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Low awareness of the link between science and innovation affects public policies in developing countries: The Chilean case

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Developing countries share disbelief about the benefits of the endogenous production of science as a tool for economical growth. Hence, public policies to strengthen science and technology and promote the culture of innovation are, in general, weak and sometimes incoherent.

Patenting has become not only an icon to protect discoveries which can yield profits and enable socio-economical growth but also a potent informetric tool to assess innovation and certainly, since the seminal work of Narin, to understand the multidimensional interactions between science, technology and innovation.

In this article we examine the impact of Chilean research articles on world technology as viewed by the link between articles produced in Chile and US patents. Our results show that from 1987 to 2003, 509 US patents had 562 citations to 273 articles produced at least, by one author working in a Chilean institution. US, not Chilean companies are the holders of patents citing Chilean produced articles. The research articles covered many disciplines but a clear concentration occurred in the biomedical field. Additionally, chemistry was also well cited.

Our results confirm that in Chile a non-patenting culture which involves researchers and institutions still prevails. Hence, public policies need to be designed and implemented to foster scientific production and innovation in order to advance progress in the current knowledge-economy-driven society which sustains competitiveness in the globalized world.

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Introduction

Developing countries share some political biases which affect their ability to face the complexity and dynamism that nurture a culture of innovation. Although the need to protect intellectual property rights has been gaining public acceptance, as discussed by CHEN & PUTTITANUN (2005) a theoretical debate often hidden and placed in a North versus South context casts some doubts in developing countries. This matter seems to be embodied in the social subconsciousness and has clear effects on the public and private attitude towards S & T and, as a consequence, on innovation. Investment for R&D in the Latin American region is extremely low when compared with developed countries. According to the Chilean Academy of Sciences, Chile spent only 0.7% of GNP in 2002 (approximately U$ 500 millions) corresponding 0.38% to public funds (in 1995 public support compounded 0.45% of Chilean S&T expenditures) whilst 0.32% was provided by the private productive sector.[*]

Although Chile has shown great improvement with respect to the number of students enrolled in high school (over 90% of the cohort), the overall educational performance as reflected in national and international assessments such as TIMSS (Trends in International Mathematics and Science Study) and PISA (Program for International Student Assessment) is very poor. Concurrently, although official adult literacy rates are high, actual literacy skills as evidenced through the International Adult Literacy Survey (EYZAGUIRRE et al., 2000) are inadequate. Access to higher education, which remains overly oriented towards professional degrees with rather low curricular flexibility, is growing rapidly. However, there is a clear deficit in the number of PhDs graduates, i.e., 15 per million inhabitants/year.[**] This is clearly a deficit when compared to international indicators (KRAUSKOPF, 2003) and to the demands of a country whose economy has grown notably during the last two decades and has free trade agreements with the US, Canada, Mexico, Central America, Europe, South Korea and China, with others being negotiated, thus demanding new paths to continue to develop and compete.

Today, the concept of innovation is flourishing in discourses of the government, political circles and entrepreneurial associations. At the same time, there is clear interest among economists and sociologists to implement policies aimed at injecting innovation into the bloodstream of Chilean economic development efforts (TOKMAN & ZAHLER, 2004).

The discussion on innovation is being carried out against a background of Chile's low performance in the scientific and technological universe. In this context we deemed important to assess, in spite of the poor performance in patenting in and from Chile, if research articles produced in the country were cited in U.S. patents. We hypothesized

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[*] ACADEMIA CHILENA DE CIENCIAS, *Exposiciones Foro. Analisis y Proyecciones Ciencia Chilena*, Santiago, Chile, 2005.

[**] CONSEJO DE RECTORES UNIVERSIDADES CHILENAS, *Anuario Estadístico 2004*, Santiago, Chile, p. 42.

that the overall value of the knowledge produced in Chile was underestimated by the society as a whole and particularly by policy makers, economists and entrepreneurs. Also, in a different manner, by scientists.

Methods

The Thomson-ISI 1981–2003 Chilean National Citation Report for Chile was standardized (38,862 documents) to correct the wide description used by authors and by the original database to depict with precision the institutional link with the authors. We also corrected the mistakes in the names of the authors to provide a precise identification of them and their institutional affiliation. Thus, a Chilean author means that articles have been originated by at least one author employed in a Chilean academic or research facility.

The standardized version of the Chilean National Citation Report was somewhat modified by ipIQ (formerly CHI research, Inc) to be used with their unique database of more than 2 million unified references from US patents to scientific articles. The modification permitted better matching of both databanks.

ipIQ matched both the Chilean database with the references contained in US patents identifying the publication year of the article, the full journal name, the first author's last name, and page number. Mismatches were dropped as well as the duplicates that can appear because the US system occasionally cites a single article more than once in the front page of the patent.*

To assess the number and impact of mainstream articles having at least one Chilean author as well as the number of articles published by other countries we used the Thompson-ISI NSIOD Deluxe database (1981–2003)

Results

The contextual Chile's science and patents scenario is depicted in Table 1. The number of mainstream articles published by authors from Chile is the lowest when compared to articles published by authors from the selected group of countries included in this sample. When normalized to population Chile performs better than its neighbors, but is still far lower that the newly emerging economies which Chile expects to follow.

* The process was performed by Kimberly Hamilton, Peter Kroll and Francis Narin, in ipIQ, Haddon Heights, N.J, using a database containing more than 2 million unified references from US patents to scientific research papers. To capture citations without introducing incorrect citations the match was expanded to all cited papers that matched on the first 12 characters of the journal name, to the first 2 characters of the first author's last name, and page. After carefully analyzing 75 citations were found mismatches and dropped. Corrections were also made for articles that were cited more than once in the same patent. The duplicates (n = 8), were removed.

Table 1. Science and Technology indicators for countries with different economic development levels

Countries of origin	Papers published by authors of country of origin		USPTO patents granted by first inventor of country of origin		Ratio of patents to papers per country of origin
	Per year 2003	Per year 2003 and per one million inhabts.	Per year 2003	Per year 2003 and per one million inhabts.	USPTO patents 2003 per 1,000 papers 2003 for country of origin
Finland	7,851	1,510	865	166.3	110
Ireland	3,061	785	163	41.8	53
Australia	23,620	1,199	900	45.7	38
New Zealand	4,666	1,167	135	33.8	29
Mexico	5,902	56	84	0.8	14
Argentina	4,679	121	63	1.6	13
Brazil	12,699	70	130	0.7	10
Chile	2,550	162	11	0.7	4

With respect to US patents granted to local inventors, Chile had a meager 11 patents granted in 2003 giving an index of 0.7 patents per million inhabitants/year. This number is close to that shown by other Latin American countries but significantly lower than the other countries depicted in the sample which show indexes of 33.8 patents per million inhabitants or higher (BENAVENTE, 2005; MENDEZ, 2005).

Finally, the last column in Table 1 show a "conversion index": the ratio of patents granted by the USPTO in 2003 to inventors from a specific country of origin per 1,000 papers published in 2003 by investigators of the same country. Once again Chile occupies the last place, lower even than the rest of the Latin American countries, with only four patents granted by the US patent office per 1,000 papers published by Chilean investigators.

When we studied whether research articles produced by Chilean investigators were having any impact in worldwide technology by matching our 1981–2003 database of 38,862 S&T articles with the database containing the references included in US patents granted between 1984 and 2003, 273 articles and 562 citations were identified in 509 patents. A total of 562 references were linked to US patents because each paper could be cited more than once. The results showed that US, not Chilean, companies are the holders of patents most often citing Chilean papers (only four of the citing patents had assignees from Chile) confirming that the research is not being utilized by the local industry.

As shown in Table 2, the scientific research in which technology is building is academic since the institutions most frequently present in Chilean authored papers were Universities.

Table 2. Chilean universities with at least one author cited in US patents (1987–2003)

University	Number of citations received	Number of articles cited
Universidad de Chile	249	127
Pontificia Universidad Católica de Chile	157	64
Universidad de Concepción	44	19
Universidad de Santiago	39	23
Universidad Austral	37	11
Universidad Técnica Federico Santa María	10	7

Concerning the fields of Chilean authored articles mentioned in US patents, Biomedical Research received 211 citations, Clinical Medicine 163, Chemistry 119, Biology 25, Engineering & Technology 24, Physics 9, Earth & Space Sciences 5, Mathematics 3 and Psychology 3. Figure 1 depicts the citations to Chilean articles by subfields.

When the numbers of Chilean articles cited (not the cites) are quantified by field of the cited article, Biomedical Research tops the ranking with 91 papers, followed by Clinical Medicine with 88, Chemistry with 49, Biology with 19, Engineering & Technology with 14, Physics with 6, Mathematics with 3, Earth & Space Sciences with 2 and Psychology with 1. Figure 2 shows the subfields of the Chilean articles cited within the examined period (1987–2003). The number of citations is larger than the cited articles because the articles cited in patents can be cited more than in one patent. Biochemistry & Molecular Biology is the most cited subfield both in number of articles and citations. Nevertheless, the 12 articles in Organic Chemistry topped the most citations per articles: 3.6.

Although citing of Chilean authored articles by US patents commenced in 1987 a steady increase is observed starting in 1997. As shown in Figure 3, the rate of growth of US patents referencing Chilean articles is higher than the rate of growth of the articles produced in the country. The average citation rate between 1994–1998 and 1999–2003 of Chilean articles in the biomedical and chemical fields has increased remarkably, e.g. Biochemistry and Biophysics from 3.92 to 5.29; Immunology from 2.33 to 6.05.

Certainly the visibility of the articles in the internet era contributes to the acquaintance of the research performed in less developed countries which in turn has increased the possibilities for collaborative endeavour with other countries. Many of the Chilean papers cited by US patents have coauthors in the USA, Italy, Argentina and France, among other countries. Therefore, the increased citation of Chilean-authored mainstream publications in patents of US companies probably reflects increases in collaborations and in the number of Chilean-authored mainstream publications. Although it is difficult to quantify the part that Chileans have played in the patented invention, the papers cited by US patents in our study represent mostly Chilean science as inferred by the specific field of work of the Chilean authors within the country.

Less developed countries, in general, seek more collaboration for their own research work because of the scarcity of the critical mass of world class investigators.

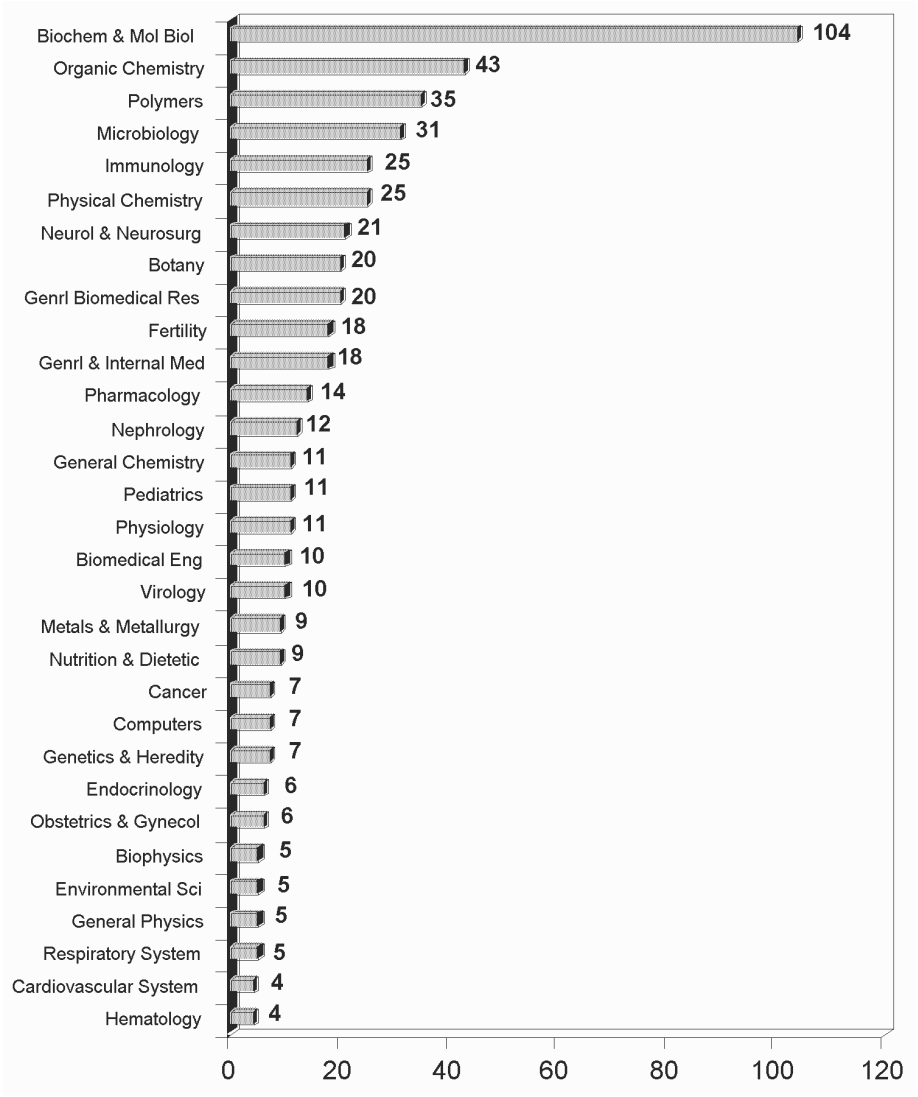

Figure 1. Citations to Chilean research articles in the 1987–2003 US patents by subfields of the cited paper. Subfields with less than 4 cites are not shown

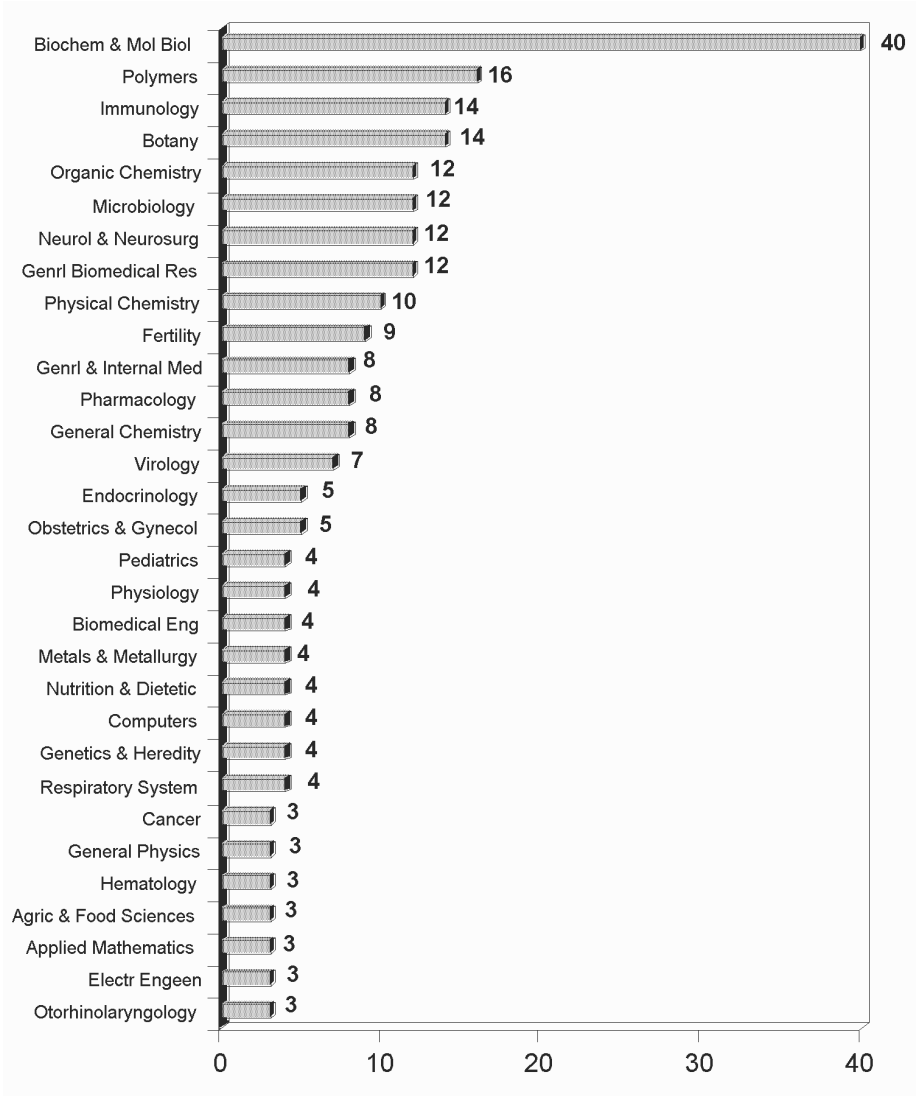

Figure 2. Number of Chilean research articles cited by US patents (1987–2003) by subfield of the cited paper. Subfields with less than 3 articles are not shown

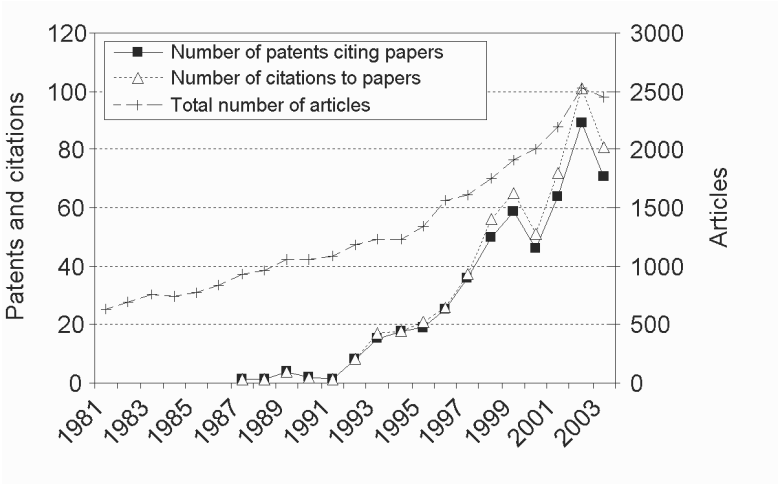

Figure 3. US patent references to Chilean papers by issue year of citing patent

Discussion

Although the direct or indirect interactions between science and technology are certainly complex, patent citation analysis of the scientific literature has facilitated the analysis of the existing relation between scientific output and inventions (CARPENTER et al., 1980; NARIN & NOMA, 1985; NARIN et al., 1997; IVERSEN, 2000; MEYER et al., 2004; MEYER, 2006a, b; ATALLAH & RODRIGUEZ, 2006). Recent work by MEYER (2000, 2006a) indicates that the link between scientific publications and patents depicts more than a unique knowledge stream from science to technology. It portrays, perhaps, in a better manner the reciprocal exchange processes that nurture both, science and technology (MEYER, 2006a). As reviewed by IVERSEN (2000), in the knowledge-driven economy, although the developer of the new information seeks to appropriate the profit of the novel awareness, some of it will spill over to other actors.

Policy-makers in many developing countries, certainly in Chile, stress the significance of non-publication factors to feed the innovative knowledge that the productive sector needs to contribute to economical development. These non-publication factors are achieved by the interaction between university research and particular entrepreneurial endeavors related to their specific problems. In this context, it is of interest to note that as shown recently by MEYER (2006b), "academic" research in three European countries, does not collide with inventions patenting. In nanotechnology, patenting scientists do better than their non-inventing peers in the number of publications and citation frequency (MEYER, 2006b). Thus non-publication

approaches, i.e., further strengthening of what is known in Spanish as the relation *universidad-empresa* do not necessarily substitute the scholarly driven path to generate science and to publish results in competitive journals.

From the indicators depicted in Table 1, particularly examining the low "conversion index" (ratio of patents granted by the USPTO in 2003 to inventors from a specific country of origin per 1,000 papers published in 2003 by investigators of the same country) it appears to be clear that the Chilean investigators are not appropriating knowledge from research into patents at a rate even comparable to the neighboring countries, and far less than the emerging countries. Conversely, articles by authors employed in Chilean academic institutions following disciplinary patterns resembling those which occur in other countries like India (GUPTA, 2006) are not appropriated by the discoverers or by the institution where they are affiliated. Instead their contribution to the knowledge-driven economy seems to be provided principally from the intrinsic spill over that science produces.

Our findings confirm that the Chilean scientific community is not imbued with the idea of needing to protect their discoveries and neither are the universities. Research policy has been inspired frequently, as tends to occur in less developed countries, by anecdotal or personally experienced paths instead of by well studied, evidence based approaches. Thus, the relation between science and technology and the role of basic sciences in patenting technological discoveries is practically ignored by entrepreneurs as well as by government policies As a consequence, publicly funded grants are poor in the amount of overhead funding, intended to cover administrative costs of the projects (17% is the maximum in Chile) as compared to an average overhead rate of 49.1% for the top 100 public institutions and 56.7% for the top private universities in the US (BRAINARD, 2005). On the contrary, in Chile, clearly a developing country, the low level of overhead funding has led host institutions to prefer revenues from under-graduate enrollment over strongly supporting research groups and PhD students.

Strong evidence has been provided for the need of governmental support for the science of industrial technology innovation. As shown by NARIN et al., (1997) the linkage between U.S. technology and public funded research is increasing significantly. The link has a strong national component, i.e., patent inventors cite their own country's articles significantly higher than expected. Even though the existence of a broad discussion on innovation in Chile, there is widespread myopia in not recognizing that inventions need a strong locally based platform of fundamental research and that these inventions will not occur simply through importing knowledge without culturing the required high level domestic capacity. This notion is supported by the fact that Fondecyt, the National Fund which vertebrates basic research based on the merit of the proposals is weak (funding for fundamental research projects has essentially not increased over the last 9 years) and does not receive proper political attention.

In countries like Chile, to make innovation a real tool for development, governments need to have the required political will to consider R&D as a power engine of the country's progress. In Chile the Congress has passed a law establishing a specific tax on mining activities, which will be used to foster innovation. This tax will yield, in the order of, U$ 200 million annually once fully established. Moreover, an *ad hoc* National Council for Innovation and Competitiveness was created last year, with the objective of delineating a long term strategy in this area and to propose measures to strengthen the national innovation system and public policies, as well as to assign, prioritize and evaluate the use of all public funds directed towards innovation. However, at a time when Chile is reaching $ 125 billion in GNP, funding of such a critical goal cannot rely on the resources from the recently established mining tax but needs to become an integral part of the country's budget at levels commensurable with the expected results (1.5% of GNP or higher). As in other emerging economies defining and implementing a long term strategy for S&T which includes increased public funding for PhD programs, for basic research grants to individuals, for creation and maintenance of centres of excellence, for a program to import scientific and technological talent and for public/private technological consortia, is essential. Furthermore, the strategy needs to include strong incentives to the private sector, individuals and organizations, to capitalize on R&D.

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