Innovation and the emergence of Brazilian pulp and paper sector

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ABSTRACT

A sustained wave of innovation has been the main driver of the Brazilian pulp and paper industry, and key component in its present success. All too often, casual observers describe availability of raw materials and low labor costs as drivers of industries in emerging economies. The Brazilian pulp and paper industry presents powerful example of the importance of long-run efforts to build knowledge based competitive advantages. Right balance of coordination and competition fostered demand-led innovation system, allowed Brazilian firms to integrate efficiently in global learning networks, and nurtured entrepreneurial culture that eventually leveraged industrial change. The subsequent expansion and success of Brazilian pulp and paper industry can to a great extent be credited to the sectoral innovation system and its dual strategy, which has established a clear division of labor between fundamental innovation and knowledge transfer. Both private firms and the public sectoral innovation system have focused Brazilian cutting edge research, development, and innovation efforts on the improvement of eucalyptus, the primary source of superior competitive advantage for the Brazilian pulp and paper industry, and in other science and technology areas created efficient mechanisms to transfer the best available scientific and technological solutions from abroad to Brazil.

INTRODUCTION

Over the last decades, Brazilian pulp and paper industry has expanded rapidly and ranks today as one of the leading centers of production and technology in the world, and stands out also as an exceptional Brazilian success story on the side of Embraer and biofuels. Though favourable natural conditions and cheap labour have contributed to industry's ascent, its international competitive advantage has been created through sustained and momentous national effort in scientific and technological innovation. Introduction of non-native pulp wood tree species, notably eucalyptus, their subsequent improvement through silviculture and biotechnology, as well as the development of new chemical pulp processes have been the most important scientific and technological accomplishments that established Brazil as world leader in quality and price in short fiber pulp production.[1]

BEGINNINGS OF EUCALYPTUS IN BRAZIL, 1900-1955

The foundation of the sectoral innovation system of Brazilian forests products industry was laid in the late 19th century, when the railroads introduced eucalyptus in the country. A fast growing hardwood tree, eucalyptus establishes the raw material base and foundation of Brazilian pulp and paper industry today. Not indigenous to Brazilian nature, the development of Brazilian eucalyptus as a raw material base for paper industry was not a mechanical replication of existing production processes, but a long interactive learning process that involved selection and adaptation of eucalyptus species into Brazilian biological environment and innovation in hardwood pulping technologies.

Eucalyptus was introduced in Brazil in 1864, and first plantations produced cross ties for railroads and coal for locomotives. Systematic scientific work to discover most suitable eucalyptus tree for Brazilian biological environment and its industrial exploitation started in the early 1900s with Edmundo Navarro de Andrade, known as the "father of eucalyptus" in Brazil. Educated in Europe, he launched experimental work to identify best eucalyptus species for large-scale industrial forestry in Brazil and suitable for the production of different lumber products.

In the early 20th century Brazil, pulp and paper was irrelevant for eucalyptus because of the lack of right pulp technology. The prevalent global standard, the sulphite pulp

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process, allowed the exploitation of soft wood and long fiber spruce that produced best quality paper. Technological solutions to make paper from eucalyptus, not to mention in profitable way, were unknown.

Although Navarro de Andrade did suggest the development of eucalyptus pulp processes in the hope of creating nascent Brazilian pulp and paper industry, it took several decades to realize the dream. Eucalyptus pulp remained a curiosity as an industrial product and research subject until the World War II, when raw material shortages and dependency on pulp imports prompted the Brazilian government to introduce incentives for research on new fiber sources.

LEARNING TO MAKE PULP AND PAPER FROM EUCALYPTUS, 1955-1970

Between 1955 and 1970, the sectoral innovation system of Brazilian forests products industry was significantly expanded and augmented. Government built knowledge creation and transfer institutions, such as research institutes and universities. It also expanded innovation policy and created new policy instruments, which focused on implementation of new knowledge and technology. These instruments included state and federal level forestry initiatives, government subsidies as incentives for investments in new pulp and paper capacity, and different regulatory and legal initiatives. The new policies created a system that can be appropriated as innovation system, as it encompassed broadly different policy sectors and actors, mobilized the private industry in implementation of policy goals through several initiatives, and amounted to real innovation policy. Finally, these initiatives allowed Brazilian system to integrate more tightly in the emerging global sectoral innovation initiatives, which were launched after the World War II.

The most important boost to Brazilian pulp and paper industry was the establishment of sulphate pulp process as the global standard mass production technology. It catapulted industrial growth in regions where traditional wood species could not be effectively processed with sulphite process. In Portugal, New Zealand, and the U.S. South whole new industrial regions emerged.

Introduction of mass production of sulphate pulp presented great opportunities for Brazilian firms, yet its successful application required intensive industry-level technological learning in the new process and its adaptation into Brazilian virgin fiber sources, Araucaria angustifolia, and, most notably, eucalyptus. Industry wide-learning in new pulp technologies during the 1950s catapulted the share of short fiber, consisting practically only from eucalyptus, production from total Brazilian pulp production from minuscule 4 per cent in 1950 to 60 by 1960.

Central vehicles of this innovation were the new industrial policies that introduced new institutions since the early 1950s. A critical tool of new policy was the Brazilian Development Bank (BNDES). It developed new financial instruments to support the industry, fostered economies of scale, and supported improvement of technological know-how in the industry.

In addition, host of new educational institutions, universities, and government and private sectoral research institutes begun to contribute to the pulp and paper sector. An important landmark was the inauguration of first Brazilian school of forestry at the Federal University of Viçosa in 1960, which in addition to education developed quickly into an important research and technology transfer center. Several other universities followed the suit and launched courses on forestry engineering, silviculture, and other aspects of eucalyptus forestry. The schools educated scientifically and technically advanced work force, accelerated the diffusion of knowledge and technology, and improved the international contacts for Brazilians.

INNOVATION, INDUSTRIAL GROWTH, AND CULTURE OF ENTREPRENEURSHIP, 1970-1985

*In the late 1960s, necessary elements of rapid growth of Brazilian pulp and paper industry were in place, including mass production sulphate pulp technology, forestry plantations of selected eucalyptus species, pools of scientifically and technologically advanced work force, comprehensive sectoral innovation system, capital, and advantageous political economy. Domestic short fiber pulp production increased tremendously and paper industry was able to practically eliminate previous dependency on pulp imports (**Table 1**).*

***Table 1.** Cellulose pulp production, import, export, and consumption in Brazil in 1957, 1963, 1968, and 1973. (metric tons)*

Year	1957	1963	1968	1973
Production	165	448	624	1.130
Imports	137	54	35	123
Exports		3	12	194
Consumption	302	499	647	1.059

Source: Juvenal and Mattos (2002)

The ascendancy of Brazilian pulp and paper industry between 1970 and 1990 enveloped significant organizational and cultural changes as new entrants and entrepreneurs emerged as the leading firms. Few new entrants, notably, Aracruz, Cenibra, and Jari leveraged most of the change in eucalyptus pulp production until 1984.

New firms and entrepreneurs defined completely new corporate strategies that departed radically from those of incumbent Brazilian firms. Entrepreneurial firms focused on export of eucalyptus pulp and pursued strategy based on innovative eucalyptus forestry, state-of-the-art sulphate pulp processes, export markets, and economies of scale. They disregarded industry's traditional emphasis on vertical integration of pulp and paper production.

Aracruz and Cenibra, for example, launched massive forestry operations with the intention to establish subsequently large-scale pulp mills, and leveraged rapid industrial change in Brazil. They spearheaded a new business strategy and model in Brazilian and global perspective, as they pursued eucalyptus forestry, economies of scale, and global export trade in contrast to incumbent pulp and paper firms that produced pulp mainly to supply own paper production in Brazil.

UPGRADING KNOWLEDGE AND INNOVATION, 1967-1990

The take-off of entrepreneurial eucalyptus pulp industry gave rise to new learning dynamics in the sectoral innovation system of Brazilian pulp and paper industry. Whereas government initiated frontiers of forestry research, nurtured scientific and technological capabilities and extended other incentives in order to generate private interest in infant industry, new entrepreneurial eucalyptus firms invested heavily in R&D. They pioneered new biotechnological research and innovations in Brazil that translated directly and immediately in new business strategies and industrial operations. In the late 1960s, Aracruz and Cenibra recognized that biotechnology allowed improved control of eucalyptus stock and thereby increased productivity. In particular, novel techniques of asexual reproduction, that is, cloning of existing trees through cuttings and avoiding the use of seedlings, marked important breakthrough in the production of standardized and controlled eucalyptus forests, and contributed to tremendous productivity improvements in eucalyptus forestry since 1970. Upon pioneering private experiments and research programs, Brazilian government and incumbent paper firms embraced these new technological opportunities and launched series of initiatives, which turned the country in leader in forestry biotechnologies.

Investments in eucalyptus R&D yielded quickly impressive returns. Standardized stock improved disease resistance, improved economies of scale in forestry and wood handling, and made the management of pulp digesting process more easy. In addition, biotechnological innovation improved growth yields. First Aracruz eucalyptus trees required 12-years to grow into logging size, but company's systematic research and development program diminished the average growth cycle to 7 by mid-1980s. IPEF (Institute of Forest Research and Studies) has estimated that average annual production of Brazilian planted forests increased from 15 cubic meters per hectar in 1970 to almost 35 in 1985.

At state level, actions taken, especially in São Paulo, were important. The Institute for Technological Research of the State of São Paulo (IPT), a public research institute linked to the Secretariat for Economic Development, Science and Technology of the State of São Paulo, installed a testing laboratory to attend requests from government agencies and private firms. In the beginning of 1960's, the lab was incorporated into the Wood Division as two labs: a Forest Products lab and by-products (extractives). In partnership with the Finnish company Jaakko Pöyry, in the 1970's, FAPESP supported the upgrading of pulp and paper knowledge and skills at IPT. As a result of these efforts, IPT established in 1967 the Technical Center for Pulp and Paper (CTCP), and inaugurated in 1981 a pilot plant for high yield pulp with 8 tons/day capacity with resources from the Interamerican Development Bank, channeled through FINEP.

A Brazilian flagship institution of forestry research, Instituto de Pesquisas e Estudos Florestais (IPEF), was established in 1968, and it was a joint venture of the university and pioneering eucalyptus forestry and pulp firms. As such, it provided a template for public-private partnerships for industrial R&D.

The private sector created quickly many new institutes and initiatives to advance eucalyptus related R&D, and the government expanded its activities too. Importantly, Brazilian Agricultural Research Institute (EMBRAPA) established Center for National Forestry Research (CNPF) in 1978 in order to address increased interest in eucalyptus forestry.

In total, eucalyptus plantations increased from one million hectares in 1970 to 3.6 million by 1990, and majority of the growth came from plantations of biotechnologically improved examples species of E. saligna and E. grandis. Growth of plantation area fuelled also environmental criticism, such as alleged spread of monoculture at the cost of biodiversity, and most forestry firms initiated plantation schemes that created pathways of natural forests inside vast eucalyptus fields.

CATCH-UP LEARNING DYNAMICS AND 2ND GENERATION INNOVATION SYSTEM

Since 1985, Brazilian pulp and paper industry's evolution has been characterized by global incumbent firms' catch-up with pioneering eucalyptus pulp firms and consolidation. Latecomers into eucalyptus business benefitted from industry's advanced sectoral innovation system that diffused rapidly latest innovations and knowledge and government policies, though their success cannot be credited only to these factors. Established large-scale paper firms had exceptional organizational capabilities and political leverage to enter eucalyptus business at a moment, when industry's operations and size reached unprecedented scale in Brazil. Between 1985 and 2005, eucalyptus pulp and paper industry expanded steadily, and Brazilian annual production of short fiber pulp increased 60 per cent between 1985 and 1995, and 81 per cent between 1995 and 2005. Total annual production of pulp leaped from 3.7 million tons in 1985 to over 10 in 2005.

This massive expansion enveloped deep changes in industry's organizational structure, as incumbent Brazilian firms begun to emulate the strategy of pioneering entrepreneurial firms and caught up with them. Not only have incumbent Brazilian pulp and paper firms entered the eucalyptus paper business, but many global industry leaders have entered Brazil. In 2000, Finnish-Swedish StoraEnso, then world's second largest pulp and paper enterprise, entered a joint venture with Aracruz, and has since built its presence in Latin America.

The forceful entry of incumbent firms into eucalyptus forestry and pulp business, and ensuing merger wave changed industry's organizational structure. In the 1990s, a consolidation wave imprinted Brazilian pulp and paper industry as over 30 major mergers occurred between 1992 and 2001. Aracruz, Cenibra, Celmar, Veracel, and Jari remained focused upon pulp production and export markets, and dominated 71 per cent of market pulp production in 2002.

The response of Brazilian sectoral innovation system to the recent rise of genomic research and improvement of eucalyptus has followed largely historical precedents. Firms, industry associations, and state and federal governments have launched cooperative initiatives that coordinate national research efforts and transfer technology. Indeed, it appears that Brazil's sectoral innovation system is renewing itself at an amazing pace and is poised to be world leader in eucalyptus genomic research. The cooperative nature and extent of the Brazilian genomic research platform, which extends to regulation of biosafety and other legislative initiatives, represents a departure from previous structure of sectoral innovation systems.

Genomic eucalyptus research took hold in Brazil, when some of the leading research institutes, such as IPEF, advocated possibilities of gene technology for forestry in the mid-1980s. A real turning point occurred in the early 1990s with global advances in genomic research, however. Since 1994, the industry advocated heavier government participation and initiation of national eucalyptus genomic mapping project, eventually launched at the turn of the millennium. Genomic eucalyptus research is supported with particularly strong investment in genomic research in Brazil. In 1997, the State of São Paulo Research Foundation (FAPESP) created the Organization for Nucleotide Sequencing and Analysis-network, which encompasses 30 laboratories across the state. In addition, National Council of Research has funded several research projects, and Federal ministry of science and technology launched Brazilian Genome Project in 2000. Its many dedicated genome mapping initiatives include Genolyptus Project – The Brazilian Network Eucalyptus Genome Network, launched in 2002, and a major cooperative project that involves all central trade associations, universities, research institutes, and government bodies. The Genolyptus Project reflects larger government ambition to create industrial competitiveness through biotechnological research and innovation programs, and it may eventual produce first transgenic eucalyptus species.

THE SECTORAL INNOVATION SYSTEM OF BRAZILIAN PULP AND PAPER INDUSTRY TODAY

The growth and evolution of the sectoral innovation system of Brazilian pulp and paper industry has been punctuated by the needs of firms, economic and industrial policies, as well as the global advances in science, technology and the world trade. The result is a unique sectoral innovation system that addresses exclusive Brazilian knowledge and innovation needs, as well as maintains division of labor between Brazilian and foreign actors. While large and somewhat diffuse, the system should be characterized as highly focused on the core issues for the competitiveness of Brazilian pulp and paper industry. A typology of the sectoral innovation system of Brazilian pulp and paper industry is provided in the ***Table 2.*** *Even at the risk of simplifying too much, one could argue that the system invests in basic research and fundamental innovation only when it comes to exploit further the advantages offered by eucalyptus. In the case of research and innovation for other scientific and technological areas, such as chemical processing, energy, equipment and machinery, the system creates national capacities to use the globally best available practices and technologies.*

Brazil as a nation is a late entrant into pulp and paper industry and thus much of the system is geared towards

Table 2. *Overview of the sectoral innovation system of Brazilian pulp and paper industry*

	Federal government	**State governments**	**Industry**	**Brazilian firms**	**Foreign firms**	**International**
Type of actors	*Federal ministries* *Federal agencies*	*State governments in:* Minas Gerais São Paulo Paraná	*Industry associations, technical associations, professional societies*	*Pulp and paper firms* *Strategic alliances*	*Pulp and paper firms* *Engineering services* *Machinery and equipment suppliers* *Strategic alliances*	*International organizations* *Scientific organizations, scientific and technical initiatives*
Central actors	MCT MDIC MMA MAPA CNPq	*Various* IPT	ABTCP BRACELPA	*Firms* e.g. Aracruz e.g. Votorantim *Strategic alliances* Veracel Cenibra	*Firms* *Engineering services* *Machinery and equipment suppliers* *Strategic alliances*	FAO The World Bank Latin American Development Bank, *Technical and scientific associations*
Training	***Universities*** UFV UFRGS UFRRJ UFPR	*Universities* USP	*Vocational schools* *Special programs* *International exchange programs* ABTCP	*Special programs at local level* *Firm specific international exchange and study programs*	*Special programs* *International exchange programs*	**FAO**
Basic research	*Universities* UFV UFRGS PUC *Dedicated research programs and funding* EMBRAPA	*Universities* **USP**				FAO Eucalyptus World *Congress* *Scientific associations*
	Special PPI programs Organization for Nucleotide Sequencing and Analysis-network / SP Forest Eucalyptus Genome Sequencing Project Consortium / SP *Brazilian Genome Project - Genolyptus Project*					
Applied research	*Universities* *Sectoral research institutes* EMBRAPA CNPF	*Sectoral research institutes* SIF IPT	*Sectoral research institutes* IPEF *Special programs* *PPI*	*Firm specific R&D* *PPI*	Firm specific R&D PPI	FAO Eucalyptus World Congress *Scientific associations*
Research funding	CNPq MCT	FAPESP State governments		*Firm specific R&D* *Special programs* *PPI*		
Industrial development and finance	BNDES	State governments				IFC Latin American Development Bank
Regulation & standardization	Forestry laws Biosafety law		ABNT ABTCP			

ABTCP= Brazilian Pulp and Paper Technical Association - Associação Brasileira Técnica de Celulosa e Papel

ABNT= Brazilian Association of Technical Norms - Associação Brasileira de Normas Técnicas

Cenibra= Celulose Nipo-Brasileira

BNDES= Brazilian Development Bank - Banco Nacional de Desenvolvimento Econômico e Social

BRACELPA= Brazilian Association of Pulp and Paper - Associação Brasileira de Celulose e Papel

CNPF= National Center of Forestry Research - Centro Nacional de Pesquisa Florestal

CNPq= National Council for Research

EMBRAPA= Brazilian Agricultural Research Corporation - Empresa Brasileira de Pesquisa Agropecuária

CNP= Center for National Forestry Research - Centro Nacional de Pesquisa Florestal

FAPESP= State of São Paulo Research Foundation - Fundação de Amparo à Pesquisa do Estado de São Paulo

FAO=The Food and Agriculture Organization of the United Nations

IFC=International Finance Corporation

IPEF=Forestry Science and Research Institute - Instituto de Pesquisas e Estudos Florestais

IPT= Institute for Technological Research of the State of São Paulo - Instituto de Pesquisas Tecnologicas do Estado de São Paulo

MCT= Ministry of Science and Technology - Ministério de Ciência e Tecnologia

MDIC= Ministry of Development, Trade, and Trade - Ministério do Desenvolvimento, Indústria e Comercio Extérior

MMA= Ministery of Environment - Ministério do Meio Ambiente

MAPA= Ministry of Agriculture, Livestock and Supply - Ministério da Agricultura, Pecúria, e Abastecimento

MG=Minas Gerais

PPI=Public private initiatives

PUC= Catholic University - Pontífica Universidade Católica

SIF=Society for Forestry Research at UFV - Sociedade de Investigações Florestais, UFV.

SP=São Paulo

UFFRJ= Federal Agricultural University of Rio de Janeiro - Universidade Federal Rural de Rio de Janeiro

UFPR= Federal University of Parana - Universidade Federal do Paraná

UFRGS= Federal University of Rio Grande do Sul - Universidade Federal de Rio Grande do Sul

UFV= Federal University of Viçosa - Universidade Federal de Viçosa

USP= São Paulo University - Universidade São Paulo

catching up. Evidently, the capacity to exploit and absorb knowledge and innovations from abroad is certainly one of the great strengths of the Brazilian sectoral innovation system. The training and educational system in Brazil turns out a body of skilful labor and scientifically and technologically advanced workforce, which can take advantage of the best technologies and practices developed elsewhere. Most firms train blue-collar workers and there exist some vocational schools. Critical for the supply of scientifically and technologically advanced workforce are the federal and state universities, which have created special curriculums in pulp and paper science and engineering, forestry engineering, and management. Most important ones of these at the Federal University of Viçosa, Federal Rural University of Rio de Janeiro, and the University of São Paulo.

State governments and regional innovation systems are playing highly critical roles too. IPT of São Paulo has provided broad range of R&D services. Most relevant products and research results of IPT have been: first works in Brazil on pyrolysis, gasification of biomasses, and biofuels; first TMP and CTMP process in Brazil; first development of models and simulation and re-evaluation and debugging of the code of GEMS simulator; first studies on pitch and stickies in Brazilian eucalyptus production; studies for hydrolysis (acidic) of wood and sugar cane bagasse for ethanol production; leadership in the Brazilian Collaborative Proficiency Testing for paper and paperboard; and strategic planning for the sector born in the CTCP with all the representatives of the top managements of the industry.

Industry associations and professional societies, of which the Brazilian Pulp and Paper Technical Association and Brazilian Association of Pulp and Paper are the two most important ones, provide also continuous education and circulate latest knowledge that is highly relevant for the industry. Knowledge and technology transfer are also catalyzed by several sectoral research institutes and international scientific and technical organizations and especially by the large presence of foreign firms in Brazil.

Apart from eucalyptus science and technology, foreign firms are a key vehicle of technological learning and source of innovations in the Brazilian pulp and paper industry. Engineering service firms, such as the Finnish Pöyry Group, provide latest scientific and technological knowledge and deliver state-of-the-art pulp and paper mills. Equipment and machinery suppliers, such as the Finnish Metso and German Voith do the same in paper and pulp equipment. The role of foreign firms for knowledge and technology transfer is also facilitated by the industry and trade associations, which often network and liaison with their international counterparts.

Eucalyptus occupies most of the attention of the Brazilian research efforts. The sectoral innovation system maintains a rather clear distinction between applied and basic research, although the recent advances in genomic and biotechnology blur this distinction. Basic research is carried out mainly at the universities and three of them stand out as central hubs of research: The Federal University of Rio Grande do Sul, the Federal University of Viçosa, and the University of São Paulo.

In 2002, IPEF listed 54 public research institutes active in forestry and 16 private ones. Although these institutes serve all kind of knowledge needs in the area of forestry, they also constitute the backbone of the Brazilian knowledge base for industrial forestry. In addition to IPEF, the most important ones of these are the Brazilian Agricultural Research Corporation and the Sociedade de Investigaçoes Florestais at the Federal University of Viçosa.

At the federal policy level, several ministries and their agencies have responsibility for the sectoral innovation system of the Brazilian pulp and paper industry. Key ministries are: The Ministry for Science and Technology, the Ministry of Environment, and the Ministry of Development, Industry and Trade, and their agencies. Naturally, BNDES continues to be of great significance.

We can summarize the existing sectoral innovation system of Brazilian pulp and paper with short, simplifying characterizations on research policy and the role of firms, its two key features in our judgement. From the point of view of research policy, fundamental and most serious scientific and technological research goal is to improve the productivity of Brazilian forests and foremost the Eucalyptus. This strategy has manifested itself with the ambition to emerge as the global leader on the subject and indeed Brazilian scholars, research institutions and firms have accomplished this. Scientific and technological ambition level on other research areas is considerably less and more attention is put in capacity building and technology transfer, which allow the quick adoption of innovations developed elsewhere. This same dual strategy also underpins educational policies and institutions.

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