Technology Diffusion Dynamics: The case of Chile's Forestry Industry

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Abstract: Based on Everett Rogers' diffusion model, the article explores diffusion dynamics in Chile's Forestry Industry. Technology adoption is defined as depending upon innovation attributes, collaboration, communication channels, research and development (R&D) capacity, and institutional environment. The attributes of innovation are in turn divided into five sub-factors: comparative advantage, compatibility, complexity, observability, and trialability. Our case study analysis is based on 21 interviews with various actors in the Chilean forestry industry and on secondary information sources. Our conclusion is that the attributes of innovation in terms of comparative advantage, observability, and compatibility are technology diffusion drivers, and that the industry needs higher collaboration, better R&D capacity, less bureaucracy, and a more flexible public funding system to achieve a better performance.

Keywords: technology diffusion, innovation systems, forestry.

1. Introduction

Chile is defined as a natural resource based (NRB) economy strongly depending upon mining and forestry, although with limited local research and development (R&D) capacity (Catalan 2007). NRB-industries have strengthened Chile's economy both internally and externally by means of job creation and boosting exports. The Chilean Forestry industry (from now on referred to as ¨the industry") is significant for the national economy, producing 130,000 direct and 300,000 indirect jobs, $5,452.5 million in exports in 2008, and revenues amounting for 13 percent of the national income during the last 15 years[1]. Gonzalez (2005) conceives of the Industry´s economic success as resulting from five factors: first, Chile's geographic and environmental conditions allowing the introduction of foreign species with similar or even better growth rates than in their native locations; second, the Decree-Law 701 of 1974 which facilitated an increase from 200,000 ha of planting area to the current 2.2 million ha; third, a cost of labor lower than the international average; fourth, a small local market prompting local producers to look for international clients; and fifth, a set of highly trained managers able to define business strategies based on local advantages and external opportunities.

Notwithstanding internationally its active local NRB industries and outstanding macroeconomic and institutional performance, often highlighted by international organizations, Chile seems to confirm Sachs and Warner´s (1995) natural resource dependency "curse": that is, NRB-economies are not able to achieve high growth rates. However, as international evidence has already shown, as long as learning and innovation reach higher levels and technology creation, absorption, adaptation, and diffusion occur,

[1] www.infor.cl

NRB-economies may be able not only to overcome the Sachs-Warner “curse” as well as seizing the opportunity of natural resources (Maloney 2002; DeGregorio and Bravo-Ortega 2005). Therefore we set out to explore how the dynamics of technology diffusion in the forestry industry, a NRB industry, in Chile, a NRB-economy, operate and whether they contribute to improve local innovative performance. To answer the research question, we set up a theoretical framework drawing on the sectoral systems of innovation (SSI) conceptual framework, and Everett Rogers’s technology diffusion model. These frameworks enabled us to describe the industry in terms of interaction and learning dynamics and to determine how technology diffusion results from a combination of endogenous and exogenous factors. We applied case study methodology based on both primary sources, that is, 21 interviews with various forestry agents, and secondary sources such as public agency and private organization reports, newspapers, and magazines. The article draws on the project “Sectoral Systems of Innovation (SSI) Impacts in Technology Diffusion Processes: The Case of Chile’s Forestry Industry” funded by Chile’s Science and Technology Bicentennial Program through its Science, Technology, and Innovation Policy Studies fund, and jointly executed by the University of Concepcion’s Biotechnology Center (CB-UDEC) in Chile and Georgia Tech’s Technology Policy Assessment Center (TPAC) in the US.

This paper is organized in four sections as follows: a) theoretical framework, b) methods, c) results and analysis, and d) conclusions.

2. Theoretical Framework

The theoretical framework for this study draws on NRB economic growth theory, the sectoral systems of innovation (SSI) conceptual framework set out by Malerba (2002), and Rogers (2003) technology diffusion theory. The section is organized as follows: first, we present contrasting positions on NRB economic growth theory; second, we describe the SSI conceptual framework; and third, we introduce Rogers's model.

2.1 NBR Economic Growth

Natural resources abundance has been at the center of an intensive and steady debate during the last decades. Is it a real "curse," deterring NRB countries from economic growth or a factor fueling economic growth once some conditions are fulfilled? There are examples of both positions. On the one hand, Australia, Canada, the United States and the Scandinavian countries are successful cases of nations able of creating wealth over natural resources and at the same time not limiting their own development to their exploitation (DeFerranti, Perry et al. 2002). On the other hand, scholars have claimed that the reason Latin American and African countries are not wealthier countries today go beyond their rich endowments of natural resources pointing instead to the absence of sound property rights systems, high learning capacities or steady R&D investment rates (Lane and Tornell 1996; Deaton 1999; Maloney 2002).

The concept of Dutch Disease has been introduced to help explain the impact of natural resources on economic growth. Coined as a term by The Economist in 1977[2] to describe the decline of the manufacturing sector in the Netherlands after the discovery of North Sea oil in 1970, the theory states that an increase in revenues from natural

[2] The Dutch Disease" (November 28, 1977). *The Economist*, pp. 82-83.

resources will de-industrialize a nation's economy by raising the exchange rate, making the manufacturing sector less competitive. Sachs and Warner (1995) show that economies with a high ratio of natural resource exports over GDP in 1971, have lower growth rates over the 1971-1989 period. The trend holds even after controlling for important growth variables such as initial per capita income, trade policy, government efficiency, investment rates and other variables. Their analysis showed that a 1-standard-deviation increase in natural resources exports as fraction of GDP leads to 1 percent point per year slower rate of growth. What kind of factors can be behind the harmfule effects of natural resources on growth? Lane and Tornell (1996) hold an explanation based on a “feeding frenzy” which starts with a windfall coming from either an improvement of terms of trade or the discovery of a new natural resource source which leads to a strong rent-seeking competition among power groups ending up in an inefficient exhaustion of public goods.

On the other hand, De Gregorio and Bravo-Ortega (2005) argue that high levels of human capital may outweigh the negative effect of natural resources on growth. They point to the case of Scandinavia as an example of how NRB economies that are well endowed with human capital may reach high growth rates through a simultaneous synergetic development of a natural resource industry and a high technology sector. Maloney (2002) identifies barriers with deep historical roots to technological adoption and innovation as the causes of Latin America’s underperformance, namely a deficient learning capacity which has been intensified in the postwar period by the implementation of import substitution policies. He notices that strengthening local human capital, reaching high literacy rates or promoting technical education, reinforced the developed countries capacity to learn from what was happening abroad, to access quickly to knowledge generated abroad, and, in the long run, to establish local clusters.

At macro level, it may be feasible that Chile, an NRB economy, might find its own way out of the so-called “natural resources curse” through achieving higher learning and innovation capacities, the implementation of a new S&T institutional setting, and higher public and private R&D investment rates (Catalan 2007). Nevertheless, for Chile to become a knowledge-driven economy and leave behind its current natural resources dependency, analyses of sectoral dynamics are needed, particularly of NRB industries. The Scandinavian example of jumping into the knowledge economy by drawing on a synergistic and complementary capacity building process between NRB and high tech industries may be a good way for Chile to catch up. Studying the technology diffusion mechanisms in the Chilean Forestry industry may provide insights on how to start off and intensify sectoral new capacity building to set the base for both manufacturing new value-added products and creating new high tech industries.

2.2 Sectoral Systems of Innovation (SSI)

As part of the Systems of Innovation (SI) family that also includes National Systems of Innovation (NSI) and Regional Systems of Innovation (RSI), SSI consists of “the actors involved in innovation, the links and relationships among actors, and the relevant institutions” (Malerba 2006). SSI deviates from both traditional industry economics more focused on R&D intensity, market structure, patents and competition and previous SI geographically-oriented approaches, by concentrating on learning and interaction dynamics occurring in relation to a product or a set of products.

Malerba (2006) identifies three concepts as pillars of SSI: a) knowledge and technologies, b) agents and networks, and c) institutions. In terms of *knowledge and technologies*, Malerba defines knowledge as highly idiosyncratic at the firm level, not diffusing freely nor automatically among firms due to differences in their competencies acquired over time. As to technologies he stresses that sectors differ greatly in their technological bases; therefor their boundaries and organizations do not respond to a common pattern. Knowledge is defined in terms of accessibility, opportunity, cumulativeness, and appropriability. To exemplify variation in each concept he uses Schumpeter Mark I, ¨creative destruction," and Schumpeter Mark II, "creative accumulation": high opportunities, low cumulativeness and low appropriability lead to high entry rates therefore to Schumpeter Mark I, whereas high cumulativeness and high appropriability to more concentrated industries therefore to Schumpeter Mark II. With regard to *agents and networks*, Malerba conceives of firms as the key actors and active participants in the generation, adoption, and use of both new technologies and new approaches. Non-firm organizations the like universities, public agencies, financial organizations, and so on are also part of the system, relating themselves to firms through market and non-market relationships. Finally, *institutions* are defined as rules, norms, laws, standards, habits, routines, and practices that shape the behavior, actions and interaction of sectoral agents. As for knowledge, technologies and firms, Malerba makes the point that institutions are not homogeneous across sectors, they may be binding or less binding, formal or informal, and sectoral or national in range.

Several industries have been already studied using the SSI approach, including pharmaceuticals and biotechnology (Senker 1996; Henderson, Orsenigo et al. 1999;

Lemarie, de Looze et al. 2000; Malerba and Orsenigo 2002; McKelvey, Alm et al. 2003; McKelvey, Orsenigo et al. 2004; Nesta and Saviotti 2005); chemicals (Arora, Landau et al. 1999; Cesaroni, Gambardella et al. 2004); computers and electronics (Bresnahan and Malerba 1999; Fung 2002; Lau 2002); software (Mowery 1999; Grimaldi and Torrisi 2001; Steinmueller 2004); machine tools (Mazzoleni 1999; Wengel and Shapira 2004); telecommunications (Edquist 2004; Morikawa 2004; Mu and Lee 2005; Corrocher, Malerba et al. 2007); forestry in Central Europe (Rametsteiner, Weiss et al. 2005; Rametsteiner and Weiss 2006); and tourism (Sundbo, Orfila-Sintes et al. 2007)

Various issues may justify use of the SSI perspective. First, as horizontal innovation and diffusion policies, i.e. those that are the same across sectors, may not meet the particular needs of each sector the need for industry-tailored policies rises. Second, since policymakers themselves appear as SSI actors, they can learn about what factors are driving sectoral innovation and diffusion therefore should be promoted. Third, the sectoral perspective allows different levels of organization and policy to be taken into account. With regard to our study, we use SSI to describe the Chilean Forestry system of innovation in terms of actors, knowledge flows, and institutional setting.

2.3 Everett Rogers' Diffusion Model

Various disciplines have been striving to set out a holistic diffusion theory by using their own either conceptual or theoretical tools. However such efforts may have fallen into what may be called "wasteful" intellectual disputes about which approach may be a better representation of reality. Knowledge flows among disciplines turn out to be fruitful since insights in one discipline end up informing research in other fields. In this paper, we use Everett Rogers's model (see Figure 1) because its sociological perspective considers the role of institutional setting, economic factors, strategies of firms, and communication channels (Hall 2005).

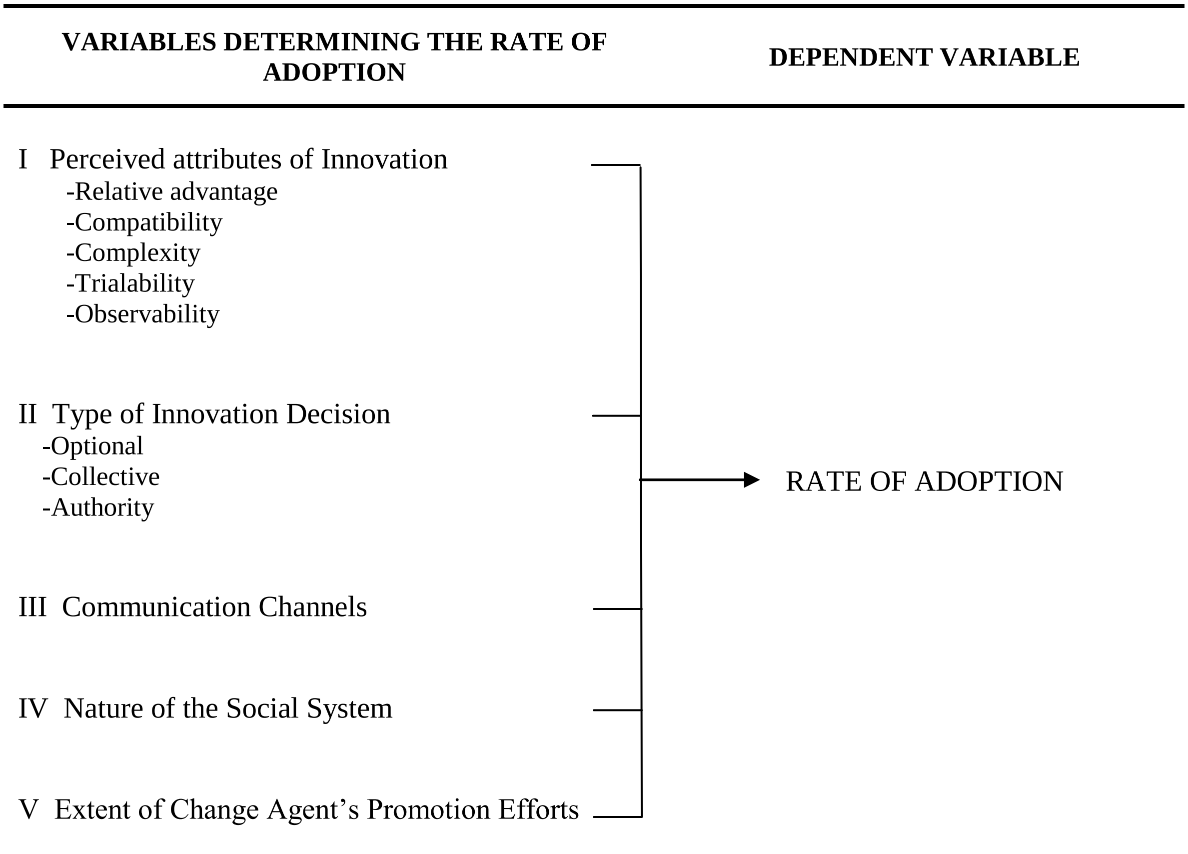
Rogers (2003) defines diffusion as "the process in which an innovation is communicated through certain channels over time among the members of a social system." He conceives of it as a special type of communication, that is, a process in which two individuals create and exchange information to reach a mutual understanding. The rate of adoption, defined as "the relative speed with which an innovation is adopted by members of a social system," serves as the dependent variable in Rogers' theoretical framework (Rogers 2003). The variable, measured as the number of individuals adopting a new innovation over a period of time, depends upon a set of individual and social factors. The former are grouped under the general category of *attributes of innovation* and involve five sub-factors dealing directly with the innovation itself: a) relative advantage, the adopter's assessment over an innovation, b) compatibility, whether the innovation complies with the adopter's values and needs, c) complexity, how difficult it is for the adopter to understand and use the innovation; d) trialability, how easy it is for the adopter to test the innovation, and e) observability, how easy it is for the adopter to observe the innovation in operation. Relative advantage, compatibility, trialability, and observability are all positively correlated with the rate of adoption while complexity is negatively correlated. Hall (2005) mentions that despite methodological differences across disciplines, Rogers's attributes of innovation are recognizable in one form or another in various diffusion studies. For instance, economists may relate their own uncertainty and risk concepts to Rogers's trialability and observability, or their own benefit-cost criterion and notions of cost and complementary investment to Roger's relative advantage and complexity, respectively.

With regard to the second set of variables, the so-called social ones, Rogers mentions four factors: a) Type of Innovation Decision, that is, whether the decision process is made individually, collectively or following a central authority; b) Communication Channels, that is, the mean used to obtain information about new innovations whether mass media or interpersonal relationships; c) Nature of the Social System, with regard to the norms, rules and the degree of interconnectedness of the system within which the adopter is embedded; and d) Extent of Change Agent's Promotion Efforts, referring to the role of the social actor leading the diffusion process and the means he/she uses in such process.

3. Methods

Our study used case study methodology, following Robert Yin (2003) approach, since our research question is an explanatory/how-type one not dealing with mere frequencies or incidence; the phenomenon to be studied is contemporary, technology diffusion in the industry is happening now; and we have no control over current diffusion events. The unit of analysis is the *firm*. We applied Yin's multiple-case/embedded or Type 2 case study design; that is, we considered a whole context, the Industry, with local forest firms as various unit of analysis.

Figure 1 Rogers's Diffusion of Innovation Model



Source: Rogers (2003)

Our theoretical model draws on SSI and Everett Rogers's technology diffusion framework. Our dependent variable is **Technology Adoption Mechanism**, the dynamics taking place as technology diffusion occurs in the Industry at firm level. TDM is affected by five variables (see Figure 2): first, *Attributes of the Innovation*, including the five sub-factors cited in Rogers' model: comparative advantage, compatibility, complexity, observability, and trialability; second, *Collaboration,* that is, what inter-agent relationships are taking place and what dynamics are ruling them; third, *Communication Channels*, the S&T information sources drawn upon by firms; fourth, *R&D Capacity*, measured in terms of forestry agents' human resources and physical infrastructure; fifth, *Institutional Setting*, that is, the Industry´s technology diffusion institutional framework. To collect information on each variable described above we designed an interview protocol including questions regarding dynamics of each of them.

Since we applied the SSI approach to describe the industry, we planned to interview public, private and academics agents. In order to determine who would be on our interviewee-list for each category, we worked with our colleagues at the University of Concepción Biotechnology Center, a prestigious R&D institution historically involved in forestry R&D. In light of its regular interaction with the public sector, we asked its experts for public actors involved in technology diffusion at the sectoral level. To choose private actors, we listed firms and professionals for three categories: National Forestry Corporations, Small and Medium Enterprises (SMEs), and service firms. With regard to academic actors, we consulted with researchers at the University of Concepción Biotechnology Center and also draw on Catalán et al (2007) bibliometric work on Forestry R&D. We came up with a final list of 21 professionals to be interviewed.

The analysis included the review of secondary information sources, namely public and private organizations' reports, databases (INFOR)[3], and sectoral journal and magazine articles. Once the interviews were completed and secondary information sources reviewed, we established a coding process to identify the dynamics related to each variable that had been defined as part of the model. As a further step, to weigh the effects of each variable, we ask interviewees to match them with one of five categories -very important, important, more or less important, not that important, not important- in terms of their effect on technology diffusion considering their own experience.

[3] Chile´s Forestry National Institute

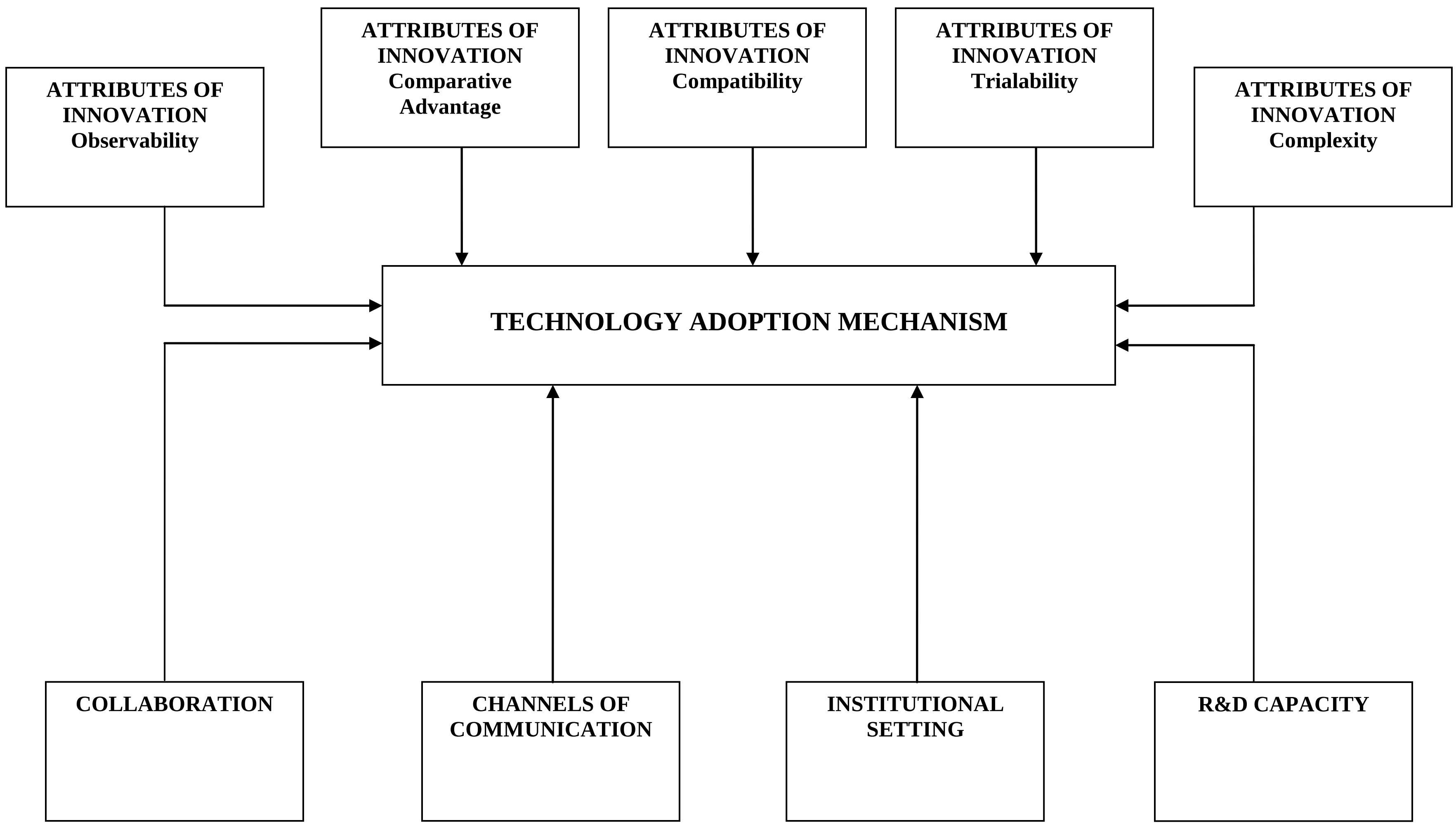


Figure 2 **Case Study Model**

4. Results and Analysis

4.1 Chile's Forestry Industry

Moreno and Dornberger (2006) describe the industry's value-chain as one in which three groups interact: Group 1, National Forestry Corporations working on silviculture, chemical and primary processes; Group 2, SMEs focused on higher value-added goods such as furniture, plywood, doors and windows; and Group 3, so-called "Side Industries" referring to consulting, services, R&D, and equipment manufacturing (see Figure 3). Although primarily a commodity supplier, the industry has evolved to become an exporter of secondary and tertiary goods covering nowadays a broad range of forest products: logs, splinter, sawn wood, hard and softwood cellulose, plywood, newsprint, furniture, doors and windows, wood toys, diapers and tissues, and others paper by-products. Production is mainly allocated to the internal market: 68.7 percent is used at the national level for construction, packing, short capacity sawmill and manufacturing wood-processing mills, whereas 31.3 percent is exported (INFOR 2006). Two non-native species, Radiata Pine and Eucalyptus, represent more than 90 percent of forest plantations in Chile, with planting areas of 1,461,212 ha and 625,808 ha, respectively[4]. Both once adapted to local conditions achieved similar growth rates than at their original locations thereby to allow the production of high wood volumes at low cost to cover national demand and to provide a competitive product at the international level. As mentioned previously, nowadays the industry face the challenges of to increase value-added, to incorporate environmental practices into forestry management, and to raise competitiveness by means of quality and productivity improvements.

[4] www.infor.cl

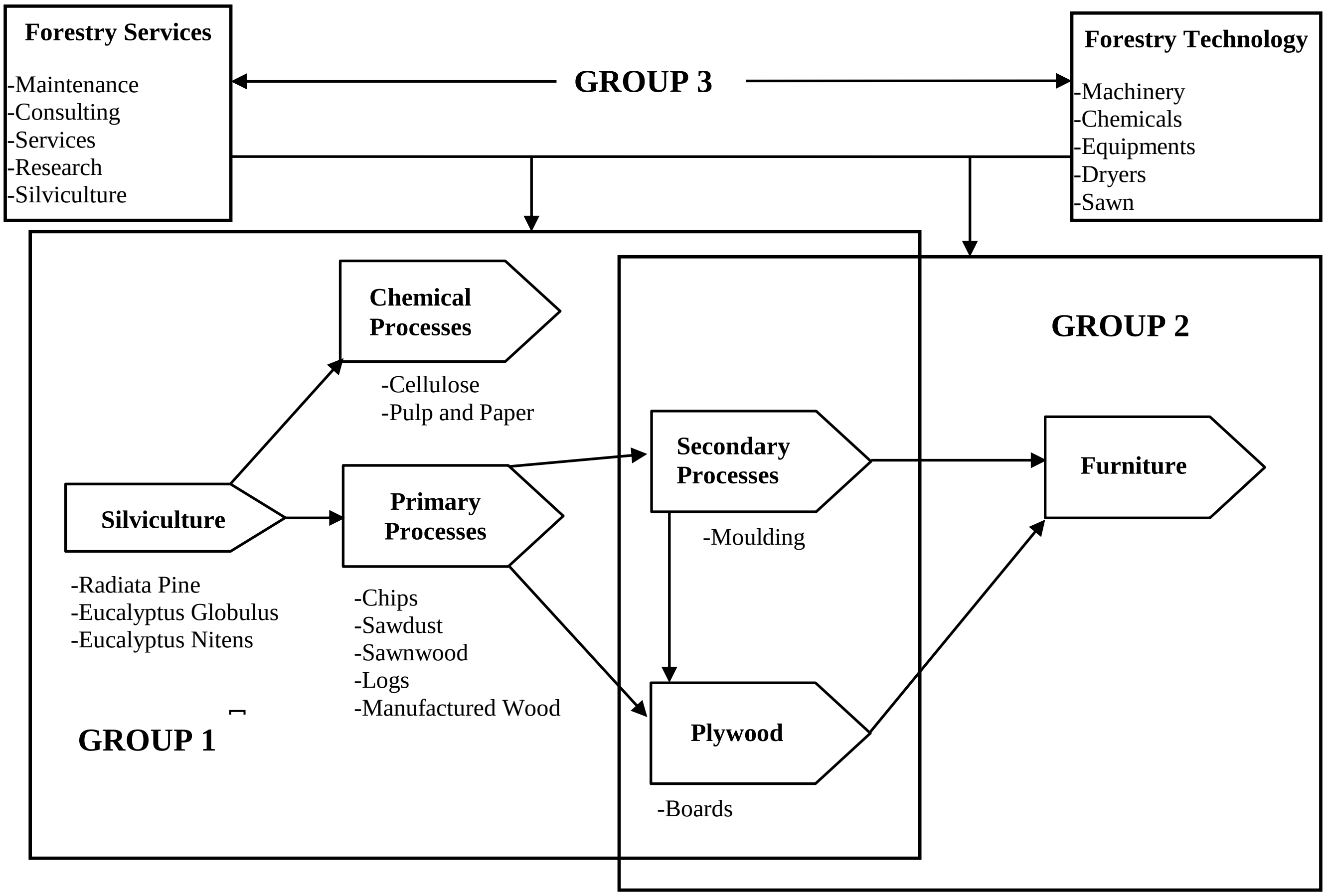


Figure 3 Chile's Forestry Industry Value Chain
Source: Moreno and Dornberger (2006)

Firms interact with public and academic agents. Public agencies such as the National Forestry Institute (INFOR), the National Forestry Corporation (CONAF), and the Ministry of Agriculture (MINAGRI) are more involved on the regulation of the Industry, whereas in terms of innovation funding the major public players are the National Science and Technology Commission (CONICYT) through the Science and Technology National Fund (FONDECYT), the Fund for the Promotion of Scientific and

Technological Development (FONDEF), and the Technological Development Agency (CORFO) through Innova Chile at national level and through Innova Bio Bio for the single case of the Bio Bio Region where the Industry is mostly concentrated. MINAGRI supports R&D through the Agrarian Innovation Fund (FIA), and does its own R&D at INFOR and the National Institute of Agrarian Innovation (INIA). With regard to academia, after reviewing the R&D public funds databases and publication productivity, it turns out that the more active local universities measured in terms of grants and publications are: University of Concepción, University of Chile, and Austral University (Catalan, Moreno et al. 2007; Catalan, Rodriguez et al. 2008) .

4.2 Attributes of Innovation

Our methodology follows Rogers' approach by defining attributes of innovation in terms of five sub-factors, that is:

-Comparative Advantage: Our interviewees identify comparative advantage as a major factor to be taken into account once the adoption decision occurs. As an interviewee stated: "the adoption of new technologies deals with the competitiveness of our business". Nevertheless, there are some points to be made. SMEs differ with national forestry corporations in their definitions of costs and benefits. The former are constrained daily in their long term decisions by budget restrictions; therefore adoption takes place as long as short term profits are part of the picture. In contrast, the latter do not perceive a high investment as a hurdle in light of what may be a long term higher productivity leading to higher returns. National forestry corporations pursue international competitiveness as a goal, not short-term local survival. An interviewee described the historical evolution of the industry in relation to technology diffusion as follows: between the years 1995 and 2005, he described the industry´s development as a “race for growth,”that is, local firms had at their disposal enormous stocks of wood so the industry was almost uniquely interested in how to achieve faster wood-processing to make higher profits. They already had the right technology in place for to do this. However, once wood availability started to decrease, the need arose for new markets and lower costs and new technologies started to be in high demand.

-Observability: Those we interviewed did find observability to be one of the most important factors affecting adoption, although less dominant than comparative advantage. We found wide agreement on two point: that organizations do not work on manufacturing their own technologies and that they do not adopt any technology if they are not able to previously observe it working well in another facility. An example given by one of our interviewees is the case of a Finnish supplier. As the supplier was unable to show its technology working in the field in Chile, a technology whose efficiency, efficacy, and quality have been strongly proved in other countries, his sales were dramatically limited at local level. However, once a group of forestry executives visited his headquarters in Finland and observed how beneficial it might be to implement the technology in their own facilities, his sales increased significantly. In terms of size, both national forestry corporations and SMEs rely on observability. The latter, although they consider their long-term planning as constrained by their limited budgets, have access to a set of public programs granting funding to visit either technology suppliers or technology users.

Interviewees recognized the benefit of such programs, but they criticized their “bureaucratic” managementfor long response time and the low flexibility in rules.

- Compatibility: In general, those we interviewed viewed compatibility with the goals and mission of the organization as an important factor affecting adoption. During the last years, the enactment of environmental regulation has prompted the industry, particularly national forestry corporations, to modify their missions and visions, even building new internal capacity to enable them to comply with such regulations. Nowadays, any technology to be adopted must fulfill the company’s environmental standards; otherwise, adoption is out of the question. A good example cited by one interviewee is his firm’s “zero fault” strategy, which promotes a set of activities to avoid any future environmental problem.

- Complexity: Almost all interviewees supported the idea that technology complexity is at least “less or more” important. New competences acquired during recent years in light of the industry’s higher international competitiveness have eased technology adoption. Even more, some interviewees point out that although the industry does not provide its own technology, nowadays it has become an “innovation adopting” industry. Therefore, the complexity of a technology is not as much of a hurdle as it was before. Size differences remain. National forestry corporations do not have any restrictions in incorporating complex technologies, as long as their implementation brings about higher profits. Aside from their own high skill technical staff, they can draw on either short stays of their own technicians or hiring international experts. SMEs, given their budget limitations, regularly go with less complex technologies because of their low cost. Furthermore, one interviewee noted the role of natural conditions in adoption: as long as a new technology adapts itself well to local weather, ground, and species, complexity is not a barrier.

- Trialability: Interviewees cite the industry's high cost operational/logistic structure as a barrier to trying out new technologies in their own locations prior to final installation. However trialability is not a common practice; size differences persist, National forestry corporations are more prone to simulation as they have fewer budget restrictions, whereas SMEs have few chances to try out the technology because of their constrained resources. It is worth noting that trialability is cited as the least important attributes of innovation by the interviewees; they do not perceive it as necessary for adoption al though they recognize it as a plus when it is feasible.

4.3 Collaboration

Collaboration is the most controversial factor; there are contradictory visions on the subject. As the industry is acquainted with international collaboration experiences, particularly those of Scandinavian countries, interviewees agree that it is linked to economic success. However, the industry has not put this lesson into practice. Local firms are perceived as highly individualistic, and the industry is defined as non-collaborative and fragmented. Interviewees agree that there is no such thing as a "Chilean Forestry Cluster." Interviewees gave two reasons for the industry's low collaborative performance: a) what interviewees call "culture" and "inter-firm distrust" among Chilean forestry firms, and b) a business model based on a "low cost-based" competitiveness. The latter created a high return during the infant phase of the industry and allowed Chile to become a major international player. But this strategy may not be the right path to follow today.

Firms cited universities most often as R&D partners, and they valued university efforts to improve their interaction with industry by implementing new technological platforms of mutual benefit. However, that response does not mean that there were no critics of universities. Interviewees pleaded for a higher number of undergraduate and graduate pulp and paper programs, as universities are not meeting the demand for human resources in terms of quantity and professional specialization. Customers, firms, public R&D institutes, and suppliers are also on the list of partner, although not as highly ranked as universities. Size matters. National forestry corporations, whose collaboration is not restricted to local level but also reaches international actors, team up actively with suppliers. In contrast, SMEs, particularly technology service providers, partner instead with customers. A good example of recent R&D collaboration is the Forestry Genomic Consortium, where the two largest national forestry corporations, Arauco and CMPC, partner with the University of Concepción, Fundación Chile, and CEFOR. The partnership, whose headquarters are located at the University of Concepción campus, started off as a public-private initiative jointly funded by the national government through CORFO, Chile's National Development Agency, and the firms involved. The consortium aims to become a source of knowledge not only for its members but also for SMEs, thereby contributing to improve sectoral collaboration.

4.4 Communication Channels

In our model communication channels refer to the sources Chilean Forestry agents draw on to update their S&T knowledge. It is worth noticing that 94 percent of our interviewees consider it "important" to have access to those communication channels; it is a must for them to be acquainted with the latest innovations, technologies, and approaches. There is no surprise, then, that 88 percent of the interviewees regularly consult cutting edge S&T information sources. Seeking knowledge refers not only to setting a contract or a formal agreement with an information/dissemination organization. It also includes those informal contacts that may be established through personal relationships with other forestry actors. Thus the roles of both suppliers and clients, who often are the ones bringing information on new technologies recently launched into the market, are recognized as "pivotal." Suppliers are involved in delivering news on new products or new processes that might increase efficiency, while clients prompt firms to keep an updated portfolio by demanding new product requirements.

The Internet is the most cited information source, however it is not perceived to make a difference in relation to competitors. Universities, scientific journals, and R&D centers are also on the list. Firms, however, do not always find the answers to their questions among such sources; universities are not always able to respond to their technical requests. Firms also draw upon fairs and seminars. With regard to fairs, firms value public programs supporting mostly SMEs to visit international fairs overseas. National forestry corporations have the resources to fund their own trips and are also able to organize seminars for themselves on particular research topics of interest. The managers we talked to did not oftren mention workers as information sources, sand perceived their knowledge levels as low and not cutting edge.

4.5 R&D Capacity

Variation in technology diffusion may be correlated with variation in R&D capacity at firm level; that is, sectoral adoption may respond to how well endowed firms are in terms of S&T infrastructure and human resources. We asked interviewees how they would define their own R&D capacity by using a low-high scale and taking into account both whether an internal R&D unit is already in place and characteristics of their own S&T staff. It turns out that 70 percent identify themselves as on average or lower than average. We found that R&D capacity is positively correlated with firm size. National forestry corporations define R&D as a path to higher competitiveness. They therefore fund R&D, despite its long-term return,. Arauco and CMPC, the two largest national forestry corporations, have strengthened their internal capacity by following different strategies. Two decades ago, Arauco created a new R&D firm, Bioforest, whose cutting edge laboratories and S&T staff, with a high rate of PhDs, have enabled the firm to develop and operationalize new technologies, particularly new genetic programs which have crated profits for the firm. On the other hand, CMPC, though has its own internal R&D unit, has chosen to focus on networking by reaching out to prestigious national and international R&D actors to cover its demand for R&D. In general SMEs have minimal R&D capacity because of their cost restrictions and short-term profit goals.

Two cases of attempts to build Chilean R&D capacity stand out: the Technology Development Unit at the University of Concepción (UDT), and the Forestry Genomic

Consortium. Both define their missions as developing new technologies in order to solve internal and sectoral challenges. The former is an initiative of the University of Concepción established in 1996 as a R&D center/technology-service-firm opened to the forestry sector, while the latter, as mentioned previously, is a public-private partnership in which Arauco and CMPC have teamed up with the University of Concepcion and Fundación Chile.

On the question of human resources, many of those we interviewed noted a deficit. They regularly cited the low educational background of workers as a sectoral drawback affecting technology diffusion. The low rate of hiring workers with S&T graduate education is said to constrain technology development at the local level, as well as S&T networking and access to cutting edge S&T information sources. Firms recognize the problem and push for new academic programs to cover their own human resource needs, not only in terms of numbers but also of work areas. However, although firms look forward to having staff with more expertise on board, most of them report that having a graduate degree would not make a difference in salary.

4.6 Institutional Environment

During the last 20 years, Chile has experienced steady economic growth, thanks to both pro-market policies and stable institutions. In terms of R&D, new publicly funded programs joined the existing basic-research-oriented Science and Technology National Fund (FONDECYT). The Fund for the Promotion of Scientific and Technological Development (FONDEF), Innova Chile, the Agrarian Innovation Fund (FIA), and the Bicentenary Program are among programs newly created to respond to the demand for applied research through mandatory private participation. In light of the new rules, firms along with universities and public research institutes started participating in the definition of working areas. However, our interviewees point out that such joint initiatives have normally been preceded by brief university-industry interactions in which the university works on proposals of their own interest, then approach firms looking for a formal signature to enable them to participate in a call for proposals. The national government addressed this situation by modifying the private funding requirement to ask firms for direct cash. The new rule resulted in more active participation of firms at the proposal phase, thereby increasing the productivity of the university-industry partnership. The implementation of pilot plants, new processes, and new products are mentioned as outcomes of public programs, alongside technology transfer activities such as fairs, seminars, and technological missions.

Despite those efforts, firms think there is room for improvement. In particular, there is no set of public programs and funds easing access to information sources and technology diffusion that are used regularly by the whole Industry. Interviewess cited two reasons. First, public instruments are not meeting the industry's R&D needs. Interivewees emphasize the inflexibility of certain requirements and in particular that the program rules do not give them enough time to develop the products or processes they need. An example is the instance in which a technological mission could not depart because the agency could not approve any deviation from the group travel dates. Second, firms point to public agency bureaucracy as a cause of the firms' low interest in public programs. Interviewees cite "ill-designed forms, excessive demand of legal records, and long response time" as drawbacks of the public funding system. They describe making a proposal as a tedious process in which firms spend long amounts of time on discussing topics, research goals and methods as well as collecting legal records. In some cases, firms do not have time to prepare the proposal themselves and they wind up hiring a consultant, thus incurring in a further cost not originally considered. On the other hand, public agencies argue that strict requirements are needed to avoid the risk of granting taxpayer money to projects executed by agents unable to carry them out or with legal problems. The agencies may want to explore new automation techniques to speed up and ease the process.

5. Conclusions

The dynamics of technology adoption in the Chilean forestry industry are driven by a set of endogenous and exogenous factors. In terms of attributes of innovation, firms do report behavior consistent with some of Rogers's premises. They take comparative advantage into account, especially larger firms. National Forestry corporations are not constrained by investment as long as profits come along in the long term, whereas SMEs need to respond to budget restrictions. Complexity follows a similar pattern, though nowadays it is not as significant as it was earlier. Compatibility is pivotal. As the national public opinion is increasingly demanding to all industries to incorporate respect for the environment into their daily activities, forestry firms do not adopt any technology that is not environmentally friendly. Firms rather prefer to observe a new innovation working in the field before they adopt, by visiting either suppliers or firms where the innovation is already in operation. But cost restrictions make it hard for firms to implement this desire.

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On the other hand, the firms report that their collaboration is low because of both inter-firm distrust and a low-cost strategy pursued during the industry’s infant phase that fragmented the industry. Communication channels are quit diverse, either formal or informal. With regard to R&D capacity, high-skill human resources shortages hinder access and management of new technologies, particularly at SMEs. The lack of workers with forestry graduate education is due to both a low demand at firm level and to the scarcity of forestry graduate programs. Althoug the programs that do exist are of high quality, they do not all necessarily respond to the forestry industry’s requirements, particularly in the pulp and paper field. In terms of institutional environment, the industry would like to see less bureaucracy in public R&D programs and less time required to prepare proposals in both technical and legal content.

The industry needs to absorb and to assimilate the concept of cluster, built upon high levels of collaboration, taking into account that creating and disseminating new technologies needs local actors with strong R&D capacity, that are able to answer short, medium, and long term requirements in a timely manner. Higher competitiveness comes along with new technologies,the diffusion of which will be determined by the industry’s collaborative performance and technological capacity.

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