. (1982), 'a firm's technological behaviour can be seen as a set of responses to stimuli in its environment'. Industrial policy has been underpinning many successful stories leading to industrial development in natural resources-rich countries (Rodrik, 2004). There is plenty of evidence of industrial policy underlying successful technological catch-ups in Asia (Amsden, 1989; Hobday, 1995; Amsden and Tschang, 2003; Kim, 1997). However, "what is less well appreciated is how the same holds for Latin America as well" (Rodrik, 2004, p. 15).

Conventionally, industrial policy is understood as a set of instruments chosen by bureaucrats and implemented on a top-down basis or principal (government) – agent (firms) model. Instead, in this paper industrial policy is understood as a *process* that combines both public and private initiatives and decision-making and involves different institutional arrangements (Rodrik, 2004, 2006). From such standpoint, industrial policy-making "cannot be one in which the private sector is kept at arm's length and autonomous bureaucrats issue directives" (Rodrik, 2004, p. 17). Instead, it is embedded within a network of linkages with the private sector (Evans, 1995; Rodrik, 2004). However, the ability of policymakers to have control on interactions is low and it is difficult to ensure that social interventions are implemented as intended (Pressman and Wildavsky, 1984). Therefore the set of relationships examined in this paper is represented in Figure 1.

Figure 1. The paper's analytical framework



As one of its limitations, this paper does not examine *how* firms' capabilities were created and accumulated over time, that is, the underlying learning processes. Neither does the paper tackle the impacts of capability accumulation (and/or non-accumulation) on the firms' performance (technical, economic or environmental) or on the diversification of industrial activities.

3. The forestry, pulp and paper industries in Brazil: a brief overview

The forestry, pulp and pulp complex in Brazil consists of 220 firms located in 17 states. It accounts for 1.5 percent of Brazil's GDP (2006) and is one of Brazil's leading export sectors. Around 15 firms respond for nearly 90 percent of total output and most of them are located in the South-east. Brazil is the world leading producer of eucalyptus pulp or "bleached eucapulp" (short fibre) with 58 percent world market-share (PPI, 2007; Bracelpa, 2008). In 2007 Brazil ranked 6th as world pulp producer (eucalyptus and pine) and 11th as paper producer (12 million tonnes of pulp and nine million tonnes of paper). Pulp production grew by 7.6 percent annually on average from 1970 to 2007, while paper production increased by 5.8 per cent annually on average during the same period. One hundred percent of all pulp and paper produced in Brazil derives from planted forests. Brazil has 5.5 million hectares of planted forest, of which 1.7 are related to pulp and paper. Such area is equivalent to only 0.2 percent of Brazil's agricultural land. Brazil holds a word leading position in productivity of forestry for pulp and paper as shown in Table 1. This leads to higher quality pulp and paper and lower costs thus greater competitive performance. Such leadership is associated with the technological advances achieved by leading firms as shown in Section 5.

Table 1. Some indicators in forestry for pulp and paper (2007)

	Brazil	Chile	Indonesia	Canada	Sweden	Finland
Proportion of planted forest in the country's territory (percent)	0.6	2.9	4.4	n.a.	n.a.	n.a.
Rotation of trees (hardwood: short fibre) – number of years	7 (eucalyptus)	10-12 (eucalyptus)	n.a.	n.a.	35-40 (birch)	
Productivity of short fibre species – hardwood (m^3/hectare per year)	41 (eucalyptus)	25 (eucalyptus)	20 (acacia)	n.a.	6 (birch)	4 (birch)
Rotation of trees (softwood – long fibre species)	15 (pine spp)	25 (pine radiate)	n.a.	45 [a] (oregon pine)	70-80 (picea abies)	
Productivity in long-fibre species – softwood (m^3/hectare/year)	35 (pine spp)	22 (pine radiate)	n.a.	7[b] (oregon pine)	4 (picea abies)	
Forest area needed to produce one million tonnes of pulp/year	100,000 ha	n.a	n.a.	n.a.	720,000 ha.	

Sources: Elaborated on the basis of data from FAO/Bracelpa (2008); Jakko Pöiry (2007). *Note*: (a) and (b) = Coastal area.

Planted forests are renewable resources for a diversity of industries based on raw materials from fibres and lignocelluloses, especially the pulp and paper industries. Innovative capability building in the upstream forestry segment (e.g. silviculture research into biotechnology for mass propagation and trees improvement) plays an important role in improving the innovation and competitive performance of pulp and paper-making processes (downstream segments): productivity, product quality, production costs, and environmental impact (de Assis, 2001). But the whole supply of physical systems for pulp and paper-making has always been dominated by the Norscan countries. In order to understand how Brazil became able to compete successfully against these incumbent leaders in the world market, one has to investigate the innovation capability building process in the upstream forestry segment, especially in terms of genetic improvement of trees that began in the 1950s as shown in Section 5.

4. Research design and methods

This paper derives from an empirical study based on a three-year fieldwork and multiple-case design consisting of 13 firms of the forestry, pulp and paper industries in Brazil. The study is centred on specific segments (focal cases) inside these firms: seven focal cases in forestry, nine in pulp, and 11 in paper, as presented in Table 2. One of the advantages of a cross-case analysis is that it permits comparisons that help to clarify if an emerging finding is merely idiosyncratic to a single case or replicated in several cases (Eisenhardt, 1989; Eisenhardt and Graebner, 2007; Yin, 2003). Therefore, in addition to conducting the case studies *across* the 13 firms, this study also examined cases *within* each these firms – an embedded design (Eisenhardt and Graebner, 2007): (i) focal cases *within* each of the 13 firms (seven forestry, nine pulp and 11 paper) and (ii) different organisational levels within each firm and focal cases (e.g. top and intermediate management, supporting units like R&D, human resources, engineering departments, labs, shop-floor and forest sites).

Table 2. The selected multiple cases

Thirteen selected firms	Start-up year	Ownership	Corporate structure	Main market	Selection →	Focal cases		
						Forestry [7]	Pulp [9]	Paper [11]
1. Delta	1945	Brazilian	Conglomerate (a)	Export	→	✓	✓	✓
2. Theta	1974	Foreigner	Specialized	Domestic	→	✓	✓	✓
3. Kappa	1941	Brazilian	Conglomerate	Export/ Domestic	→	✓	✓	✓
4. Zeta-A	1954 (1990)	Brazilian	Specialized	Domestic	→	✓	✓	✓
5. Sigma-A	1988	Brazilian	Conglomerate	Export	→	✓	✓	✓
6. Alpha	1978	Brazilian	Specialized	Export	→	✓	✓	None
7. Beta	1975	Foreigner	Specialized	Export	→	✓	✓	None
8.Gama	1960 (1990)	Foreigner	Specialized	Domestic	→	None	✓	✓
9. Sigma-B (b)	1988	Brazilian	Conglomerate	Export	→	None	✓	✓
10. Epsilon	1980 (1990)	Brazilian	Conglomerate	Domestic	→	None	None	✓
11. Zeta-B	1985	Brazilian	Specialized	Domestic	→	None	None	✓
12. Iota	1978	Brazilian	Specialized	Domestic	→	None	None	✓
13. Lambda	1966	Brazilian	Specialized	Domestic	→	None	None	✓

Note: (a) This means that the firm also operate industries other than forestry and pulp and paper.
(b) Sigma-B does have forestry operations, but this business line was not selected for this study.

The cases were purposefully selected based on the following criteria: (i) these firms respond for nearly 85 per cent of pulp and paper output in Brazil; (ii) they are large exporters and domestic market suppliers; (iii) some of them are top players in world market; (iv) most of them have played an important role in the formation and development of these sectors in Brazil; and (v) these firms reflect a variety of catch-up paths (successful and less successful) thus providing a good basis for analytical generalisation. The strategy for the study underpinning this paper sought to draw on protocols and tools to establish solid *construct validity, internal validity* and *reliability* (Eisenhardt, 1989; Shadish et al., 2002; Yin, 2003).

The exploratory phase of fieldwork sought to test the research questions and analytical framework and to negotiate with firms the access for data collection. This negotiation proved essential to tap into a wide range of sources including professionals (e.g. industrial directors, managers, engineers, researchers, technicians, consultants, operators and retired staff) and archival records. Professionals and archival records from related organisations were also an important data source.[4]

The tools for data-gathering involved a combination between (i) a matrix of types and levels of capabilities (see compacted version in Appendix Table), (ii) a structured interview guide, and (iii) a detailed enquiry form. These instruments derived from the break-down of the research questions and components of the analytical framework (Figure 1) into simple categories for the data-gathering in the field. Data collection during pilot and main field work within firms involved 155 formal interviews (from one to three hours), 44 informal interviews, 19 direct observations, and 27 consultations to the firms' archival records. Following the main fieldwork, 259 enquiry forms were sent to targeted informants (of which 90 percent were returned). The

[4] These refer to technical and business associations, universities, research institutes and consulting firms.

idea was to re-confirm and deepen information related to specific issues. At industry-related organisations there were 11 formal interviews and 15 archival consultations.[5]

Interviews were conducted by two people (always with my presence) to minimize mis-interpretation or limited application of the interview guide due to fatigue or other factor. Interviews were never recorded, but verbatim notes were taken. Snowballing and cross-checks with a third interviewee proved helpful to clarify discrepancies and obtain precious details about specific projects. Transcripts reviews occurred at the end of each day and were important to harmonise interviewers' interpretations. Transcripts were later sent to targeted informants for review. Double-checks of specific events were made via e-mail and/or phone calls. Such procedures and instruments were essential to organise the fieldwork and keep the data-gathering process focused on the research questions and analytical framework.

Formal data analyses were undertaken on the basis of descriptive and analytical tables that permitted to examine main stages of innovation capability building processes across different phases of industrial policy regimes (Miles and Huberman, 1984). Evidence from the cases' innovative activities over time was matched with the detailed versions of the capability framework in Appendix Table. Qualitative evidence of cases' capabilities was transformed into quantitative evidence to examine rate (speed) at which each case accumulated types and levels of capabilities for specific functions over time and across different industrial policy phases (results are shown in Sections 5.1 and 5.2) Capability accumulation patterns of each case were reconstructed with key events within firms and policy contexts. Such procedure permitted to identify stages of capability accumulation over time and their implications for innovative performance.

[5] In Brazil there are respectable archival records in pulp and paper firms and related organisations (interviews, photographs, commemorative publications, technical reports).

Rather than reducing all qualitative data to quantitative observations, both types of evidence were combined to enrich the empirical analysis. The qualitative evidence presented in Section 5.3, in the form of narratives, helps both strengthen the arguments and establish causal relationships (see Dougherty, 2002), as well as interpret the quantitative evidence. These procedures allowed a close view on the patterns of each issue examined and how such patterns and their inter-relationships changed over time (Eisenhardt, 1989). Following the completion of the main fieldwork, a *case study database* was organised containing all transcripts from interviews and observations and firms' documents.

5. Empirical findings and discussions

In the light of the framework in Section 2, this section presents the main empirical findings and discussions. Sections 5.1 and 5.2 scrutinise, respectively, firms' current levels (or 'depths') of innovation capabilities and the rate (speed) at which they were accumulated over the 1950-2007 period. Section 5.3 draws on qualitative evidence to examine the evolution of the cases' capability building paths across different industrial policy regimes over time. A summary of the key findings and discussions is outlined in Section 5.4.

5.1 Levels of innovation capability accumulated in the focal cases

The evidence from Table 3 and Figure 2 indicates that the paths of innovation capability in the focal cases involved a high degree of *variability* across firms and within firms in terms of levels ("depths") and also speed at which capabilities were accumulated, with varied implications for their innovative performance over time. Some firms engaged in innovation capability building processes at their inception stage and moved up to world leading innovation levels; others engaged in similar efforts, but had their innovation capability building paths discontinued before reaching the innovation frontier; some were stuck at a much lower level of innovation capability.

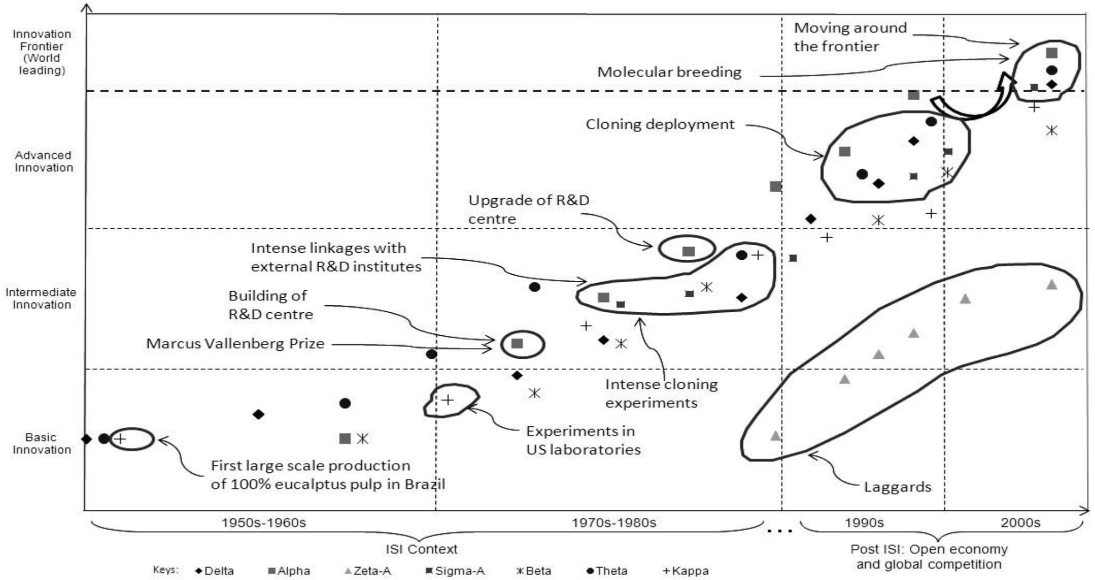
Table 3. Accumulation of innovation capability along the eucalyptus-based technological trajectory

Capability levels		Forestry cases	Pulp cases	Paper cases
Innovation capability levels	Innovation Frontier (World leading) ⇧ **[E]**	**4** **[57 percent]** Alpha Theta Sigma-A Delta	**4** **[44 percent]** Alpha Delta Sigma-A Sigma-B	**4** **[36 percent]** Delta Kappa Sigma-A Sigma-B
	Advanced Innovation ⇧ **[D]**	**6** **[86 percent]** Alpha Theta Sigma-A Delta Beta ⬭ Kappa ⬭	**6** **[67 percent]** Alpha Delta Sigma-A Sigma-B Gamma ⬭ Kappa ⬭	**7** **[63 percent]** Delta Kappa Sigma-A Sigma-B Gamma ⬭ Zeta-B ⬭ Theta ⬭
	Intermediate Innovation ⇧ **[C]**	**7** **[100 percent]** Alpha Theta Sigma-A Delta Beta Kappa Zeta-A ⬭	**8** **[89 percent]** Alpha Delta Sigma-A Sigma-B Gamma Kappa Beta ⬭ Theta ⬭	**11** **[100 percent]** Delta Kappa Sigma-A Sigma-B Gamma Zeta-B Theta Lambda ⬭ Epsilon ⬭ Zeta-A ⬭ Iota ⬭
	Basic innovation ⇧ **[B]**	**7** **[100 percent]** Alpha Theta Sigma-A Delta Beta Kappa Zeta-A	**9** **[100 percent]** Alpha Delta Sigma-A Sigma-B Gamma Kappa Beta Theta Zeta-A ⬭	**11** **[100 percent]** Delta Kappa Sigma-A Sigma-B Gamma Zeta-B Theta Lambda Epsilon Zeta-A Iota
Production-based capability levels	Advanced production ⇧ **[A]**	**All** **[100 percent]**	**All** **[100 percent]**	**All** **[100 percent]**
	Basic Operations ⇧ **[A]**	**All** **[100 percent]**	**All** **[100 percent]**	**All** **[100 percent]**

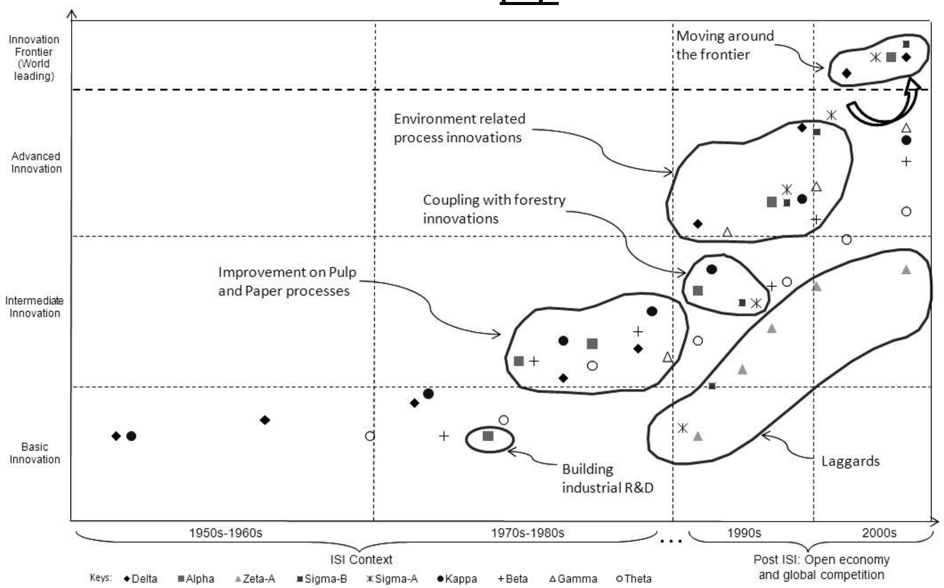
Source: Framework adapted from Bell and Figueiredo (2008). Derived from the empirical study.
Key: ⬭ = Cases whose capability levels remained near, halfway from or far away from the innovation frontier

Figure 2. Paths of innovation capability building along the eucalyptus-based technological trajectory

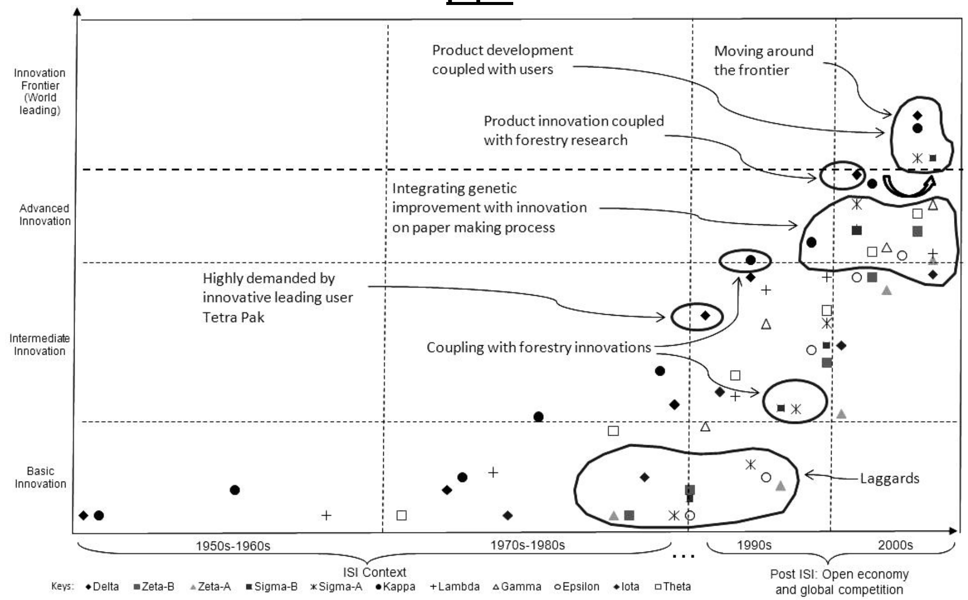
Paths of the <u>forestry</u> case-studies



Paths of the <u>pulp</u> case-studies



Paths of the <u>paper</u> case-studies



Source: Derived from the empirical study.

As some firms moved into the accumulation of higher innovative capability levels, they also strengthened their production-based and basic to intermediate innovation capability levels. Such *cumulativeness* seems to be a necessary condition for latecomer firms to attain leading innovation positions (Bell and Pavitt, 1993). However, this progression up successive steps on the innovation capability "ladder" is far from automatic and linear: in some firms the capability innovation building process seemed to have stopped permanently or paused and their paths evolved in an inconsistent manner.

For instance, some focal cases have attained world leading innovations capability levels, while some have moved towards near such innovation frontier level, independently of the discontinuity in the industrial policy regime. Some, however, have reached capability levels halfway from world leading capabilities, while some laggard firms stayed at capability levels far away from the innovation frontier level. Some firms like Alpha, Kappa and, later, Sigma-A and Sigma-B engaged in R&D activities since their inception in the industry under the ISI policy context. Alpha, for instance, began to engage in research-based activities in the upstream (forestry) segment about 10 years before the start-up of its pulp mill. This means that Alpha was undertaking R&D activities even *before having built up production-based capabilities*. Sigma-A, Sigma-B, Delta and Theta are integrated firms operating in the three segments (forestry, pulp and paper). While the first three reached capability levels at the innovation frontier in the three segments, Theta's path was highly variable: frontier in forestry, halfway from the frontier in pulp and laggard in paper.

Forestry and pulp-making firms like Alpha and Beta, for instance, started up almost at the same time and began their innovation capability building at their early stages. However, while Alpha attained world leading innovation capability levels in the segments it operates, Beta's capabilities only reached the innovation frontier for forestry, but stayed halfway from it in pulp.

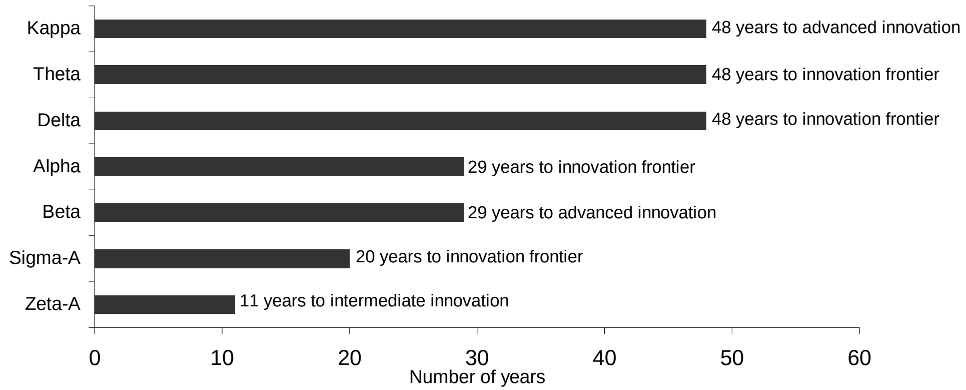
Strikingly, the large paper-maker Epsilon started up under an entrepreneurial and innovative management style in the early 1900s. In 1925 this firm implemented the production of chemical sulphite pulp from its own pine forests. In 1927 Epsilon pioneered tissue paper production in Brazil. Based on innovation-oriented values, in the late 1940s, it also pioneered the produced high-performance tissue paper from eucalyptus and as early as 1950 it engaged in pioneer research to obtain improved bleached pulp from *Eucalyptus*. Yet by the early 2000s its innovation capability accumulation process had not moved beyond the intermediate level. Indeed, following the structural reforms of the early 1990s, Epsilon stopped its innovation efforts. Cases of discontinuity in capability building like this seem to give support to Cimoli and Katz's (2003) argument of negative consequences of the macro-level imposed discontinuity. Epsilon's case also seems to have involved micro-level inconsistencies in innovation strategies [in line with Dutrénit's (2000) truncation perspective] and strategic rigidities [or Leonard-Barton's (1995) flip side of innovation capability].

5.2 Speeds of innovation capability accumulation in the focal cases

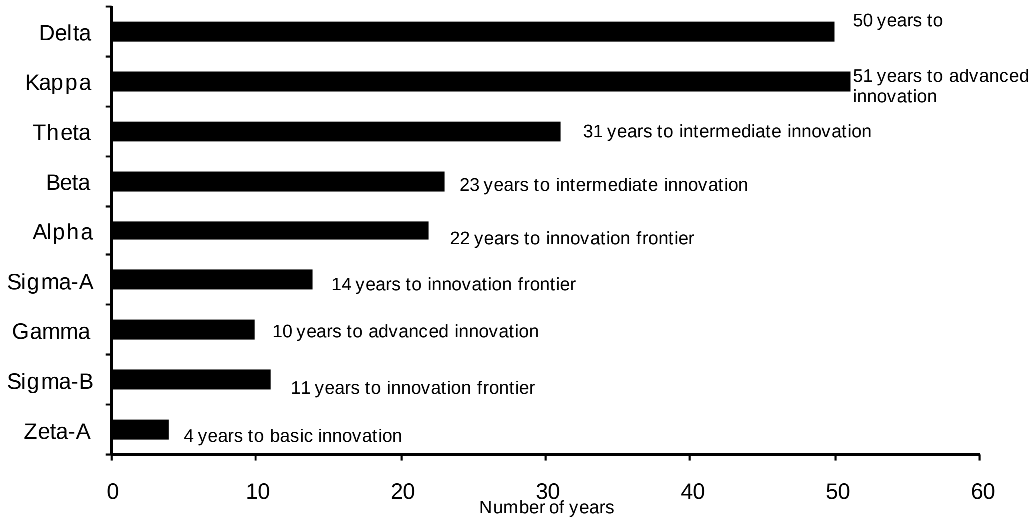
Drawing on previous research (Ariffin, 2000; Figueiredo, 2003), the rate (or speed) of capability development is defined here as the time (number of years) a firm took to reach a specific capability level. Although the innovation capability building is a slow process (Bell, 2006), the evidence here indicates a high degree of variability in the time-scales involved in the focal cases' innovation capability accumulation processes, as shown in Figures 3 and 4. Specifically, the process of capability accumulation at advanced to world leading innovation levels involved highly varied time-scales: some firms took around 26 to 33 years to move into world leading capability level, whereas others took 50 to 57 years to achieve the same capability level. Some firms in forestry, pulp and paper spent long time periods stuck at production to basic innovation before they moved beyond intermediate innovative capability levels (e.g. Kappa, Theta, Delta, Beta).

Figure 3. Time (number of years) taken by each firm to reach their highest capability levels during their lifetimes (aggregate)

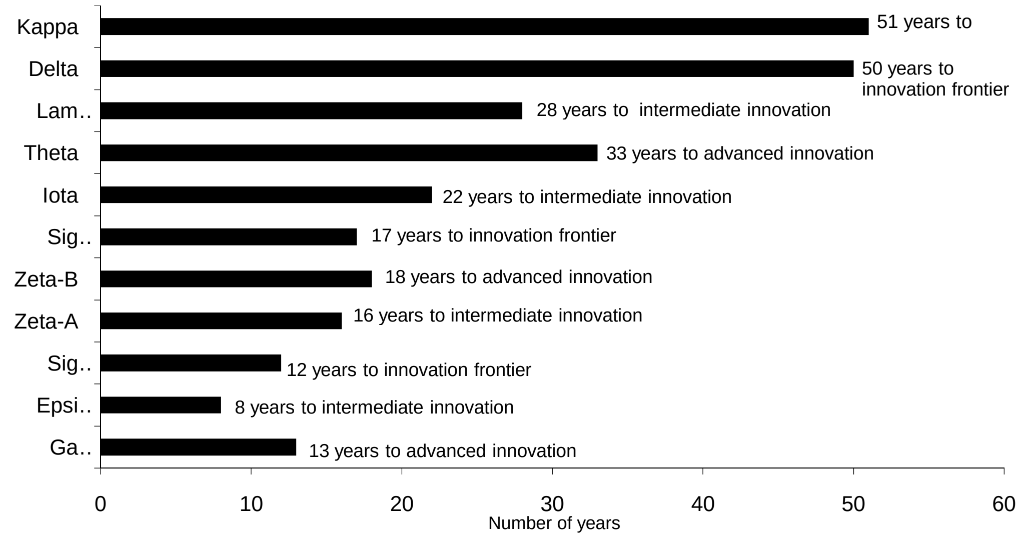
Forestry cases



Pulp cases

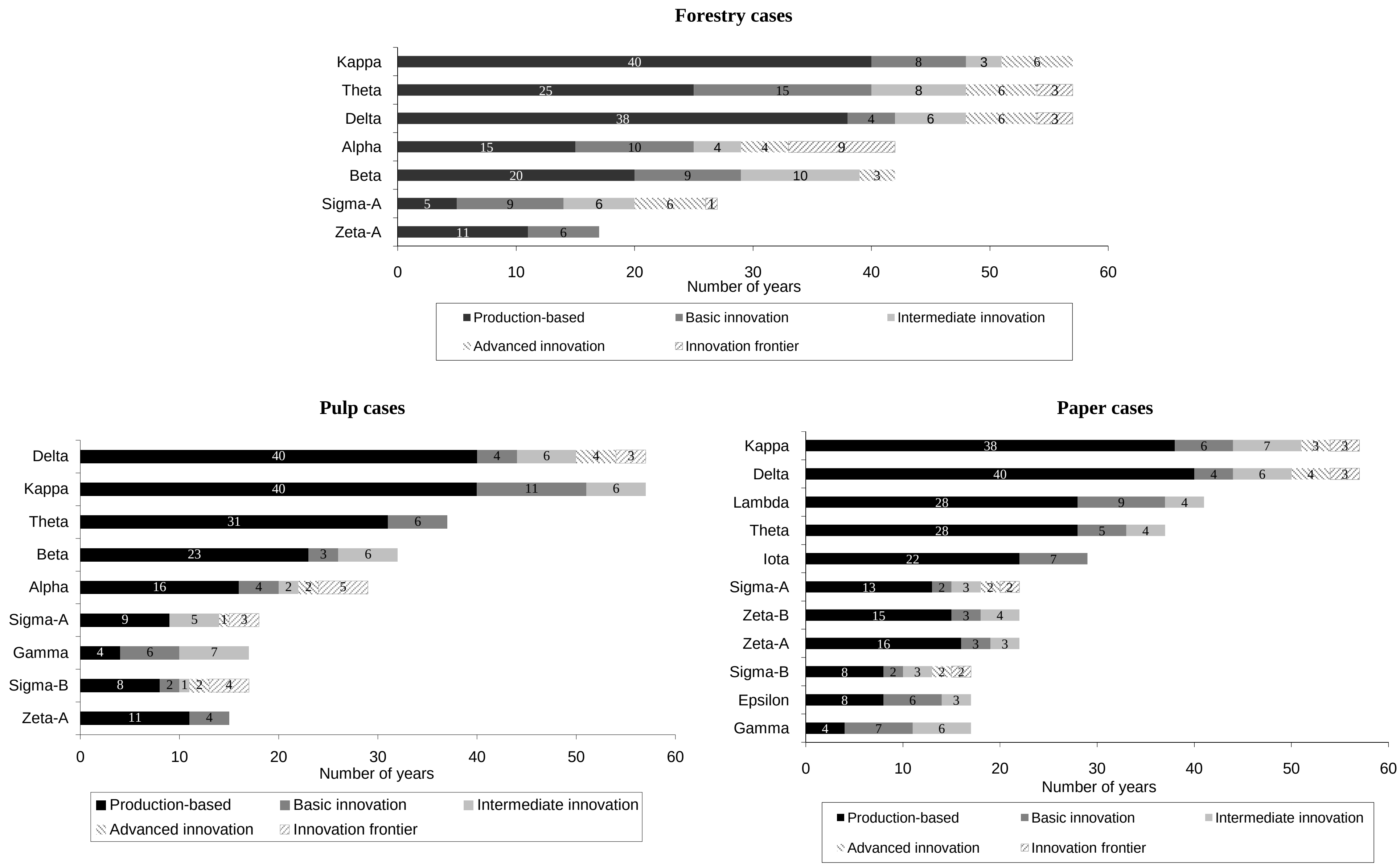


Paper cases



Source: Derived from the empirical study.

Figure 4. Average time in which each firm remained (or still remains) stationed at particular capability levels during their lifetime (aggregate capability level)



Source: Derived from the empirical study.

Forestry cases spent more time stuck at basic innovation levels than did the pulp and paper cases. Differently, some firms moved faster and spent much less time at production and/or basic innovation levels, but stopped at intermediate levels; others, however, proceeded into advanced and even into world-leading innovation level.

Although older firms like Delta and Kappa proceeded to high capability level accumulation, they took considerable more time than the younger Alpha and Delta. Statistical tests showed that the pulp and paper cases between the age of 17 to 30 were much faster than cases above the age of 50 in terms of the rate at which they moved from production capabilities levels to advanced innovation capability levels for specific functions: 16.5 years for project management ($p<0.10$) and 14.4 years for equipment-related activities ($p<0.05$). Additionally, firms aged between 31 and 50 took 19 years less than firms aged above 50 years to move from basic innovation capability level into advanced capability for process equipment-related activities. However, there were exceptions. Alpha is 10 years older than Sigma-A and both have accumulated world-leading capability level. However, the time taken by Alpha to reach that capability level corresponded to 79 percent of its lifetime and 96 percent of Sigma-A's.

There also was great variability across cases *within* the forestry, pulp and paper segments of each firm. For instance, while firms Alpha and Sigma-A took 35 and 27 years, respectively, to reach the world leading capability level in forestry and 23 and 15 years, respectively, to reach this capability level in pulp, firm Delta took 54 to reach such innovation capability level in these two segments. Specifically, Alpha (forestry-pulp integrated) took 33 years to move into world leading innovation capability level in forestry and 23 years to achieve that capability level in the pulp segment. Similarly, Sigma-A (forestry-pulp-paper integrated) took 26 years to reach world leading capability level in the forestry segment, 13 to 15 in pulp and 14 to 19 in paper. As it will be shown by the qualitative evidence in Section 5.3 it seems that Alpha's and Sigma's efforts on innovation (research-based) capability accumulation in forestry (upstream) seems to have contributed to accelerate their innovation capability building in pulp (downstream). However, the firm Delta (forestry-pulp-paper integrated) took 51 to 57 years to achieve world leading capability level in forestry and 54 years in pulp and paper segment. Also slow, but innovative, the firm Kappa took 51 and 57 years to reach the advanced capability level in forestry and pulp, respectively, and 54 years for world leading capability in paper.

5.3 Evolution of firms' innovation capability paths across industrial policy contexts

In the light of the framework in Section 2, this section draws on qualitative evidence to scrutinise the main stages in the evolution of the relationship between the firms' capability accumulation and innovative performance across main phases of different industrial policy contexts: 1950s-1960s and 1970s-1980s under the ISI policy context (Sections 5.3.1 and 5.3.2, respectively) and 1990s and 2000s under the post-ISI policy context (Sections 5.3.3 and 5.3.4, respectively). As it will be shown here, during the 1950s-1980s period, most of the innovative efforts were centred on the upstream forestry segments. Significant innovative activities in pulp and paper-making processes only appeared from the early 1990s.

Before I go any further, it seems useful to provide you with some contextual background related to the 1920s-1940s period in Brazil and the pulp and paper industries. This was marked by constraints that stimulated industrial and government leaders' to search for new raw materials sources for pulp and paper. During the early 1920s Brazil experienced a growing demand for paper and a progressively severe scarcity of pulp. Such lack of raw material had been caused by the import constraints of the WW1. From the early 1940s, import restrictions imposed by the WW2 and the Korean War stimulated industrial leaders to begin a campaign for Brazil's self-sufficiency in pulp "to free the country from cyclic instability that threatened growth of local pulp and paper industries and industrial growth".[6] This instigated the Getulio Vargas' government (1930-45) to implement measures that marked the beginning of protectionism and

[6] Decoration issued by industrial leaders at that time.

the ISI policy. These events also triggered individual and firms' initiatives to search for new raw materials.

For instance, from 1940, eucalyptus became cheaper as locomotives were converting into diesel and stopped using it as timber in their boilers. Eucalyptus had already diffused in Brazil and its potential use as raw material for paper and paper began to receive more attention. Within a railway firm, Mr. Navarro took efforts on the investigation of eucalyptus properties for pulp and paper. Facing lack of proper research facilities in Brazil he carried out his experiments in the Madison's Laboratory of Forestry Products (Wisconsin, US). His results challenged the then prevailing view that that paper made out of eucalyptus would not resist the pressure of rollers in paper machines and newspapers printers.

Drawing on findings from previous experiments that had been conducted under the Navarro's programme, in 1946 the firm Epsilon demonstrated the feasibility of eucalyptus as a raw material for pulp and paper production in laboratory and some small-scale production. However, Brazil lacked the technology (knowledge) to transform eucalyptus into an innovative, sustainable and competitive raw material for large-scale pulp and paper production. Firms and government had to organise themselves to engage in this kind of innovation.

5.3.1 Organising for innovation during the initial formal ISI policy phase (1950s-1960s)

This period was marked by the government and firms' efforts on the building of initial institutional and knowledge bases that permitted firms to engage in a qualitative discontinuity of the established technological trajectory over the subsequent decades. On the one hand, there was the formation of the institutional frameworks that took up the tasks of designing policies to stimulate forestry, pulp and paper firms' technological development in Brazil. These also involved the building of government-led research facilities and research-funding arrangements that were crucial to complement firms' innovation capabilities. As firms lacked research capabilities, an external and collective R&D arrangement was built up based on the interaction between firms and government-funded education and research organisations. On the other hand, some firms engaged in the building up of their own innovation (research-based) capability. These intra-firm capability building efforts were crucial to absorb the knowledge generated through the interaction with the external R&D arrangements located in Brazil, but also abroad. These findings match to what was predicted in Section 2 (see Mowery, 1983; Bell, 1993; Bell and Pavitt, 1993)

From the mid 1960s, the National Bank for Economic and Social Development (BNDES)[7] conditioned its funding for the pulp and paper industries on the basis of their own supply of wood derived from planted forests. This measure was in line with the Forestry Law, of 1966, an explicit government policy to stimulate re-forestation activities and eucalyptus diffusion. Such incentives involved a reduction of 50 percent in the income tax of individuals and firms.[8] The Brazilian Institute for Forestry Development (known as IBDF) as created in 1967 to implement such policy.[9]

Such initiative influenced the firms' upstream integration and, consequently, their engagement in systematic reforestation efforts (e.g. Kappa, Theta-Forestry, and Delta). These projects led to an increased demand for high-quality seeds and for qualified human resources in silviculture. However, there were critical hurdles: until the early 1960s knowledge of silviculture in Brazil was shallow and firms lacked research capabilities on forestry for a sustainable and feasible large-scale pulp and paper production based on eucalyptus. In order to overcome such obstacles a series of initiatives were taken as illustrated below.

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[7] Created in 1952 as BNDE (National Bank for Economic Development) it became Brazil's first institution dedicated to long-term funding of infra-structure and industrial development.
[8] This was formalised under Federal Law 5106 of September 1966.
[9] This policy was formally implemented from 1967 to 1987. Between 1967 and 1986 re-forestation projects associated with this policy reached 6.2 million hectares, of which 52 percent were based on eucalyptus. From 1967 to 1987 eucalyptus reforestation projects increased by 14.1 percent annually on average, while pine-based projects 13.8 percent.

From the mid-1950s, the firm Kappa engaged in systematic experiments on the use of eucalyptus for large-scale pulp and paper production. Although some foreign laboratories were already producing eucalyptus pulp, the existing scientific literature still classified such raw material as improper for printing and office paper manufacturing. The son of Kappa's owner engaged in a research project to challenge such findings. Results from his initial experiments were fruitless. He persisted, though, with the investigation in the laboratories of Florida University at Gainsville in the US from 1955 to 1962. After the sixth year, his research eventually confirmed that it was possible to obtain quality paper with 100 percent eucalyptus pulp. In 1962 the new product began to be manufactured, on a large scale, in their new plant in the municipality of Suzano (São Paulo state). Despite these and other efforts taken by firms, there were very little (if any) capabilities in Brazil (both human capital and organisational) to undertake more sophisticated forestry research.

Responding to such industry's needs, in the early 1960s the College of Agriculture of the University of São Paulo (Esalq) began to offer degree courses on forestry (from undergraduate to PhDs).[10] It enlarged its post-graduate programmes with the support from government agencies for the provision of studentships and laboratories for pilot production of pulp and paper.[11] This kind of indirect industrial policy was inspired in the model of the Forestry School of North Carolina University.

During the early 1960s some companies began to demand studies and experiments from Esalq to speed up their forestry development activities. In October 1967, a meeting involving 13 firms, Esalq and the Brazilian Institute of Forestry Development (IBDF) generated the guidelines for a research programme on forestry improvement. Such programme would be located at Esalq and funded by the industry through the Forestry Research Fund. In December of 1967, a meeting

[10] This school originally started up in 1901. In 1934 it was integrated to the University of São Paulo.

[11] The national providers of scholarships involved government bodies like the National Council for Scientific and Technological Development (CNPq) and the Brazilian postgraduate agency (Capes). Funding for the building of laboratories came from the State of São Paulo Research Foundation (Fapesp).

involving 18 firms led to the creation of the Forestry Science and Research Institute (known as IPEF). Its initial focus was to undertake research on high-quality and cost-effective raw material for Brazil's pulp and paper industries. The associated firms defined the research lines of IPEF to meet their own needs. The main research goal fell on the increase of eucalyptus productivity (around 24 m^3/ha/year by 1968). This was pursued via search of new species for seeds.

In 1968 the seeds development programme, which until then was under the São Paulo Railways Co (Fepasa), was transferred to IPEF. IPEF, in turn, built on Fepasa's previous research to engage in its own vegetative propagation programme based on seedlings of *Eucalyptus sp* and *E. urophylla*. In that same year, concerned with the genetic and physiologic quality of the existing seeds, two companies sponsored the visit of a renowned researcher from the Canberra University to review IPEF's research methods. His recommendations led IPEF to search new species (e.g. *E. grandis*) – better suited for the local pulp and paper industries and with less hybridization, a cause of high forest variability.

By the late 1960s the emergence of Aracruz (Alpha) out of the initiative of 12 entrepreneurs, represented a decisive thrust for the commercial success of the eucalyptus-based technological trajectory. Aracruz began its *Eucalyptus* plantation programme in the South-eastern state of Espírito Santo in 1967. Initially, Aracruz considered *Eucalyptus grandis*, *E. Saligna*, *E. urophylla* and *E. Alba* as the most suitable species. Aracruz's forestry segment was built up on the basis of eucalyptus plantations using seeds produced in Fepasa (the railways company) where Mr. Navarro, the forestry scientist, had developed the early experiments from the 1920s. However, there were uncontrolled hybridisation and high variability in growth rates, stem forms, and wood properties. These problems indicated inadequate sources of seeds. Consequently, the *E. Saligna* faced susceptibility to trunk rot, while the *E. Alba* showed variations in physical or biochemical characteristics (phenotypical). Their average productivity was not higher than 22 to 26 m^3/ha/year. These problems prompted Aracruz to move from vegetative propagation, based on seeds, into tree improvement and clonal programmes.[12] To tackle these problems in a more systematic manner, Aracruz had to set up, as early as 1968, its own forestry research centre.

5.3.2 Making the qualitative discontinuity in the technological trajectory during the ISI policy context (1970s-1980s)

During the 1960s and 1970s the Brazilian economy was marked by huge investments in infra-structure and the development of basic industries and high rates of industrial growth. But the 1980s involved a mix between recession, hyperinflation and a sequence of failed macro-economic stabilisation plans. Such instabilities disrupted investments and entire industrial sectors. Nevertheless, Brazil's forestry and pulp and paper industries thrived across these macro-economic discontinuities on the basis of leading firms' systematic innovative efforts combined with an industrial policy-making embedded on a network of relationships with these industries in the sense referred to in Evans (1995) and Rodrik (2004).

At the macro-level the 1970s was marked by the implementation of national development plans that supported entrepreneurs' initiative in industries like forestry and pulp and paper. For instance, BNDES not only funded investment projects, but became a shareholder of some of them like Aracruz. The then state owned mining company Vale do Rio Doce, that run a large reforestation project (Celpav) became a shareholder of Gamma. Later, Vale do Rio Doce's Celpav project was taken over by the private group Votorantim, permitting the emergence of firms Sigma-A and Sigma-B. This acquisition of previous forestry capability helps to explain the rapid speed of innovation capability accumulation in these two firms as shown in Section 5.2.

Despite the two energy crises of the 1970s, the Second National Development Plan (1975-79) with the First National Plan for Pulp and Paper, sought to stimulate the growth of sectors like pulp and paper and export activities. By the late 1970s, Brazil had achieved self-sufficiency in

[12] See also Campinhos (1999) and Evans and Turnbull (2004).

pulp and paper. Despite the economic stagnation of the 1980s, pulp and paper production grew by 3.5 per cent annually on average and paper exports grew by 17.2 per cent annually on average. BNDES's involvement in the structuring and growth of these (always private) sectors was so intense that between the early 1970s and early 1980s, around 27 per cent of the bank's disbursements were related to the forestry and pulp and paper industries.

As typical latecomers, Brazilian pulp and paper firms faced several barriers to enter international markets: customers were sceptical about a hitherto non-traditional supplier like Brazil and about the efficacy of the eucalyptus pulp. To tackle this problem, the Pulp and Paper Technical Centre at the University of São Paulo was created to promote the eucalyptus fibre in the world market. Indeed, since its inception, Brazil's pulp and paper industries has demonstrated an ability to organise themselves to defend their interests. For instance, it began with the National Centre of Papermakers upgraded the Federation of Papermakers (1925) which, in the 1940s evolved into the National Association of Pulp and Paper Makers (ANFCP) to today's Brazilian Association of the Pulp and Paper (Bracelpa), and the Brazilian Technical Association of Pulp and Paper Industries (ABTCP) from the 1960s among others. These kinds of arrangement, that became more intense from the 1970s, were used by some firms to overcome hurdles to their commercial, but also technological achievements.

The 1970-1980s period was marked by innovations based on clonal forestry such as macro- and micro-cuttings, tissue culture and clonal deployment.[13] Firms like Aracruz took the lead in introducing new vegetative propagation techniques. By 1970 the number of firms organised around IPEF had increased from 18 to 29. In 1976 there were 388 projects under implementation by dedicated teams of engineers and researchers to meet the firms' demands. In conjunction with

[13] Clonal plantations offer a number of advantages compared to those developed with seedlings: (i) Cloning enables genetic gains from selection and breeding to be captured quickly; (ii) It is a cost effective way of using hybrids (e.g. *Eucalyptus Urophylla* x *E. Grandis*); (iii) It permits easier use of desirable characteristics such as pulp yields and disease resistance; (iv) It produces a uniform material for processing in the production process. However, such benefits are only fully obtained if there is integrated planning and implementation of plantation strategies involving tree breeding, clonal testing, operational propagation and clonal deployment. See Evans and Turnbull (2004).

firms, IPEF developed organisational arrangements that sought to achieve the integration between IPEF and firms' technological activities, as described by one interviewed researcher:

> "During the 1970s our aim was to advance in research demanded by companies and transform our findings into inputs for them to improve their processes and final products. Along each year we had several formal and informal meetings, technical visits (on both sides) and joint field days. Hundreds of professionals from the companies participated in these activities. Within the companies there always were supporting facilities for the groups to conduct experiments and test them on the production areas."

Such kind of organisational arrangement became known as the "IPEF model" and was emulated by other organizations involved in forestry research in South-eastern and Southern Brazil. By the mid 1970s, IPEF's efforts, led by researchers F. Poggiani and W. Suiter Filho, in association with firms', pioneered the development of a *rooted cutting technology (macro-cutting)*. Although not a radical innovation, the advances they attained involved the control of critical factors that increased the rooting rates. Building on these advances, the researcher E. Campinhos Jr., from Aracruz, led a research project in the late 1970s that permitted the mass production of clonally propagated plantations of eucalyptus pulpwood in areas considered of difficult rooting: the coastal area in Southeastern Brazil where Aracruz and other firms had been set up.

Further ground-breaking studies led by the researchers A. Borba and A. Brune and also E. Campinhos and Y. Ikemori achieved successful rooting results under controlled conditions – i.e. *ex vitro* or indoor clonal hedges).[14] These research achievements paved the way for the successful intensive clonal *Eucalyptus* forestry in Brazil.[15]

[14] This method permits to skip the *in vitro* stage. The *ex vitro* method is desirable because of cost reduction in labour force and infra-structure, but mainly the high degree of juvenility of micro-propagated plantlets or rooting cutting.

[15] Experiments in cloning of *Eucalyptus* based on rooted cuttings from mature trees had been developed earlier in Marrocos (1956) and advances for commercial use had been achieved in the Republic of Congo (late 1960s). But it was from the early 1970s in Brazil, mainly within Aracruz, that new methods were developed for large-scale cloned forests for large-scale pulp production (see Poggianni and Suiter Filho, 1974; Evans and Turnbull, 2004). Indeed, from a Schumpeterian perspective, the Brazilian firms innovated by *combining and putting together* new kinds of knowledge to achieve a new kind of commercially feasible raw material for large-scale, high-quality and lower cost pulp and paper production.

From the early 1970s, drawing on these studies and combining them with its in-house research capabilities, Aracruz began to perfect its own genetic improvement programme based on clonal forestry to increase the productivity of its eucalyptus pulpwood plantations. By combining strategies of sexual and asexual propagation, Aracruz's research indicated that gains in volume production and wood quality could be achieved using hybrid clones (e.g. *E. grandis* x *E. urophylla*).[16] In 1979 Aracruz decided gradually to substitute its plantations, derived from seeds, for clonal plantations. Cloning enabled Aracruz to use the results of its selection and breeding programme. Aracruz initially selected 5,000 trees from a 36,000 ha plantation, of which 150 clones were identified as potentially suitable. Only 31 of the very best were used in the plantation programme. By 1980, Aracruz first commercial clonal plantation with 1,000ha had been established; by 1989 it had evolved to 15,000 ha. By 1987 Aracruz's annual production of cuttings was 16.8 million. As a result of this cloning strategy, Aracruz's eucalyptus productivity increased from 30 to 45 m^3/ha/year.[17] Such kinds of genetic improvement have economic impacts on the pulp-making process. It is estimated that an increase in wood chips density from 0.155Kg/l to 0.165Kg/l results in a productivity gain of around US$ 3million annually for a mill of 300,000 tonnes per year (de Assis, 2001).

Aracuz pioneered introduction of the rooting stem-cutting on an industrial scale. It was able to propagate clones resistant to feared fungus that caused canker in eucalyptus plantations. In 1984, nearly 17 years after having started its research activities, Aracruz achieved international recognition by being awarded the Marcus Wallenberg Prize (Sweden).[18] Mass production of clonally propagated planting stock became largely diffused to other firms in Brazil (e.g. by the late 1980s, Delta's production of cuttings was of 10 million/year).

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[16] Sexual propagation involves the exchange of genetic material between two parent tree, while asexual reproduction, the new plants are genetically exact copies or clones of a single parent tree.

[17] See also Ikemori (1990); Evans and Turnbull (2004).

[18] Established in 1980 in Sweden, under the Marcus Wallenberg Foundation, this is a highly respected prize that seeks to encourage and stimulate path-breaking scientific achievements which contribute significantly to broadening knowledge and to technical development within the fields of importance to forestry and pulp and paper industries.

However, the rooting stem-cutting technology presented its own drawbacks such as an accelerated maturation process causing rapid loss of rooting-predisposition and alterations of root system architecture causing root deformation (de Assis, 2001).[19] This challenged the Aracruz to another upgrade of its forestry R&D centre, to strengthen links with local universities and to build up partnerships with cutting-edge international research institutes.[20]

The organisational arrangement involving IPEF and the firms proved decisive for the progress in Brazil's forestry between 1969 and the 1975. However, in late 1970s the quantity of seeds produced was not sufficient to meet the growing demand. Additionally, the industry put pressure on the federal government to improve regulation on imported seeds and suspicious reforestation projects that benefited from the federal incentives. As a result, in 1977 the whole institutional framework for the pulp and paper industry was restructured. A new inter-organizational arrangement was created to control for the quality of seeds and to issue certifications of planted areas.

The Brazilian Agricultural Research Corporation (Embrapa), created in 1973, took up the responsibility for the National Programme of Forestry Research incorporating previous programmes. In 1984 Embrapa created the Working Group for Forestry Genetic Improvement. Its objectives were to issue guidelines for using of genetic material, create procedures for experiments and organise scientific and technical meetings. From the early 1980s, while Embrapa undertook the genetic improvement programmes, IPEF became dedicated to new research methods based on forestry handling and exploitation as firms' plantations reached the stage of cuttings.

[19] This is why new technologies involving rooting of micro- or mini-cuttings, have improved rooting potential, rooting speed, and root system quality, have reduced costs and have shown their potential to substitute for root stem cuttings (see de Assis, 2001; Evans and Turnbull, 2004).
[20] Although very interesting, the issue of sources of capability (learning) is outside the scope of this paper.

By the late 1980s, 20 years after the first systematic forestry research activities, Brazil had consolidated a position as a major exporter of pulp and paper derived from innovative eucalyptus forestry. At the same time, industrial policy based on the ISI regime was weakened. In 1987 the government ended the fiscal incentive for forest plantations, which had begun in 1966 and had played a major role in stimulating the forestry development in Brazil. Some firms realised that, because of their specific forestry characteristics and research needs, they could no longer draw on the collective R&D arrangement around IPEF and Embrapa. They began to strengthen their own research capabilities. But not all firms did that. Conversely, in 1983 firms like Aracruz had already taken the initiative of building its R&D centre dedicated to pulp and paper activities. This added to the forestry research unit that had been built in the late 1960s. In late 1980s, the creation of firms Sigma-A and Sigma-B, of the Votorantim group, with the support from BNDES, represented another major thrust to expand research activities in forestry and pulp and paper in Brazil.

5.3.3 Innovation capability building across the open and market-led policy context of the 1990s

The early 1990s was marked by a major discontinuity in the industrial policy regime in Brazil. From 1991 there was a gradual and steady reduction of trade barriers combined with a set of actions to de-regulate and open up the Brazilian economy to foreign competition. After nearly 40 years of state-led industrialization policy, there was an abrupt and radical change into a “Washington Consensus” type of industrial regime. The trade liberalizing measures adopted by the federal government in March 1990 led to a drastic reduction in the historically high import tariffs in Brazil (e.g. from 114 per cent in 1966 around 12 to 8 per cent in 1993). Following such measures, several firms from a number of sectors were swept away as they were not able to cope with the international competition brought on by such changes (e.g. several firms in assembled products and consumer durable industries).

Large paper firms, like Delta, almost collapsed and had to radically re-focus its scope. In the case of pulp and paper industries this was worsened by the international fall of paper prices in the world market. Additionally, the strategic collaboration between government and the forestry and pulp and paper industries, that had marked the industrial policy process during the 1950s-1980s period, was replaced by a kind of "principal-agent" type of industrial policy. In this type of fruitless policy-making, the industry is kept at arms' length and government bureaucrats issue directives (see Rodrik, 2004).

The Industrial and Foreign Trade Policy (PICE), implemented from April 1990, sought to stimulate the development of industrial capability and to prepare the economy for world competition. Such policy involved several programmes and fiscal and credit incentives: the Brazilian Programme of Quality and Productivity (PBQP) sought to disseminate new management and production organisation techniques (e.g. TQC/M, JIT) and the creation and upgrading of organisations for manufacturing quality control (e.g. the strengthening of metrology-related organisations).

Despite the discontinuity in the institutional framework in the early 1990s, firms like Alpha, Delta, Sigma-A, Sigma-B, Kappa and Theta (forestry) showed resilience by intensifying their efforts on innovation capability building. Firstly, greater attention was given to innovation capability building in pulp and paper making processes and products. Practices had to be changed in order for firms to benefit from the innovations implemented upstream in forestry. For instance, because of the progress they had made in genetic improvements in the upstream forestry segment, the wood that was used in the production process required less chemicals for pulping and bleaching (e.g. wood with reduced content of lignin) and, consequently, less liquid effluents. It is estimated that there is an economic gain of around US$1 million annually from each per cent point of lignin reduction in wood, only in the first phase of the pulp making process, for a mill of 300,000 tonnes per year (de Assis, 2001).

Secondly, pulp and paper firms realised that in order to secure world market competitive positions, they had to respond pro-actively to growing pressures from regulators and society relative to environmental concerns from the early 1990s (see Dalcomuni, 1997). Consequently, intense efforts were taken to accumulate environmental related innovative capabilities in most of the researched firms. By 1992 the firm Alpha had adopted the elementally chlorine-free (ECF) and totally chlorine-free (TCF) processes, at the same time as leading firms in Canada and Scandinavia. However, Alpha went further to create a variant in the TCF process, with a much lower level of absorbable organic halogens (AOX). This process became known as Aracruz chlorine-free (ACF) and was patented in 1997. One year later, the VCF (Votorantim chlorine-free) was implemented in Sigma-A and Sigma-B. About two years later, 10 of the 13 firms researched here had already changed their processes to TCF.

Thirdly, firms concomitantly intensified their efforts on forestry R&D capability accumulation. For instance, new techniques for cloning *Eucalyptus* were developed like mini- and micro-cutting.[21] In the early 1990s the development of micro-cutting technology for *Eucalyptus* contributed significantly to the progress in systems for large scale production of vegetative propagules *ex vitro*. Originally, the system was based on mini-hedges established through rooted mini-cuttings, grown in small containers. The idea of hydroponics, in an operational indoor system based on drip fertigated sand beds, was introduced in Brazil by projects led by researchers like E. Higashi and colleagues. Later, researchers in Aracruz (see Campinhos et al., 2000) used the same concept in a highly efficient intermittent flooding system, where containers of the mini-stumps became immersed in a nutritive solution for fertigation. These systems began to produce annually about 25,000 propagules of *E. grandis* x *E. Urophylla* hybrids compared about 120 propagules m^{-2} for conventional clone banks or hedges.

[21] Compared to stem-cuttings (macro-cuttings), the rooting of micro- or mini-cuttings improves rooting potential, rooting speed, root system quality, and reduces costs. These technologies are very similar in concept and operational procedures. The main difference is in the origin of the initial propagules. Micro-cuttings uses the apices obtained from micro-propagated plantlets, whereas the mini-cutting is based on the rooting of axiliary sprouts from rooted stem-cuttings (see Evans and Turnbull, 2004).

5.3.4. Innovation capability building under the "new industrial policy" of the early 2000s

During the 2000-2007 period, especially from 2003, the Lula administration, sought to re-establish the role of industrial policy in the Brazil's economic development. This was done by the design and implementation in 2004 of the Industrial, Technological and Foreign Trade Policy. However, such "industrial policy" was conceived in a conventional manner: it involved the selection four sectors (micro-electronics, software, pharmaceutical and capital goods) to receive special funding and related support. The problem is that government bureaucrats do not have the adequate knowledge to take *ex-ante* stand on activities to be promoted (Rodrik, 2004). It also contradicted Brazil's large industrial diversification as it overlooked other important sectors.

In 2007 a new industrial policy began to be designed involving 24 industrial sectors with specific goals. For the pulp and paper sector, the goal was to keep the position among the world's five largest producers and increase R&D investments to 2 per cent of sales. However, again, the principle was based on a principal-agent type of policy in which government issues directives to be accomplished by the industry. Again, forestry and pulp and paper industries experienced another type of disruption in the industrial policy process as compared to the previous synergetic relationship.

Even so, leading firms sought to deepen and expand their genomic research capabilities in order to keep up their internationally innovative performance. For instance, from 2001 to 2004 firms Sigma-A, Sigma-B, and Kappa and two other firms jointly undertook the large-scale ForEST research project (Eucalyptus Genome Sequencing Project Consortuim), funded by the State of São Paulo Research Foundation. Drawing on DNA microarrays and bio-informatics, this project identified about 15,000 genes via the sequencing of approximately 100,000 ESTs (expressed sequence tags). It led to the development of a technology that permitted the identification of genes involved in the wood genetic control. This, in turn, led to new improvements on the chemical properties of the pulp and paper making processes of those firms involved in the project.[22]

Another large-scale research project started in 2002, the Genolyptus Project – Brazilian Network of Eucalytus Genome Research. The design of this project somehow resembles the initiative of the 1960s (see Section 5.3.1). From the late 1990s a group of leading Brazilian forestry, pulp and paper firms and biotechnology-related organisations began to design a nationwide network dedicated to an integrated molecular breeding of eucalyptus in Brazil. The initiative involved 13 firms of the forestry and pulp and paper industries (among them Alpha, Kappa, Beta, Gamma, Delta, Theta, Sigma-A and Sigma-B), seven universities and Embrapa. This group managed to obtain funding from the Brazilian Ministry of Science and Technology. One of the novelties of this project is the intensity, refinement and comprehensiveness of efforts on field experiments to generate the structure of phenotypes needed to study the functions of genes.

Additionally, by adopting a multidisciplinary approach, this multiple-knowledge bases project involves researchers from genetics, biochemistry, molecular biology, breeding, statistics, phytopathology, wood technology and industrial process engineers.[23] Based on a pre-competitive design, this project has been advancing the molecular breeding in eucalyptus. It is based on the building a suite of genomic, field and information resources to discover, sequence, map, validate and understand the underlying variation of genes and genomic regions of economic importance in eucalyptus with a focus on wood and disease resistance and its implications for pulp and paper industries in Brazil. By doing this, Brazil became one few countries to undertake cutting-edge eucalyptus genomic research based on a nation-wide biotechnology network.

Within firms, during the 2000s firms gave greater attention to the organisational dimension of capabilities to support innovations not only on forestry biotechnology, but to link this with pulp and paper-making processes at the levels of mills. These involved the reconfigurations of

[22] See also Grattapaglia (2004)
[23] See Grattapaglia (2004)

existing R&D and non-R&D arrangements (e.g. in Alpha, Kappa, Delta, Sigma-A, Sigma B) and the creation of cross-functional, company-wide and inter-disciplinary committees and dedicated teams to tackle innovative projects.

In relation to the re-configuration of R&D activities in the majority of these firms during the 2000s, one researcher described: "During the 1980s and early 1990s our research focus was on wood itself. Now [2000s] our research seeks to find genetic materials that add new value to our pulp and paper products and ensure financial return to the company". During the fieldwork, this research group was carrying out a project based on eight different genetic materials with implications for wood density and innovations in production process phases like pulping, bleaching, and physical-mechanical properties of the bleached pulp. As a result, they would be able to match the features of wood production with the needs of specific paper markets (e.g. printing or tissue).

In 2002 the firms Sigma-A and Sigma-B (of the same conglomerate) reorganised their R&D units into the Centre for Pulp Technological Development to integrate activities that had been working separately: research, quality and technical assistance. Interviews suggested that by combining these different knowledge bases, the company sought to speed up product development projects to improve performance. For instance, in 2005 this unit designed a software, based on a complex set of equations, to calculate the economic value of a clone, allowing the firm to choose the best clone for specific sites. In 2002, the firm Delta re-configured its research centre based on a review of routines and procedures, documentation and analyses processes. Drawing on its biotechnology capabilities, in 2005, this firm co-developed with Sadia,[24] a "water-barrier package" that increased the safety of packed frozen food. From 2003 up to the fieldwork in 2007 Delta up had been ranking as first and second most innovative supplier

[24] This Brazilian firm is a world leading exporter of chilled and frozen food.

of Tetra-Pak worldwide. By 2004, Alpha had obtained nearly 30 patents and by the time of fieldwork, had 17 under analyses and was strengthening its intellectual property system.

5.4 Summary of main findings and discussions

This section summarises the main findings and discussions presented in Sections 5.1 to 5.3.

(1) The nature of the innovation capability accumulation path taken by the case-study firms in Brazil involved a *qualitative departure* from the established technological trajectory then led by firms in Norscan countries. Specifically, the nature of the capability accumulation examined here consisted of firms following different qualitative directions of technological development from those already pursued by the then global industry leaders. Such deepening of innovation capabilities did not signify that the firms moved towards a pre-determined technological frontier. Instead, they opened a new segment (or *qualitative discontinuity*) in the established technological trajectory especially from the upstream forestry area. This form of "catch-up" slightly differs from those examined in previous studies (e.g. Kim, 1997; Hobday, 1995) and mainly from Lim and Lee's (2001) "path-creating" catch-up. In addition, as firms proceeded along this "new trajectory" they had to cross different discontinuities and disruptions originated at the macro-macro-economic level, mainly the abrupt and radical changes in the nature of the industrial policy regime.

The study report here moves beyond common views that suggest a two-told and simplistic distinction between ISI *versus* open and global competition-based based policy regimes. The findings here suggests a more nuanced perspective showing that there was much going in these two broad policy contexts, as represented in Figure 5.

Figure 5. Relationship between firms' capability accumulation paths and industrial policy contexts.[25]

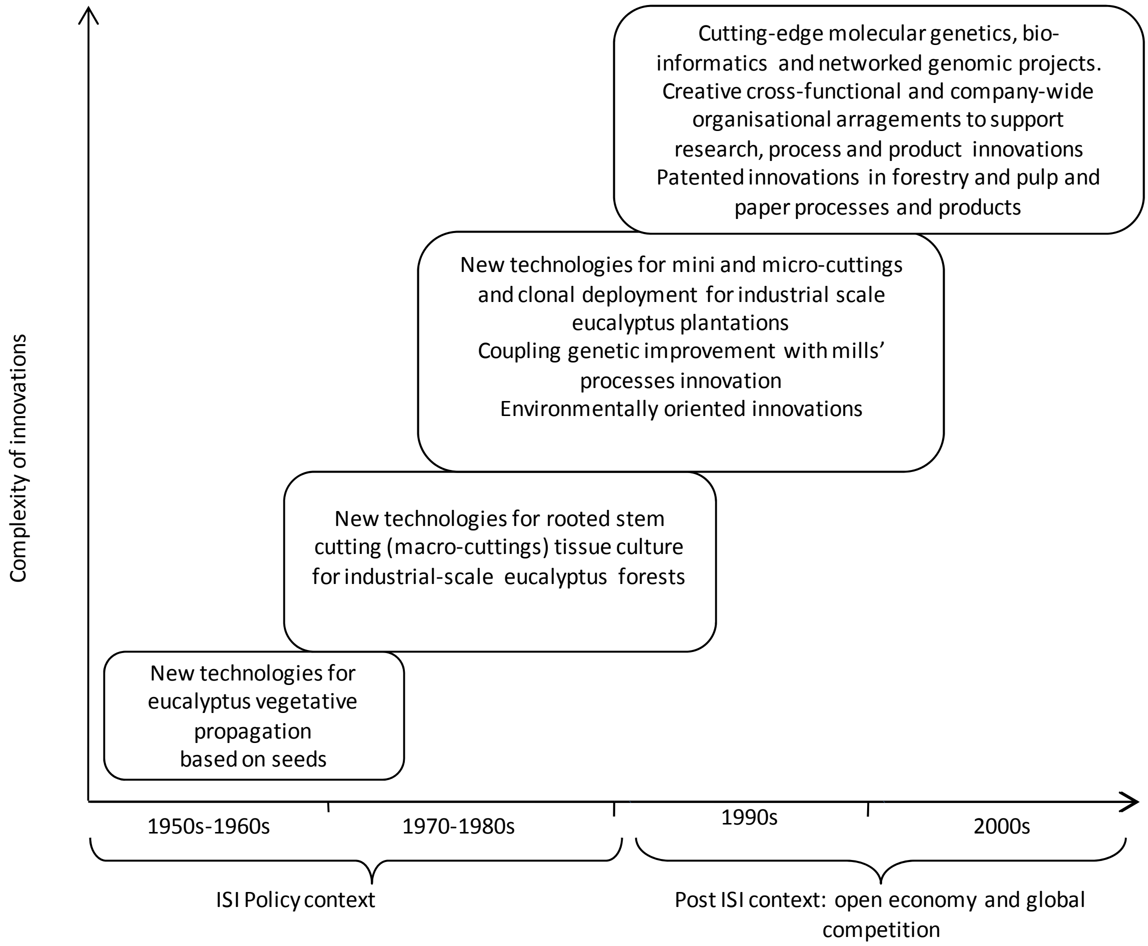
Innovation capability levels	ISI policy context (1950s-1980s)			Post-ISI policy context : open economy and global competition (1990s-2000s)		
	Plus nothing else	Plus firms' 'pro-active' innovation capability building strategies and entrepr. mgt	Plus other government-originated direct influences on firms followed by firms' responses	Plus nothing else	Plus firms' innovation capability building Strategies and entrep. mgt	Plus other government-originated direct influences on firms followed by firms' responses
Innovation frontier						Alpha Delta Kappa Theta (forestry)
Advanced innovation		Alpha Delta Kappa		Gamma Zeta-B Lambda		
Intermediate innovation		Theta (pulp) Iota Beta Gama Lambda Zeta-B Epsilon		Iota Theta (paper) Beta		
Basic innovation		Theta (paper) Zeta-A				

Source: Derived from the empirical study.

The new direction in capability accumulation – along the eucalyptus-based technological trajectory – was reflected in the firms' innovative performance, that is, the different kinds of innovation implemented by some of the firms in terms of new technologies, new processes and products, starting in the upstream forestry segment and moving, cumulatively and additively, into the pulp and paper areas, across different policy regimes, as represented in Figure 6.

[25] I am indebted to Martin Bell for suggesting the presentation of this finding in this manner.

Figure 6. Evolution of the focal case-studies' successful innovative performance

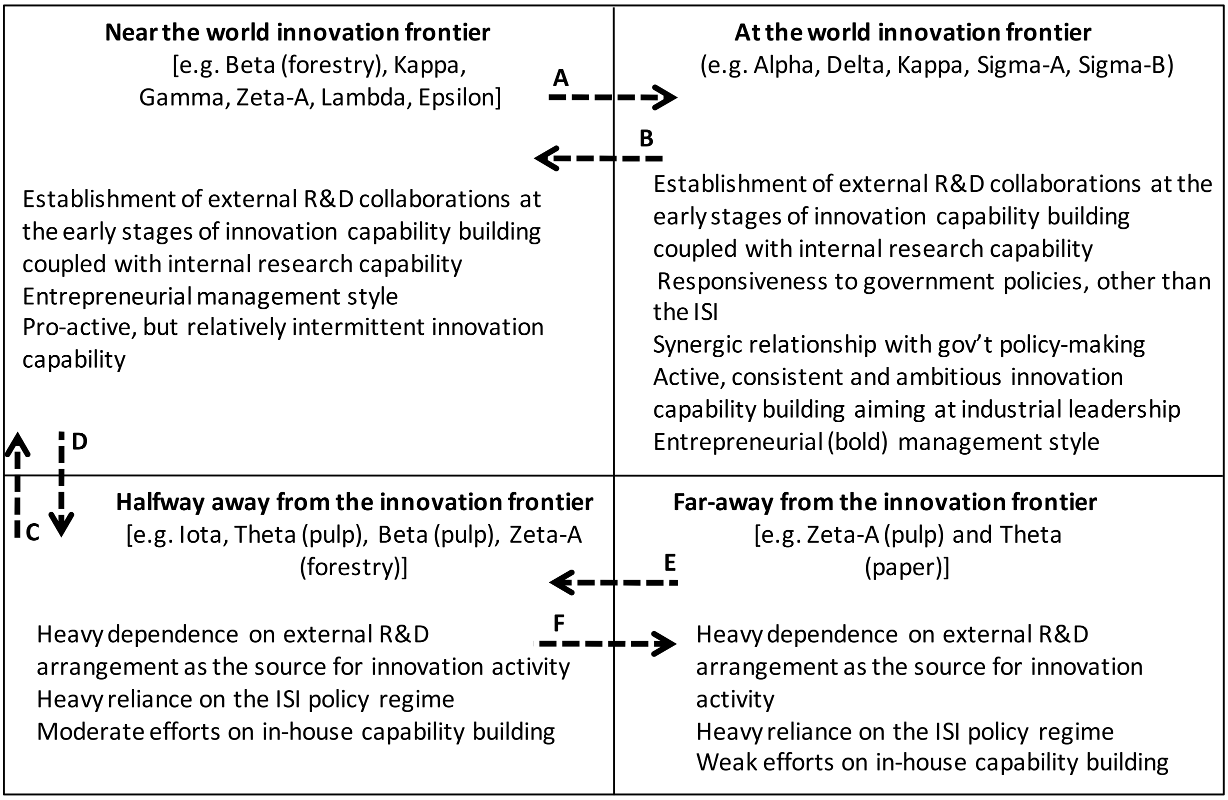


Source: Derived from the empirical study.

At least from the standpoint of these industries and firms examined here, the findings here do not support the view that the ISI policy context constrained the depth of innovative capability building at the "intermediate" (incremental) level of innovation thus setting up a long-lasting discontinuity in the deepening of innovation capability in Brazil. Indeed, the end of the ISI policy regime may have been destructive for some sectors in Brazil (e.g. automotive, micro-electronics) thus imposing a discontinuity on the accumulation of innovative capability during the main phases of the ISI context, as argued in Reinhardt and Peres (2000), Ocampo (2001) and Cimoli and Katz (2003). However, at least within the context of this study, these sectors and, especially, some of the researched firms have been able to deepen and sustain their innovation capability accumulation process – along the new segment they had opened in the established technological trajectory – across discontinuous (even disruptive) macro-economic and industrial policy contexts. Such firms were able to move close to the new innovation frontier or even becoming world leading innovators. Consequently, the findings here dismiss the "inherent discontinuity" thesis (e.g. Viotti).

(2) However, as shown in Sections 5.1 to 5.3, the process by which firms proceeded along the new direction of innovation capability accumulation was far from linear, smooth or wholly successful, but marked by a high degree of *variability* in the "depths" and speed of firms' innovation capability accumulation. The path-ways (or "catch-up" paths) opened up and followed by the focal cases can be organised around four categories as shown in Figure 7.

Figure 7. Types of capability accumulation paths in the focal case studies



Source: Derived from the empirical study.

Firms that relied solely in the ISI policy regime and on external sources of R&D from the late 1950s to the early 1980s, despite having an entrepreneurial management, were not able to cross the macro-level discontinuities of 1980s (macro-economic) and the early 1990s (structural reforms) with sustained innovative performance. However, those that responded pro-actively to government policies other than the ISI and engaged in systematic building and strengthening of increasingly internal innovation capability accumulation, as they interacted with external R&D arrangements (in line with Mowery, 1983; Cohen and Levinthal, 1990; Bell, 1993; Bell and Pavitt, 1993) and were led in a entrepreneurial manner, exhibited sustained innovative performance across disrupted and discontinuous macro-level contexts.

(3) Indeed, the policy making process (especially from the 1950s to the 1980s) was marked by a synergetic interaction between the policy-making process, meso-level industry organisations and firms aiming at technological development in Brazil's forestry and pulp and paper sectors. This finding gives support to Evans (1995) and Rodrik (2004, 2006) about industrial policy as a *process* whereby the state and the industry – not necessarily thoroughly formal – take joint efforts to achieve, in this case, industrial innovation.[26] Also in line with Rodrik (2004, 2006) this finding suggests that "good institutions" play a crucial role helping firms to overcome the various hurdles related to the accumulation of innovation capability.

(4) It should be remembered that, obviously, the accumulation (or non-accumulation) of innovation capability at levels near and/or at the international innovation frontier did not happen incidentally. These were somehow associated with the invisible dimension of capabilities, namely firms' norms and values materialised in their management style (see Leonard-Barton, 1995, Kim, 1997, 1998). The efforts, the risks taken and, mainly the perseverance to overcome constraints (e.g. resources scarcity) and hurdles, and the investments involved were certainly associated with an entrepreneurial management style and audacious leadership in some successful innovators (e.g. Alpha, Delta, Kappa, Sigma-A, Sigma-B), but less intense or even absent in less successful innovators (e.g. Iota, Beta, Zeta-A).

[26] Indeed, a study focused on policy support for technological development in the electronics industry in Korea, India and Brazil, Evans (1995) showed that, differently from Korea, India and Brazil did not achieve a "public-private synergy". However, in the forestry and pulp and paper sectors studied here such symbiotic relationship was attained.

(5) This combination of features were associated with a rapid accumulation of advanced to world leading innovation capability levels and the achievement of highly innovative performance in young (and faster innovators) firms like Alpha, Sigma-A and Sigma-B (14 to 25 years) – see Section 5.2. They also were associated with the acceleration of the catch-up process and the achievement of international level of innovative performance in older firms like Delta and Kappa (slower innovators), although these firms had an entrepreneurial management style. There are cases that started with this combination of features during the 1950s, but reached the 2000s with relatively a poor innovative performance (e.g. Epsilon). Other firms were led by an entrepreneur management, but missed a systematic innovation capability building strategy (e.g. Zeta-A and Zeta-B). The firm Theta, nevertheless, gave emphases to high-level innovation (research-based) capability accumulation in the forestry segment, but, *purposefully*, opted for taking lesser efforts on the pulp segment especially, paper.

(6) Yet, there are two caveats for the Brazilian cases. First, the nature of the policy process from the 1990s and 2000s does not seem to be synchronised with the demands of the Brazilian forestry and pulp and paper industries. Second, we do not know whether and to what extent innovative firms like Alpha, Delpa, Kappa will continue to invest in R&D programmes to sustain, deepen and renew their research-based innovation capabilities. This is crucial to keep their leading position at the innovation frontier together with other competitors of other countries (e.g. Chile, South Africa, Indonesia). Thus, the sustainability of such leading innovation positions will depend on firms' innovation strategies, options, as well as the efficacy of the industrial policy making process in Brazil. Otherwise, Brazil's leading position could be outperformed by other natural resource-rich countries such as Chile, African countries, Indonesia or Russia. Also endowed with similar natural resources, they may engage in fierce capability building process aiming at international leadership. Thus one challenge is whether and how firms that are near the frontier will move into more innovative levels of capability (arrows A, C and F in Figure 7). At the same time, it is crucial to avoid the risk of weakening existing innovation

capability levels already achieved by firms. This is a concrete fact to be faced up as innovation capability may take time to be accumulated, but may deteriorate rapidly in the absence of proper inputs (arrows B, D and E in Figure 7).

(7) Finally, the findings here provide support to the arguments in Perez (2008) that the accumulation of highly innovative capabilities in natural resources based industries may lead to industrial leadership in context like Latin America. The successful catch-up experience of some of the Brazilian firms studied here shows that despite the natural resources endowment, however, the process of achievement of leading international innovative performance involves long-term, consistent and deliberate efforts on innovation capability. These efforts include both macro-level (industrial policy) and micro-level. The absence or malfunction of these kind of efforts, like in other industry, may simply obstruct the catch-up process as in the case the laggard firms in this study and also other countries endowed with the same kind of natural resources like Indonesia (see Bell and van Dijk, 2003; van Dijk and Bell, 2007).

6. Conclusions

This paper sought to examine a kind of “path-creating” innovation capability accumulation path in natural resource-processing industries, namely by drawing on multiple-case evidence from 13 firms from the forestry, pulp and paper industries in Brazil (1950-2007) gathered during a three-year fieldwork. This involved a qualitative discontinuity in an established technological trajectory at the early stage of firms’ innovation capability development. The paper went further to tackle the implications of firms’ capability building processes for innovative performance across discontinuous macro-level policies.

By tackling some neglected issues in existing related studies, this paper has moved step further in relation to prevailing approaches to latecomer firms’ technological “catch-up”. These have largely been based on a kind of micro- and macro cumulative continuity in capability building along technology-following trajectories across relatively continuous policy regimes and centred on assembled-products kinds of industry. The findings shed light on the role of firms' innovation strategies and government policy in achieving international technological leadership in natural resource-processing industries from latecomer natural resource-endowed countries.

Finally, from a methodological perspective, this study shows how the application of a comprehensive and qualitatively-generated measurement of innovation capability building, beyond conventional approaches based on available data derived from patent statistics or R&D expenditures, can capture the nuances and reveal relevant features of the real dynamics of the process of technological development in developing and emerging economies contexts. However, one of the main limitations of this study is that it was not possible to know how and the extent to which *learning processes* influenced the nature and speeds of the focal cases' innovation capability accumulation paths. Neither did the paper tackle the micro- and meso-levels impacts of the firms' innovation capability paths. Future research could address such issues.

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Appendix Table 1. Levels of Latecomer Firms' Innovative Capability: An Integrated (and Compacted) Framework

LEVELS OF CAPABILITY	*ILLUSTRATIVE EXAMPLES*
World leading (Innovation frontier)	Development of models using eco-physiological variables. Clone evaluation, selection and enhancement for seedlings production (forest genetics). Development of projects and programs for species and soil conditions improvement and biotechnology applications. Strategic management system by performance metric with IT support (process simulation, SAP, supervision system). Intellectual property system. Development of new production processes or phases of processes (e.g. bleaching, ash leaching) based on R&D and engineering. Generation and application of mathematical models that support the activities of maintenance. Development of alternative pulps to customized papermaker on the basis de R&D, (integration forest to paper production) working with partnership, university, etc.
Advanced	Development of alternative processes and resources for clonal seedling production and biological diversity protection related to forest ecosystem. Development of processes and resources for evaluation and management of operation impact on soil properties. Project development of impact monitoring and evaluation for forest operation. Development and improvement of mechanical equipments working in partnership with capital goods and engineer and systems firms. Simultaneous support to important customer that have a different product features segment. Project management for new products and process creation and new equipment implementation in partnership with customer, suppliers and R&D organization.
Intermediate	Development of resources for forest installation, attendance and recovering and alternative processes and resources for disease and pests control. Project and recovering of degraded permanently protected areas. Improvement of the product characteristics and standardization by continues introductions of process automation systems. Introduction and improvement of bleaching pulp processes with elemental chlorine free characteristics. Elaboration of technical and management recommendations to adapt the process to the new product characteristic, implementing controls systems that minimize problems in the pulp and paper production.
Basic	Seedling quality and features evaluation. Monitoring and execution of soil and hydro resources preservation processes. Planning and maintenance of road, railroad and waterway infrastructure. Treatment and control of effluents in forest production areas. Implementation the general process of chain of custody certification (eg. FSC) guaranteed that the process use usual woods according to sustainable development. Identification, planning and control of equipment change following preventive maintenance requirement made by specialized firms (e.g. equipment supplier). Improvement of the product characteristics and standardization by little introduction of process automation systems. Pulp production for special or customized features paper production (eg. special pulp).

Source: Compacted form adapted from Bell and Figueiredo (2008). The original frameworks applied during fieldwork and data analysis involved three tailored matrixes for forestry, pulp and paper. Each of them identified levels of capabilities for specific functions (e.g. forestry: sivilcuture, harvesting, logistics, environmental and social forest management; pulp and paper: project management, processes and production organisation, process equipment, and product centred. The adaptation process of each of the three frameworks took approximately six months as it involves several consultations with industry experts and companies' specialists. Qualitative data obtained from the application of these frameworks was transformed into quantitative observations in order to allow the speed of capability accumulation to be calculated.