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Abstract

This paper builds on influential studies of technological catch-up (e.g. Lim and Lee, 2001) to examine a slightly different kind of “path-creating” capability accumulation trajectory in latecomer natural resource-processing industries across discontinuous policy regimes. Drawing on multiple-case evidence from 13 forestry, pulp and paper firms in Brazil (1950-2007) the study 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) Firms’ paths along the new technological segment involved a high degree of variability (from world-leaders to laggards) in terms of levels and speeds of innovative capability accumulation; (3) Firms that attained progressively higher levels of innovative performance more rapidly, across discontinuous policy regimes, engaged pro-actively in internal creative capability building efforts, as they developed bottom-up synergetic relationships with government policies, other than protectionism. The paper suggests that in-house innovative capability accumulation efforts affect the extent to which latecomer firms overcome hurdles and cross policy discontinuities as they pursue significantly new directions in the international technological frontier. Thus firm-centred innovative capability building should be a key policy target.

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

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; Mathews and Cho, 1989; Hobday, 1995; Kim, 1997; Mathews, 1997). 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 electronics products and unique market positions. The evolution from technology-following into technology-creating for a new generation of mobile systems in China was examined in Yu (2007).

Such kind of studies are consistent with frameworks that have been elaborated 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 thus saving time and *path-creating* catch-up, when:

> … latecomer firms explore their own path of technological development. This kind of catching-up 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 in related studies over the past few years.

First, in most of the studies the catch-up process has been studied on the basis of a *long-term continuity* at both micro and macro-levels. As far as micro-level continuity is concerned, most studies tackle firms' capability accumulation on the basis of (successful) technology-following trajectories. There are also cases in which firms change *later* into path-creating trajectories. However, the issue of discontinuity, either in terms of departing early from existing trajectories or in relation to the truncation of the capability accumulation process has received less attention. There have been, however, some initiatives in that direction. For instance, Dutrénit (2000) explored elements of *truncation* in catch-up associated with the firm's limited innovation strategy. In Viotti (2002) 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.

As far as macro-level continuity is concerned, most catch-up processes, especially in the Asian contexts, have been examined under relatively *continuous* policy contexts. For instance, despite the Asian crisis in 1997-1998 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 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 across discontinuous policy contexts [e.g. the abrupt and structural changes from the import substitution industrialisation (ISI) policy into the open economy and global competition regime in Latin America].

Second, various catch-up studies from the 1980s have shown awareness relative to time for catching-up. For instance, Dahlman et al. (1987) have pointed out that considerable "time" is involved in moving through different innovation capability stages, while Perez and Soete (1988) indicate that catch-up also involves running in new directions. It has also been argued 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 empirical studies of latecomer firms' capability building, especially from the 1980s, 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.

Third, the great majority of the catch-up studies, especially those from the Asian contexts, has examined firms and industries based on assembled and discrete products. The catch-up paths normally involve a progress from assembly, low-part development, high-tech development and, finally, concept design capability for products (see Lim and Lee, 2001). This is understandable as these sectors have been the main drivers of industrial growth in East Asian countries. And over the past decades, most of the academic studies and policy analyses related to industrial development in emerging economies have focused on the role of "high-technology" industries and "high-tech content" of exports in achieving economic progress (e.g. Lall, 2000; Lall et al., 2004). But since East Asia had an abundance of labour and poor natural resources, the specialization in manufactures was a natural choice, although this factor endowment alone was obviously not sufficient to achieve industrial leadership (Rodrik, 2006). But, what about the dynamics of the catch-up paths of firms in natural resources-rich contexts like Latin America? There is scanty systematic firm-level scrutiny in that direction.

As argued in Cimoli and Katz (2003), following the structural reforms of the 1990s in Latin America, natural resource-processing industries (e.g. forestry, 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.[1] As pointed out in Perez (2008) and ECLAC (2008) an intelligent combination between natural resources and innovation capability building is viewed as a new "window of opportunity" for Latin America to improve its competitive position in relation to East Asia. Yet, there is scanty empirical analysis of the nature and extent of firm-level innovation capability building paths across different policy regimes in the region in these industries in Latin America.[2]

Previous research has indicated that Brazil's forestry, pulp and paper industries offer a rich empirical setting to examine innovation capability building paths. 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

[1] 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.
[2] It is not the purpose of the paper to engage in the debate based on ISI *versus* open economy policy regimes in terms of impacts on industrial capability accumulation.

into bleaching technologies for pulp production processes and research linked to upstream forestry activities. There is plenty of industry-level evidence indicating that Brazil has sustained a leading competitive performance in the world market for pulp and paper derived from eucalyptus forestry or “bleached eucapulp” with 58 percent of world market-share (see, for instance, Evans et al., 2004; FAO/PPI, 2007; Bracelpa, 2008).

However, there are scarce studies about the extent and the speed at which the innovative capabilities underpinning the competitive performance of firms from the forestry, pulp and paper industries in Brazil have been accumulated, especially if we consider that: (i) these industries have traditionally been dominated by global leading firms from North American and Scandinavian (Norscan) countries; (ii) these industries in Brazil started up during the 1950s and evolved across discontinuous policy regimes and disrupted macro-economic conditions. The latecomer literature has not properly explored how latecomer firms overcome (or fail to overcome these kinds of hurdles), especially in the context of natural resource-processing industries.

Brazil thus seems to offer an interesting setting to investigate the real nature of the catch-up process and whether and the extent to which it was related to innovation capability accumulation. In a different context, for instance, Bell and van Dijk (2003) and van Dijk and Bell (2007) found in the Indonesian pulp and paper industries 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. 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.

This paper seeks to extend previous research on firm-level catch-up by exploring some of the neglected issues referred to above. The setting is the large-scale forestry and pulp and paper industries in Brazil from 1950 to 2007. Thus this paper is driven by this central question: *What kind of capability accumulation path have the main firms from Brazil's forestry, pulp and paper industries taken to achieve worl-leading innovative performance even across discontinuous policy regimes?*

The results reported here, derived from multiple-case studies, suggest that firms from the forestry, pulp and paper industries in Brazil engaged in a kind of "path-creating" innovation capability accumulation trajectory. They began to drive away from the existing technological trajectory at 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 the 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]

Specifically, 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, the Brazilian 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 across *discontinuous* policy regimes. Such capability accumulation process is slightly different from Lim and Lee's (2001) *path-creating catch-up mode*. The paper explores the manner in which the case-study firms in Brazil have carved and

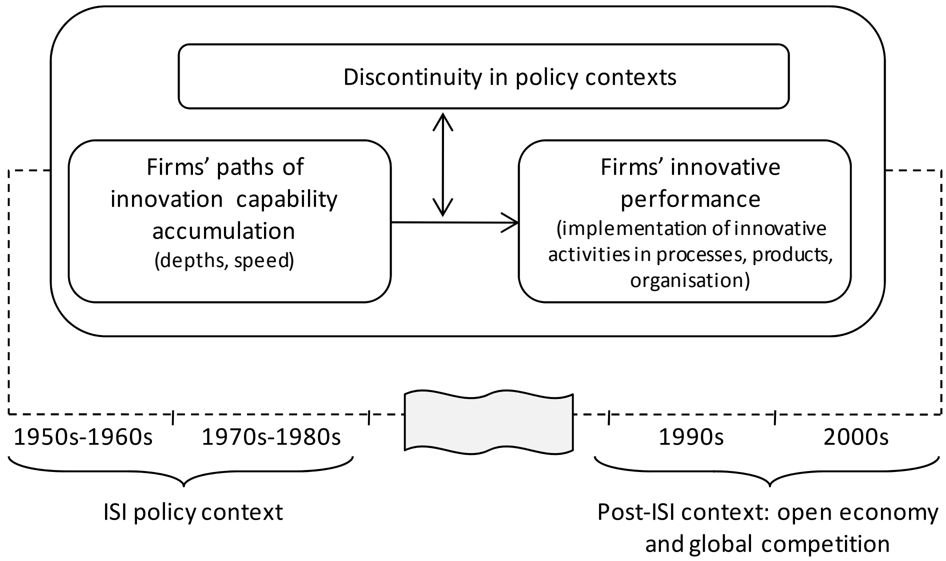
[3] I thank Richard Nelson for commenting on this findings and advising me to bring it to the front of the paper.

sustained (or failed to sustain) such innovation capability building path. 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' "path-creating" innovation capability building paths (technological "catch-up") and its implications for innovative performance across different industrial policy contexts, as represented in Figure 1. This section provides the analytical basis to examine this set of relationships.

Figure 1. The paper's analytical framework



2.1 Capability building paths, innovative performance and catch-up

Firms' capabilities involve a stock of resources that permit them to undertake *production* and *differing degrees* of innovation activities Capabilities involve dimensions like: "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, including 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 (see Bell and Pavitt, 1993; Leonard-Barton, 1995; Kim, 1997, 1998; Dutrénit, 2000; Teece, 2007).

Following Bell and Pavitt (1993, 1995), this paper distinguishes between *production-based* and *innovation* capabilities. The paper focuses on the accumulation of the latter, as the concern here is with "path-creation" innovation capability accumulation. It refers to change-generating resources to create, change or improve products, processes and production organization.

The manner and 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 paper adopts a view of innovation that involves increasing *degrees* of novelty and complexity in terms of processes, products and organisation thus in line with the Oslo Manual (OECD, 2005). This approach is most relevant to latecomer firms. In line with such perspective, the innovation process also includes "new combinations" of knowledge to develop, for instance, new sources of raw materials (Schumpeter, 1934; Kline and Rosenberg, 1986).

The notion of 'catch-up' 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". Therefore, this paper is concerned with *technological* and not economic catch-up. 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). Thus 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".

As far as the measurement of capabilities is concerned, traditional innovation indicators based solely on R&D expenditures and personnel and patenting statistics are not suitable to capture latecomer firms' paths of innovative capability (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 (see Lall, 1992; Bell and Pavitt, 1995). It identifies "levels" of innovative capabilities running from "basic" to "world leading" and consistent with the Oslo Manual (see condensed version of the framework in Appendix Table). Such kind of typology has been used successfully in empirical studies, with slight 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 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*.

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). Such approach is particularly relevant when latecomer firms engage in "path-creating" innovation capability accumulation at the early stage of their capability development process, examined here.

2.2 Technological catch-up and changes in industrial policy contexts

Numerous studies point to the role of government policy in influencing the capability building process at the level of firms and industries (Lall, 1987, 1992; 2006; 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).

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. One hundred percent of all pulp and paper produced in Brazil derives from planted forests. 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 will be 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). *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 the downstream pulp and paper-making processes (de Assis, 2001). In order to understand how Brazil have been to compete successfully against global leaders from Norscan countries, one has to investigate the innovation capability building process in the upstream forestry segment that began in the 1950s as shown later 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 involving 13 firms from the forestry, pulp and paper industries in Brazil. 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). Specifically, the study is centred on particular segments (focal cases) inside these firms: seven cases in forestry, nine in pulp, and 11 in paper (see Table 2). Thus the study sought to draw on an embedded design (Eisenhardt and Graebner, 2007) by combining studies *across* the 13 firms and *within* them.

Table 2. The selected multiple cases

Thirteen selected firms	Start-up year	Ownership	Focal cases		
			Forestry [7]	Pulp [9]	Paper [11]
1. Delta	1945	Brazilian	✓	✓	✓
2. Theta	1974	Foreigner	✓	✓	✓
3. Kappa	1941	Brazilian	✓	✓	✓
4. Zeta-A	1954 (1990)	Brazilian	✓	✓	✓
5. Sigma-A	1988	Brazilian	✓	✓	✓
6. Alpha	1978	Brazilian	✓	✓	None
7. Beta	1975	Foreigner	✓	✓	None
8.Gama	1960 (1990)	Foreigner	None	✓	✓
9. Sigma-B [(b)]	1988	Brazilian	None	✓	✓
10. Epsilon	1980 (1990)	Brazilian	None	None	✓
11. Zeta-B	1985	Brazilian	None	None	✓
12. Iota	1978	Brazilian	None	None	✓
13. Lambda	1966	Brazilian	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 implementation of this study sought to draw on protocols 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. The tools for data-gathering involved a combination between (i) a matrix of types and levels of capabilities (see Appendix Table), (ii) a structured interview guide, and (iii) a detailed enquiry form. Data collection during pilot and main field work involved 155 formal interviews (from one to three hours), 44 informal interviews, 19 direct observations, and 27 consultations to firms' archival records.

Interviews were conducted with professionals from different organisational levels (e.g. top and intermediate management, supporting units like R&D, human resources, engineering departments, labs, shop-floor and forestry sites). 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. Double-checks of specific events were made via e-mail and/or phone calls. Following the main fieldwork, 259 follow-up questionnaires were sent out to targeted respondents. As they already knew the project and me, a 95 response rate was achieved. At industry-related organisations there were 11 formal interviews and 15 archival consultations.

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 policy regimes (Miles and Huberman, 1984). Evidence from the cases' innovative activities over time was matched against the capability framework (Appendix Table). Qualitative evidence of cases' capabilities was transformed into quantitative evidence to examine speed at which each case accumulated innovative capabilities over time and across different policy regimes (as shown in Sections 5.1 and 5.2).

Rather than reducing all qualitative data to quantitative observations, both types of evidence were combined to enrich the empirical analysis. The qualitative evidence 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

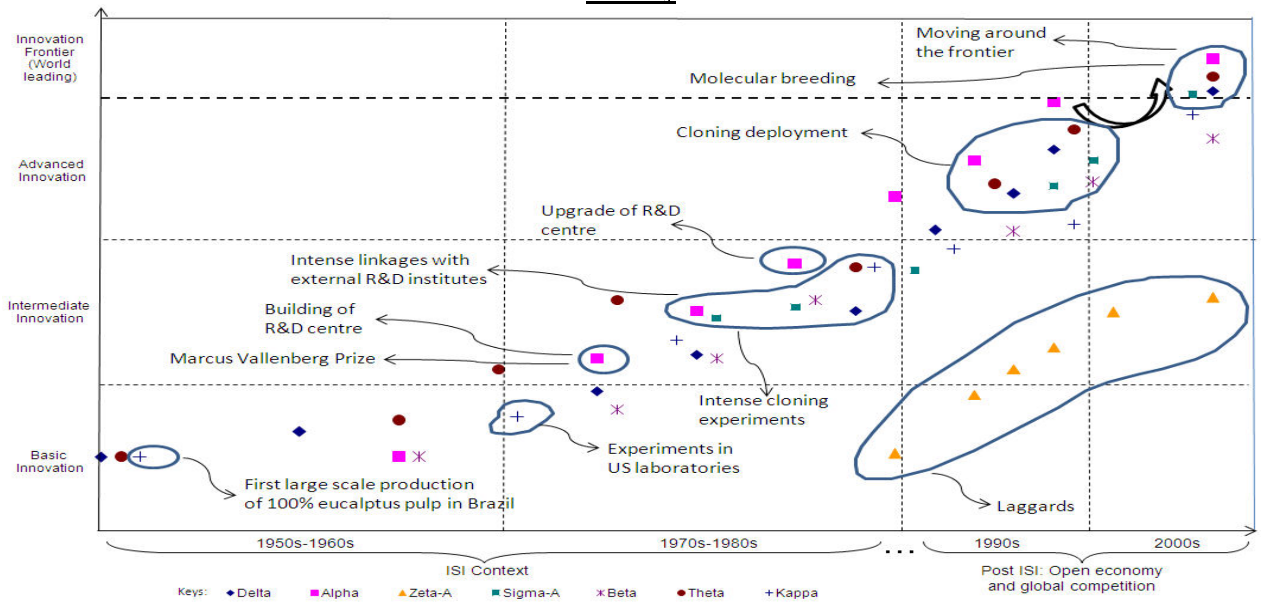
In the light of the framework in Section 2, this section presents the main empirical findings and discussions. Sections 5.1 and 5.2 scrutinise, respectively, evidence related to the shape and speed of capability accumulation paths in the case-study firms over the 1950-2007 period. Section 5.3 draws on qualitative evidence to examine the evolution of the firms' "path creating" capability building path across different policy regimes. Section 5.4 contains a summary of key findings discussions.

5.1 Shape and speed of the focal cases' innovation capability accumulation paths

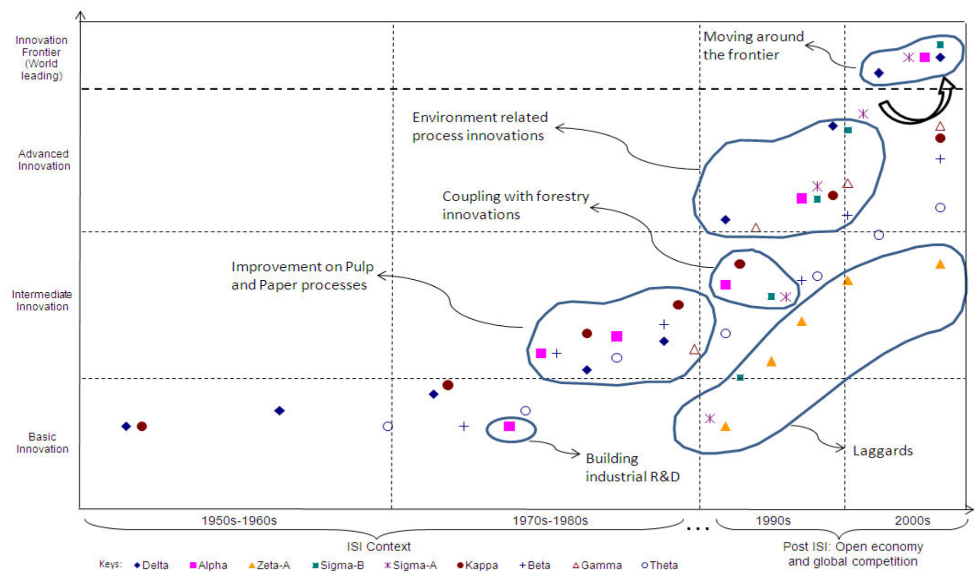
Figure 2 represents the paths of innovation capability accumulation along the new technological segment that was opened up in the existing trajectory. However, the paths followed by firms were far from wholly smooth, but marked by a high degree of variability: from world-leading and advanced innovators to laggards. This had varied implications for their innovative performance over time.

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

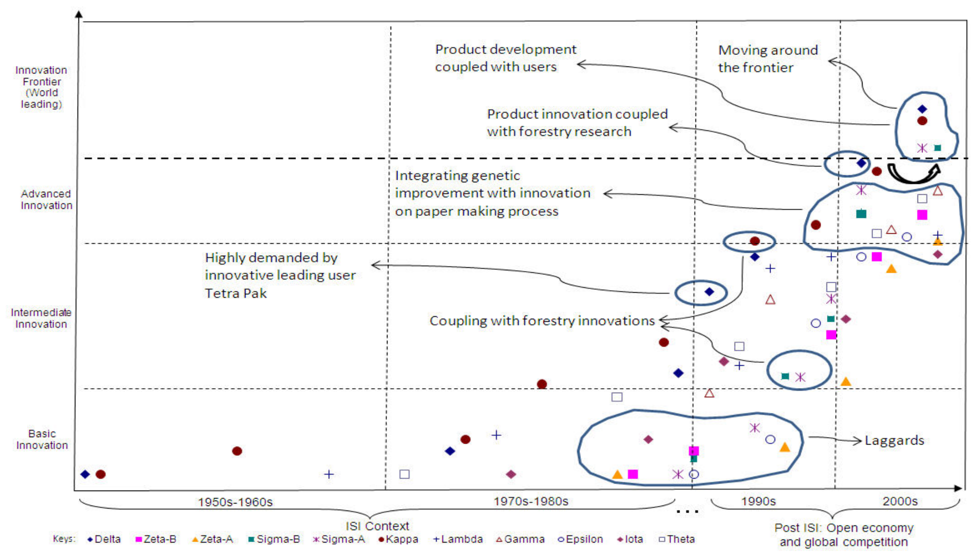
Paths of the forestry case-studies



Paths of the pulp case-studies



Paths of the paper case-studies



Source: Derived from the empirical study.

Evidence from Figure 2 suggests that six of the seven forestry cases (86 percent) reached advanced innovation capability level (Alpha, Theta, Sigma-A, Delta, Beta and Theta), of which four firms, Alpha, Theta, Sigma-A and Delta attained the world leading innovation level. Six of the nine pulp cases (67 percent) accumulated advanced innovation capability (Alpha, Delta, Sigma-A, Sigma-B, Gamma, and Kappa), of which four cases (Alpha, Delta, Sigma-A and Sigma-B) attained world leading innovation capability level. Of the 11 paper cases, seven moved into the accumulation of advanced innovation capability (Delta, Kappa, Sigma-A, Sigma-B, Gamma, Zeta-B, and Theta). Of these, only four cases (Delta, Kappa, Sigma-A, Sigma-B) achieved world leading capability levels.

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*. This somehow resembles what Feng and Ling (2007) found in a different kind of industry, as referred to earlier in Section 1. Additionally, while Sigma-A, Sigma-B, and Delta reached world leading capability levels in forestry, pulp and paper, Theta's path was highly variable: frontier in forestry, halfway from the frontier in pulp and laggard in paper. As suggested by fieldwork evidence, this is more related to Theta's *strategic option* to emphasise innovation in the forestry business, than to a failure to build up innovative capability in pulp and, especially, in paper.

However, other cases reflect inconsistencies and discontinuities *across* and *within* firms in the capability building paths. For instance, forestry and pulp-making firms like Alpha and Beta started up almost at the same time and began their innovation capability building efforts early in their lives. However, while Alpha attained world-leading innovation capability levels in forestry and pulp, Beta's capabilities only reached the world-leading level for forestry, but stayed halfway from it in pulp.

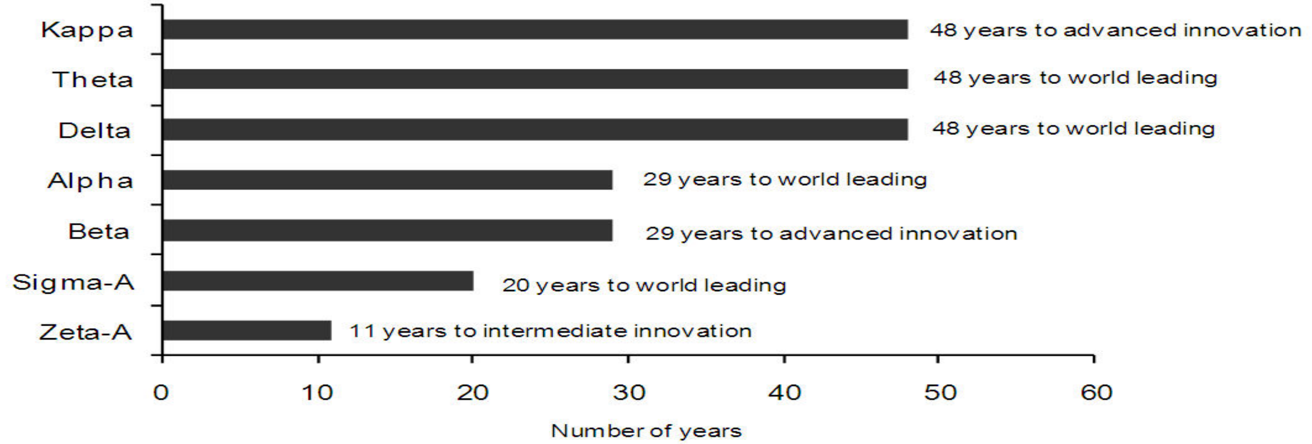
Other firms' paths reflect "breaks" in innovation capability accumulation in association with discontinuity in policy regimes. For instance, the large paper-maker Epsilon started up under an entrepreneurial and innovative management style in the early 1900s. In 1925 this firm implemented the production 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 production of high-performance tissue paper from eucalyptus and as early as 1950 it engaged in pioneer research to obtain improved bleached pulp from eucalyptus. But 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. Such evidence seems to illustrate situations in which firms could not stand up to the macro-level imposed discontinuity in the policy regime thus interrupting their innovation efforts. Fieldwork evidence suggests that Epsilon's case also seems to have involved micro-level inconsistencies in innovation strategies, thus in line with Dutrénit's (2000) truncation perspective, and weakened entrepreneurial values thus in line with Leonard-Barton's (1995) flip side of innovation capability.

5.2 Speeds of innovation capability accumulation in the focal cases

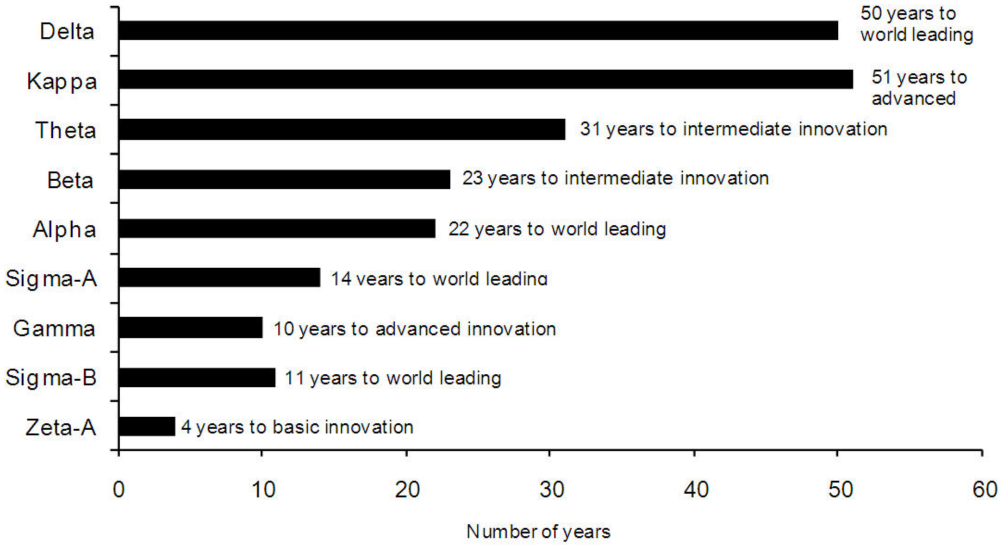
Drawing on previous research (Ariffin, 2000; Figueiredo, 2003), the rate (or speed) of capability development is defined here as the time (number of years) a firm took to reach a specific capability level. Although innovation capability building is a slow process (Bell, 2006), the evidence here indicates that the process of capability accumulation at advanced to world leading levels involved highly varied time-scales (see Figure 3): 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.

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

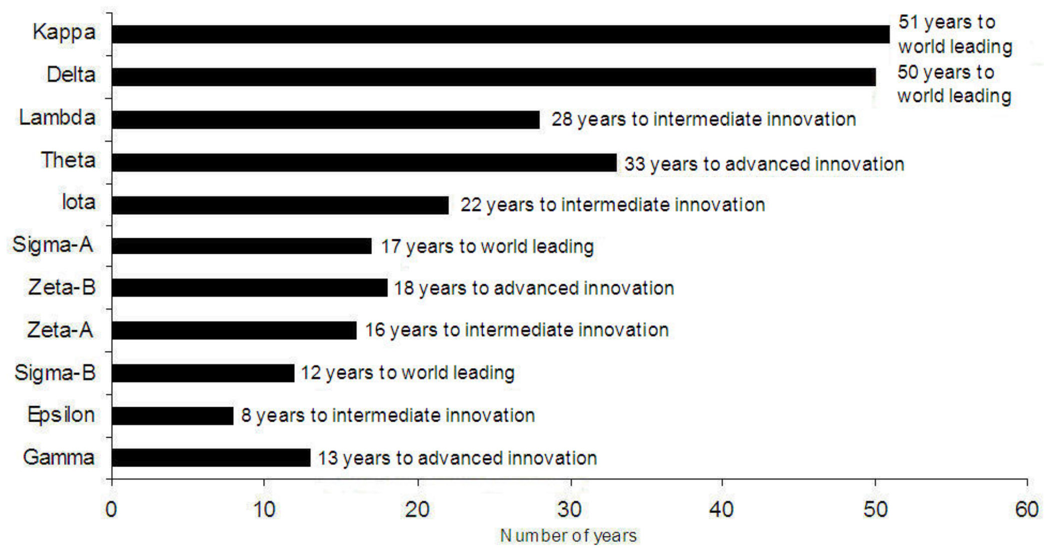
Forestry cases



Pulp cases



Paper cases



Source: Derived from the empirical study.

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 ($p<0.05$). Additionally, firms aged between 31 and 50 took 19 years less than firms aged above 50 to move from basic innovation capability level into advanced capability ($p<0.05$). However, there were exceptions. Alpha is 10 years older than Sigma-A. 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, but 96 percent of Sigma-A's.

There also was high degree of variability *across* the forestry, pulp and paper segments of specific firms. 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 years 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, but 13 to 15 in pulp and 14 to 19 in paper. As it will be shown in Section 5.3 it seems that Alpha's and Sigma's efforts on research-based innovation capability building in forestry (upstream), early in their lives, seems to have contributed to accelerating their innovation capability building in pulp (downstream) in subsequent stages of their lives. 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 the pulp and paper segments. 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 the "path-creating" innovation capability paths across policy contexts

This section draws on qualitative evidence to scrutinise the evolution of the case-study firms' capability accumulation and innovative performance across four different stages of policy regimes: 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.

Some background related to the 1920s-1940s period in Brazil seems useful at this stage. 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 campaign for Brazil's self-sufficiency in pulp. This instigated the Getulio Vargas' government (1930-45) to implement measures that marked the beginning of protectionism and the ISI policy. These events also triggered individual entrepreneurs' and firms' initiatives to search for new raw materials.

From 1940, as eucalyptus became cheaper, because locomotives were converting into diesel, its potential use as raw material for pulp and paper began to receive more attention. For instance, 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 paper made out of eucalyptus would not resist the pressure of rollers in paper machines and newspapers printers. Drawing on these findings firms like Epsilon in 1946 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 began to organise to innovate.

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

This period was marked by the Brazilian government's and firms' efforts on the building of the 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. These also involved the building of government-led research facilities and research-funding arrangements that were crucial to complement firms' innovation capability building efforts. 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 research-based innovation 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 are in line with the conditions for interdependencies in firms' capability building efforts (see Mowery, 1983; Bell, 1993; Bell and Pavitt, 1993).

From the mid 1960s, the National Bank for Economic and Social Development (BNDES)[4] 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 (Federal

[4] 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.

Law 5106, 1966). The Brazilian Institute for Forestry Development (known as IBDF) was created in 1967 and implemented such policy until 1987.

Such policy influenced firms' 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.

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 the 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 Kappa began to manufacture the new product. Despite these and other efforts taken by firms, there were very little capabilities in Brazil 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). 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. 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 state-level government.

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 generated the guidelines for a research programme on forestry improvement. In December of 1967, a meeting 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, which was 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. This, in turn, built on Fepasa's previous research to engage in its own vegetative propagation programme based on seeds of *Eucalyptus sp* and *E. urophylla.* In that same year, concerned with the genetic and physiologic quality of 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 the firm Alpha from the initiative of 12 entrepreneurs, represented a decisive thrust for the commercial success of the eucalyptus-based technological trajectory. Alpha began its Eucalyptus plantation programme in the South-eastern state of Espírito Santo in 1967. Initially, Alpha considered *E. grandis, E. Saligna*, *E. urophylla* and *E. Alba* as the most suitable species. Alpha's forestry segment was built up on the basis of eucalyptus plantations using seeds produced in the railways company Fepasa, where early experiments had been developed during the 1920s and 1930s. 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 m^3/ha/year. These problems prompted Alpha to move from vegetative propagation, based on seeds, into tree improvement and clonal programmes (see Campinhos, 1999; Evans and Turnbull (2004). To tackle these problems in a more systematic manner, Alpha 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, pulp and paper industries thrived across these macro-economic discontinuities on the basis of leading firms' systematic innovative efforts combined with a 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 Alpha. 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 the 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) and the First National Plan for Pulp and Paper, sought to stimulate the growth of sectors like pulp and paper and their export activities. By the late 1970s, Brazil had achieved self-sufficiency in 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 private sectors was so intense that between by 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 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, in 1925 the National Centre of Papermakers was upgraded into the Federation of Papermakers which, in the 1940s evolved into the National Association of Pulp and Paper Makers (ANFCP) and to today's Brazilian Association of the Pulp and Paper (Bracelpa). The Brazilian Technical Association of Pulp and Paper Industries (ABTCP) was created in the 1960s. These kinds of arrangement 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.[5] Firms like Alpha 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 firms, IPEF developed organisational arrangements that sought to integrate IPEF's 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 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 the firm Alpha, 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 Alpha and other firms were located.

[5] Clonal plantations offer a number of advantages compared to those developed with seedlings (Evans and Turnbull, 2004): (i) It 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; and (iv) It produces a uniform material for processing in the production process.

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). 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. These research achievements paved the way for the successful intensive clonal *Eucalyptus* forestry in Brazil.

Indeed, 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 not until the early 1970s, mainly within the Brazilian firm Alpha, that new methods were developed for large-scale cloned forests for industrial-scale pulp production (see Poggianni and Suiter Filho, 1974; Evans and Turnbull, 2004). Thus, from a Schumpeterian perspective (Schumpeter, 1934; Kline and Rosenberg, 1986; Teece, 2007), 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, Alpha 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, Alpha's research indicated that gains in volume production and wood quality could be achieved using hybrid clones (e.g. *E. grandis* x *E. urophylla*).[6] In 1979 Alpha decided gradually to substitute its plantations, derived from seeds, for clonal plantations. Cloning enabled Alpha to use the results of its selection and breeding programme. Alpha 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

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

programme. By 1980, Alpha first commercial clonal plantation with 1,000ha had been established; by 1989 it had evolved to 15,000 ha. By 1987 Alpha's annual production of cuttings was 16.8 million. As a result of this cloning strategy, Alpha's eucalyptus productivity increased from 30 to 45 m^3/ha/year (see also Ikemori (1990); Evans and Turnbull (2004)). 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, Alpha achieved international recognition by being awarded the Marcus Wallenberg Prize from Sweden.[7] 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).

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; Evans and Turnbull, 2004). This challenged the firm Alpha 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.[8]

The organisational arrangement involving IPEF and the firms proved decisive for the progress in Brazil's forestry between 1969 and 1975. However, in late 1970s the quantity of seeds produced

[7] 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.
[8] It should be reiterated that the issue of sources of capability (learning) is outside the scope of this paper.

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 the use 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.

By the late 1980s, 20 years after having initiated 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 forestry development in Brazil.

As far as the external R&D arrangements are concerned, by the late 1980s, 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 Alpha 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 the firms Sigma-A and Sigma-B, 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, there was an abrupt and radical change into a kind of "Washington Consensus" 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 (e.g. metalworking, automotive, and electronics) were swept away as they were not able to cope with the international competition brought on by such changes.

In the case of pulp and paper industries this was worsened by the international fall of world market paper prices. Large paper firms, like Delta, almost collapsed and had to radically re-focus its scope. 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 policy. In this type of fruitless policy-making, the industry is kept at arms' length and government issues 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. 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. These were based on the introduction of changes in the chemical and equipment-related processes in order to incorporate innovations that had been implemented earlier in the upstream in forestry segment. These, in turn, impacted the firms' innovative (and competitive) performance. For instance, because of the progress that firms like Alpha, Delta, Sigma-A, and Sigma-B had made in genetic improvements in the upstream forestry segment, the wood that was used in their production processes 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. This was implemented 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 Alpha chlorine-free (ACF) and was patented in 1997. One year later, the firms Sigma-

A and Sigma-B also created their own versions of the TCF process. By 1995, 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. 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).

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, 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 the firm Alpha (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 to 120 propagules m^{-2} for conventional clone banks or hedges.

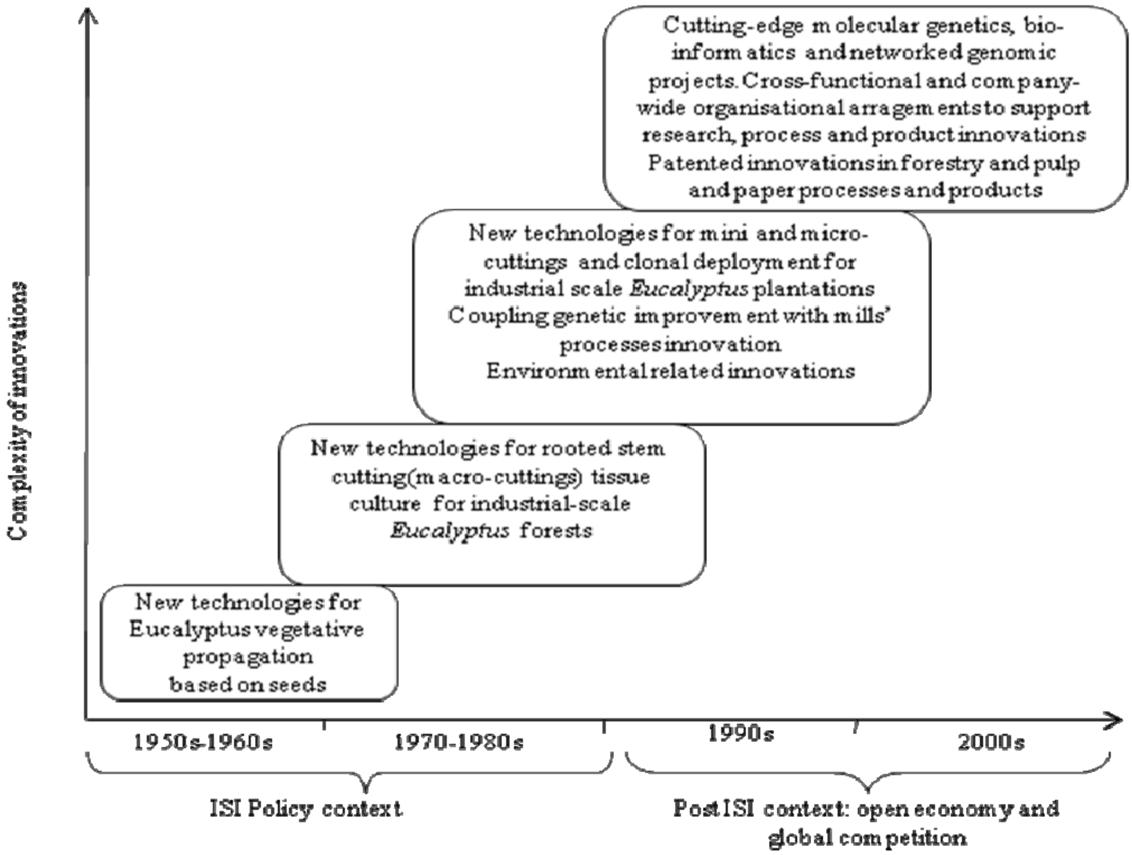
5.3.4 Innovation capability building under the "new industrial policy" of the early 2000s

During the 2000-2007 period, especially from 2003, the Lula administration, sought to re-establish the role of government policy in 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 of 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 industrial 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, the Productive Development Plan, began to be designed on the basis of the selection of 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" and "picking-winners" types of policy.

Nonetheless, during the early 2000s leading firms sought to deepen and expand their genomic research capabilities in order to keep up their internationally innovative performance. The new direction in capability accumulation – along the eucalyptus-based technological trajectory – was reflected in the firms' innovative performance by the early 2000s. This involved the different kinds of innovation *cumulatively 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 (see Figure 4).

Figure 4. Evolution of the focal case-studies' successful innovative performance



Source: Derived from the empirical study.

For instance, from 2001 to 2004 the firms Sigma-A, Sigma-B, 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 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 (see also Grattapaglia, 2004).

Another large-scale research, the Genolyptus Project – Brazilian Network of Eucalyptus Genomics Research was implemented from 2002 to 2008. The initiative involved 13 firms of the forestry, pulp and paper industries (among them Alpha, Kappa, Beta, Gamma, Delta, Theta, Sigma-A and Sigma-B) and seven universities, under the coordination of Embrapa. This group managed to persuade the Brazilian Ministry of Science and Technology to fund the project. 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 (see Grattapaglia, 2004).

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 genomics, 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 of the few countries to undertake cutting-edge eucalyptus genomic research based on a nation-wide biotechnology network.

During the 2000s, the firms with higher capability levels began to pay greater attention to the organisational dimension of capabilities to support innovations, especially to link their advances achieved in forestry with innovative activities in pulp and paper-making processes. Specifically, such efforts aimed at integrating the design of the biology of trees with the requirements of production processes and end users. Organisationally, such efforts involved reconfigurations of 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. As a researcher from one the firms 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. At the moment we undertake a project based on eight

> different genetic materials with implications for wood density and innovations in processes phases like pulping, bleaching, and physical-mechanical properties of the bleached pulp. By the time we finish this project, we will be able to match the features of wood production with the needs of specific paper markets like printing or tissue."

In 2002 the firms Sigma-A and Sigma-B 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, a large Brazilian exporter of chilled and frozen food, a "water-barrier package" that increased the safety of packed frozen food. From 2003 up to the fieldwork in 2007 Delta had been ranking as first and second most innovative supplier of Tetra-Pak worldwide. By 2004, Alpha had obtained nearly 30 patents and by the time of fieldwork, had 17 patents 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 as follows:

(1) The nature of the innovation capability accumulation path taken by the case-study firms involved a *qualitative departure* from the established technological trajectory led by world leaders from Norscan countries. Specifically, the "path-creating" innovation capability accumulation trajectory examined here consisted of firms following *different qualitative directions* of technological development from those already pursued by the 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 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-economic level, mainly the abrupt and radical changes in the nature of the industrial policy regime.

Despite such discontinuities in the policy regime some of the researched firms were able to deepen and sustain their innovation capability accumulation process along the new technological segment they had opened up. Such firms were able to move close to the new innovation frontier or even becoming world-leading innovators, as represented in Figure 5.

Figure 5. Firms' innovation capability accumulation paths across discontinuous policy contexts.[9]

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
World leading						Alpha Delta Kappa Theta (forestry)
Advanced innovation		Alpha Delta Kappa		Gamma Zeta-B Lambda		
Intermediate innovation	Theta (pulp), Iota, Beta, Gama, Lambd,a Zeta-B Epsilon			Iota Theta (paper) Beta		
Basic innovation		Theta (paper) Zeta-A				

Source: Derived from the empirical study.

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

(2) However, as shown in Sections 5.1 to 5.3 and also indicated in Figure 5, 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. Thus the path-ways taken by the focal cases can be organised around four categories as shown in Figure 6.

Figure 6. Types of capability accumulation paths in the focal case studies

Near the world innovation frontier [e.g. Beta (forestry), Kappa, Gamma, Zeta-A, Lambda, Epsilon] Establishment of external R&D collaborations at the early stages of innovation capability building coupled with internal research capability Entrepreneurial management style Pro-active, but relatively intermittent innovation capability	**At the world innovation frontier** (e.g. Alpha, Delta, Kappa, Sigma-A, Sigma-B) Establishment of external R&D collaborations at the early stages of innovation capability building coupled with internal research capability Responsiveness to government policies, other than the ISI Synergic relationship with gov't policy-making Active, consistent and ambitious innovation capability building aiming at industrial leadership Entrepreneurial (bold) management style
Halfway away from the innovation frontier [e.g. Iota, Theta (pulp), Beta (pulp), Zeta-A (forestry)] Heavy dependence on external R&D arrangement as the source for innovation activity Heavy reliance on the ISI policy regime Moderate efforts on in-house capability building	**Far-away from the innovation frontier** [e.g. Zeta-A (pulp) and Theta (paper)] Heavy dependence on external R&D arrangement as the source for innovation activity Heavy reliance on the ISI policy regime Weak efforts on in-house capability building

Source: Derived from the empirical study.

Firms that relied heavily on 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 improve or sustain their innovative performance across the macro-economic disruptions of the late 1980s and the structural reforms of the early 1990s. However, firms that exhibited sustained innovative performance across disrupted and discontinuous macro-level contexts, responded pro-actively to government policies, other than protectionism, and engaged in systematic building and strengthening of increasingly internal innovation capability accumulation, as they interacted with external R&D arrangements. This finding is in line with Mowery (1983), Cohen and Levinthal (1990), Bell (1993), Bell and Pavitt (1993).

(3) There was a kind of bottom-up synergetic interaction between firms and government policy-making aiming at technological development in Brazil's forestry and pulp and paper sectors, especially between the 1950s and 1980s. This finding gives support to Evans (1995) and Rodrik (2004, 2006) about industrial policy as a *process* whereby state and industry – not necessarily formally – take joint efforts to achieve industrial innovation. Also in line with Rodrik (2004, 2006) this finding suggests that "good institutions" play a crucial role in helping firms to overcome the various hurdles related to the accumulation of innovation capability. In a study focusing 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, this does not seem to be the case of the forestry and pulp and paper industries studied here.

(4) The nature and speed of firms' capability accumulation paths towards advanced and world-leading innovative performance along the new technological segment were also associated with intra-firm factors like norms and values materialised in their management style – which are an invisible dimension of capabilities – and leadership (see Leonard-Barton, 1995; Kim, 1997, 1998). The efforts, risks taken and, mainly, the perseverance to overcome constraints, were strongly related to a pro-active management style in some successful and fast-moving innovators (e.g. Alpha, Sigma-A, Sigma-B), but less intense or even absent in less successful innovators (e.g. Iota, Beta, Zeta-A). However, some firms were led by an entrepreneurial management, but engaged later in successful systematic innovation strategies (e.g. slower innovators Delta and Kappa), while others missed a systematic innovation capability building strategy (e.g. Zeta-A and Zeta-B). There were also cases in which the firms' innovation pro-activeness was severely

weakened during the policy regime discontinuity of the early 1990s (e.g. Epsilon). Finally, there was the case of Theta, in which the firm's leadership *opted for* prioritising innovation capability accumulation in one segment (forestry) and less in others, especially paper.

6. Conclusions

This paper sought to examine a kind of "path-creating" capability accumulation trajectory in natural resource-processing industries. It did so by drawing on multiple-case evidence from 13 firms from the forestry, pulp and paper industries in Brazil during the 1950-2007 period. By building on influential studies on technological catch-up such as Lim and Lee (2001), this paper contributes to expanding our understanding of the manner in which latecomer firms overtake (or fail to do so) world leaders in terms of capability accumulation and innovative performance in three ways. First, the paper empirically examined firms' innovation capability accumulation paths that involved a *qualitative departure* from the established technological trajectory at the *early stage* of their capability development. The paper did so by interpreting the innovation frontier as a "horizon" to be explored, rather than an end-point to be reached. By doing so, the paper moved beyond the catch-up perspective based on a kind of cumulative continuity along a technological trajectory previously developed by global leaders. Such kind of "path-creating" capability accumulation was examined in the paper across discontinuous policy regimes.

Second, this paper has examined the dynamics involved in this kind of capability accumulation path. Specifically, the paper tackled the speeds at which firms moved (or failed to move) towards progressively innovative capability levels along the new technological segment that they carved. Third, the paper examined these issues in natural resource-processing industries. By doing that the paper sheds some empirical light on the kind of firms' and government's strategies that are involved in achieving international innovative performance in natural resource-rich countries, especially those in Latin America. The findings suggest that the nature of the in-house innovative capability accumulation efforts conditions the way in which latecomer firms overcome hurdles and cross policy regimes discontinuities as they pursue significantly new directions in the international technological frontier.

Additionally, the paper explores how the combination between firm-level pro-active innovation strategies and, to some extent, a synergetic relationship with government policies, other than mere protectionism, permits firms to cross discontinuities to achieve world leading innovative performance. Thus, at least from the standpoint of the firms researched here, the findings dismiss the thesis of "inherent discontinuity" (Viotti, 2002). On the other hand, the paper provides some support to the arguments in Perez (2008) and ECLAC (2008) that a systematic and sustainable accumulation of highly innovative capabilities in natural resource-based industries could be pursued as a strategy to gain international leadership in countries like Brazil. However, the paper does not suggest that countries like Brazil should pursue a specialisation route on natural resources. This is obviously inconsistent with the country's diversified industrial fabric.

Nonetheless, the natural resource-based sectors should receive a more detailed attention in the policy agenda of countries like Brazil. One of the implications for policy makers is how to re-design policies that move away from "principal-agent" and "picking-winners" types of policies to engage in the building of policy institutions (Rodrik, 2004) that target on firm-level innovation capability accumulation. That kind of policy-making process should aim more at partnerships between firms and policy makers, rather than on the mere autonomy of the latter. From the standpoint of the firms' path-ways represented in Figure 6, such kind of policy initiative seems to be crucial to (i) avoid that firms move back from world-leading levels and (ii) push more firms into the two top quadrants of Figure 6. The absence or malfunction of these kind of efforts, like in other industry, may simply obstruct the innovation capability accumulation process, as in the case the laggard firms in this study or the case of some firms in Indonesia (see Bell and van Dijk, 2003; van Dijk and Bell, 2007).

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 patent statistics or R&D expenditures can capture the nuances and dynamics of the process of technological development in latecomer firms.

However, this paper has some limitations that could be overcome by further research. For instance, it was not possible to know how and the extent to which *learning processes* influenced the nature and speeds of firms' innovation capability accumulation paths. Neither did the paper tackle the impacts of capability accumulation (and/or non-accumulation) on the firms' technical, economic, environmental, and social performance indicators. Additionally, it would be interesting to know whether the firms' capability accumulation paths generated any kind of spill-over effects. Finally, the paper draws on evidence from one country and firms from one type of sector. Inter-sector and cross-country national comparative analyses would be beneficial to further our understanding the nature and speed of technological catch-up.

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Appendix Table 1. Levels of latecomer firms' innovative capability: a condensed 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 (e.g. 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 (e.g. special pulp).

Source: The original frameworks applied during fieldwork and data analysis involved three individually 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 involved several consultations with industry experts and companies' specialists. Qualitative data obtained from the application of these frameworks was transformed into quantitative observations to allow the speed of capability accumulation to be calculated.