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Abstract

We present the results of an empirical study of the national innovation systems of countries in the Iberian Peninsula and Latin America from a comprehensive neo-Schumpeterian economics (CNSE) perspective. The empirical study covered the period from 2000 until 2011 and the countries analyzed are Argentina, Brazil, Chile, Mexico, Portugal, and Spain. Unlike previous approaches that used cluster analyses as a methodological framework to analyze national innovation systems from a CSNE perspective, we use a novel approach based on multicriteria decision analysis (MCDA) to rank innovation performance. We show how an MCDA approach can be followed in order to rank the performance of national innovation systems and provide an analysis of the results obtained at the financial, public and industry pillars of the CNSE model.

Keywords: Comprehensive neo-Schumpeterian Economics; Innovation Performance; Multicriteria Decision Analysis; National Innovation Systems.

1 Introduction

In this article, we assess the innovation systems of countries in Latin America that can be classified as "catch-up economies" and evaluate their recent progress against their counterparts in the Iberian Peninsula over the period of time from 2000 until 2011. As a theoretical framework, we use the Comprehensive Neo-Schumpeterian Economics model put forth by Hanusch and Pyka (2007a,d).

The motivation for conducting an empirical study of the innovation systems of Latin America and the Iberian Peninsula is manifold. Firstly, the innovation systems adopted by the countries in Latin America is deeply rooted in the history and tradition of Portugal and Spain, is strongly influenced by cultural and socioeconomic ties with these two countries, is based on a legal system inherited from them, and is embedded in a common geopolitical setting.

Secondly, actors at the industry pillar in Latin America have traditionally seen Portugal and Spain as the natural target markets when driving the international expansion of export-oriented firms in knowledge-intensive industries. This is also the case for actors at the industry pillar in Portugal and Spain that have traditionally seen Brazil and the Spanish-speaking markets in Latin America as the natural addressable markets for international expansion. In both cases, these strategic decisions are predicated on the "better strategic alignment" between the opportunities presented by these markets, on the one hand, and the resources, capabilities and competences of the firms to capitalize on these opportunities, on the other—not on the size of the market *per se*. In fact, for firms driving radical or substantial innovation in either of these regions the size of the addressable market and the absorptive capacities available in the national innovation system of the U.S. would indicate that early commercialization in North America should take priority over expansion in Latin America or the Iberian Peninsula. The real or perceived lack of resources, capabilities and competences to do so is often seen as an insurmountable obstacle that prevents them from doing so. This is to be compared with the strategic decisions made by innovative firms in knowledge-intensive industries located in complex regions of innovation and entrepreneurship such as Silicon Valley whose strategy is radically different. Highly innovative firms emerging out of regions such as Silicon Valley and backed by tier-1 venture capitalists will have the resources, capabilities and competences required to execute their acceleration and international expansion agendas first in North America and then in the tier-1 markets in Western Europe and the Asia Pacific region. To address the markets in the Iberian Peninsula and Latin America is less strategic for them and is therefore executed only at a later stage.

Thirdly, for many countries in Latin America, including some of the countries considered in this study, to achieve the level of Portugal and Spain in terms of indicators measuring the competitiveness of their national innovation systems have become an objective that is considered as attainable within the foreseeable future. In the case of Chile, the first South American country to join the OECD in 2010, actors at the public pillar of the CNSE model have stated that attaining the level of Portugal in terms of per-capita income and global competitiveness of industry sectors based on natural resources is a goal of public policymaking that is expected to be achieved by 2020.

Last but not least, we have felt less compelled to include in our study the national innovation systems of countries in the Americas whose economies qualify as "knowledge-based developed economies," such as the U.S. and Canada, as they stand out in categories of their own in terms of innovation performance not only in the Americas but also globally. For similar reasons, we do not include in our study the national innovation systems of countries in Latin America whose economies clearly qualify as "less-developed economies."[1] We also decided not to include in our analysis the national innovation systems of countries in Eastern Europe, Asia and the Pacific Rim that may qualify in the category of "catch-up economies." Though many of these countries might also face the challenge of transitioning from the catch-up-economy category into the category of "innovation-based economy," their history and tradition differ from the countries analyzed in this study, they are strongly influenced by cultural and socioeconomic ties with other former colonial powers from whom they also inherited a different legal system, and they are embedded in different geopolitical settings.[2]

[1] We refer the interested reader to (Hartmann *et al.*, 2010) for an analysis of a larger set of countries in Latin America.

[2] See (Hanusch and Hara, 2012) for an analysis East Asian and Pacific countries from a CNSE perspective.

2 The CNSE Model

The theoretical foundation for the empirical study presented in this article is provided by the Comprehensive Neo-Schumpeterian Economic (CNSE) model put forth in (Hanusch and Pyka, 2007a, d). These authors put forth a model that can serve as a framework to assess the performance not only of EU member states but also of other emerging regions of innovation around the world along three main pillars: the financial, the public and the industry pillars of the economy.

The use we make of the CNSE model as a theoretical foundation for our empirical study is grounded on the following previous results:

i. Hanusch and Pyka have shown that CNSE is an adequate theoretical framework to model and measure the impact of economic policies based on innovation in knowledge-intensive industries (Hanusch and Pyka, 2007b, c, d);

ii. These authors have also shown that the CNSE model is an adequate theoretical framework to measure the so-called "future orientation of innovation systems," that is, their ability to proactively create the conditions within regions of innovation to compete in dynamic economies driven by intensive and rapidly changing knowledge (Hanusch and Pyka, 2006);

iii. Finally, the indicator-based three-pillar model is a direct implementation of the CNSE approach to public-sector economics (Hanusch and Pyka, 2007a).

Based on this previous body of work, we conducted an empirical study of the main economies of Latin America, including the economies of the Iberian Peninsula. In order to characterize the interaction of actors at the financial, public, and industry pillars of the CNSE model, we used the following approach:

i. We first compiled a dataset containing innovation indicators for the period from 2001 until 2011 for the countries under study. The dataset was obtained primarily from data contained in the World Bank and was motivated by previous research in the area of evolutionary learning and economic development (Arocena and Stutz, 2005), economic development and the national innovation systems approach (Johnson *et al.*, 2003), recent research on the factors that determine innovation performance in emerging economies (Furman *et al.*, 2002; Wang and Kafouros, 2009), as well as on previous analyses of the national innovation systems in Latin America (Hartmann *et al.*, 2010; López-Claros *et al.*, 2006).

ii. Based on this first dataset, we then put together a dataset containing three sets of indicators at the three pillars of the CNSE model for the period from 2000 until 2011.

iii. Finally, we performed multicriteria decision analysis in order to rank each of the countries under study in terms of their innovation performance.

3 Previous Work

Our work builds upon previous work on the application of the CNSE model for conducting an empirical analysis of the innovation systems in Latin America reported in (Hartmann *et al.*, 2010) and recent research on the economies of East Asian and Pacific countries (Hanusch and Hara, 2012).

The approach we follow departs from this previous work, though, in several respects, as described below:

i. Firstly, our dataset has been compiled with a focus on indicators at the three pillars of the CNSE model, that is, the financial, public, and industry pillars, that more directly impact on the performance of the innovation systems of the countries under study than those originally proposed by Hartmann *et al.*, 2010.

ii. Secondly, we focus on the tier-1 economies of Latin America, namely, Argentina, Brazil, Chile and Mexico, and include Portugal and Spain in the analysis. The reason for restraining our analysis to the economies of these countries is that the aim of our work is to ascertain to what extent the main Latin American economies can be compared with their natural counterparts in the Iberian Peninsula.[3]

[3] As mentioned, a stated goal of some of these Latin American countries, most notably Chile, has been to reach the level of Portugal, in terms of such indicators as per-capita income and competitiveness of its national innovation systems, by 2020.

iii. Thirdly, and more importantly, we depart form a cluster analysis and adopt a rather novel approach to ranking the performance of the national innovation systems of the countries under study based on multicriteria decision analysis.

The cluster analysis undertaken in (Hartmann *et al.*, 2010) encompassed a total of 44 indicators, 19 of which were indicators for the category “knowledge,” 12 of which were more directly connected with innovation performance, to analyze a total of 20 Latin American countries, most of which would be classified in the category of “less-developed economies” in terms of innovation performance. More importantly, though, the notion of socially sustainable Comprehensive Neo-Schumpeterian Development put forth in (Hartmann *et al.*, 2010) was based on objective classes of indicators along the categories “freedom,” “knowledge” and “economic structure,” which constituted quite a departure from the original CNSE model in terms of its original objective of providing a theoretical framework for assessing innovation performance. Another reason for departing from a cluster analysis as the methodological framework for conducting our study was the reduced amount of countries under analysis.[4]

But the main reason from departing from a cluster analysis and adopting a multicriteria decision analysis approach is that the latter goes far beyond cluster analysis as a quantitative analysis tool in that, starting from a given set of indicators, it allows us: (i) to compare national innovation systems by providing a metric of aggregated global utility of a national innovation system when compared to the national innovation systems of other peer countries and (ii) to inform and guide investment decisions that may directly or indirectly impact on the value of the indicators chosen in order to preserve or improve the performance of a national innovation system expressed in terms of aggregated global utility.

4 The Methodology

We depart from previous empirical studies that used cluster analyses to analyze the future orientation patterns of national innovation systems based on, or at least inspired by, the CNSE model and adopt an approach that introduces the notion of utility.

[4] In fact, a similar critique could be made of previous approaches that used cluster analysis as a method to identify patterns of future orientation of national innovation systems for a relatively few number of countries (Hartmann et al., 2010; Hanusch and Hara, 2012).

4.1 Introducing the Concept of Utility

Utility in the context of our present discussion can be construed as the "competitiveness" or "performance" of a national innovation system in relation to the national innovation systems of other peers at a sectoral, regional, national, supranational or global level. From a CNSE perspective, this notion of utility is connected with the concept of "future orientation" introduced in the CNSE model. The future orientation of an innovation system denotes the extent to which actors at each of the pillars of the CNSE model mutually cooperate to proactively create the conditions that are necessary to achieve a future state, the expected state, of sectoral, regional, national or supranational innovation competitiveness along the so called "neo-Schumpeterian corridor" (Hanusch and Pyka, 2007).

From a MCDA perspective, this notion of competitiveness is connected with the concept of flexibility, which is defined as the adjustment capability of a system to adapt to its environment, known as "robustness," and the time and effort required for such adjustment to take place (Pereira *et al.*, 2011). Taken together, these three dimensions of flexibility give rise to different co-evolutionary patterns that are the result of the dynamic nature of flexibility of actors at the three pillars of the CNSE model in knowledge-intensive industry sectors.

According to these dimensions, the local flexibility of an innovation system is defined as the capability of the system to adjust its current state to an expected state (Pereira and Paulré, 2001). Therefore, we define robustness in the present context of innovation systems as the property of an innovation system to adjust from a series of actual states to a series of expected states. For the purposes of our study of innovation systems, robustness analysis aims to evaluate flexibility of an innovation system when a given environment is considered. In this sense, robustness is different from sensitivity, as it is not concerned with the stability of a specific state of an innovation system when it faces uncertainty factors. Instead, it is about the capability of the innovation system to reach an expected state.

Under this novel approach, we view the problem of analysing national innovation systems not as a classification problem *per se* but as a ranking problem, which may even lead in the future to postulating a benchmark of competitiveness at a sectoral, regional, national, and supranational level, and even at a global level.

4.2 Ranking Innovation Systems as a Multicriteria Decision Analysis Problem

The problem of ranking the innovation systems at sectoral, regional, national or supranational level can be modelled as a multicriteria decision analysis (MCDA) problem. Traditionally, MCDA methods are used to aid a decision analyst in making strategic decisions concerning a set of *alternatives* and a set of *criteria*. The task of the decision analyst is to choose among alternatives that are being compared according to a set of criteria.

For the purposes of our analysis of innovation systems, we construe the set of alternatives as the set of countries under study and the set of criteria as the set of indicators used to analyze them. Following this approach, a set of indicators were compiled at each of the three pillars of the CNSE model. Each indicator contributes a positive or negative utility for each of the countries under study. The relative utility is then compiled for a given indicator at a given pillar for a given country in relation to all other utilities contributed by the same indicator for all other countries. The countries are then ranked according to the overall utility achieved at each of the pillars of the CNSE model. In our application, the aim is not to choose one country over another but to come up with a ranking of the countries under study at each of the pillars of the CNSE model.

Methodologically, the empirical study presented in this article is based on the following phases of a decision aiding process (Bouyssou *et al.*, 2006):

i. Problem Formulation: The problem is formulated as the triplet $\Gamma = \langle A, V, \Pi \rangle$, where A is a set of actions, in our case national innovation systems defined in terms of the CNSE model, V is a set of points of view, in our case indicators considered to characterize elements of A at each of the pillars of the CNSE model, and Π is a procedure stating what should be done with the elements of A, which in our case corresponds to ranking the innovation systems.

ii. Evaluation Model: An evaluation model is a tuple $M = \langle A, C, U, R \rangle$, where C is a set of criteria derived from V allowing the evaluation of elements of A in terms of each criteria; U models the uncertainty regarding the available information in $A \times C$; and R is an aggregation logic defining the way that the information concerning A and C is operated in order to obtain a global conclusion by solving the problem Π. As we will see, such logic is provided by the method introduced in Section 4.3 and further described in Section 4.4. The evaluation model produces a process output, i.e., the ranking of innovation systems.

iii. Recommendation: Using the output of the evaluation model, a recommendation is given to the decision maker in a way that is both understandable and operationalizable by him/her, verifying that the recommendation is technically sound and can be implemented and deployed by the decision maker. During this phase scenario analysis is also performed, that is, the decision analyst investigates "how a solution fares under different scenarios" (Bouyssou *et al.*, 2006).

Though the third phase is usually the final motivation behind any multicriteria decision analysis, we do not focus on it in this article. In our case, this recommendation phase would take the form of "tweaking" the innovation system, that is, adjusting the investment decisions for each of the indicators considered at the financial, public, and industry pillars of the innovation system in order to alter the rankings obtained.

4.3 Choosing a Multicriteria Decision Analysis Method

A number of discrete multicriteria methods have been developed and are in current use for solving various complex evaluation and decision making problems (Balezentiene and Kusta, 2012; Baležentis *et al.*, 2012; Mulliner *et al.*, 2013; Ginevičius *et al.*, 2008; Vaidogas *et al.*, 2007). Of all the multicriteria decision analysis methods available, we use the TODIM method, as introduced in (Gomes and Lima, 1991).

Unlike most other discrete multicriteria decision aiding methods, the TODIM method is founded on Prospect Theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992). The choice of this method for our particular ranking problem is based on the fact that the TODIM method utilizes the notion of positive and negative utility for each indicator, expressed as gains and losses, as opposed to more traditional methods of multicriteria decision analysis such as PROMÉTHÉE (Brans and Mareschal, 1990).

TODIM is an acronym in Portuguese for Interactive and Multicriteria Decision Making. The TODIM method with its prospect theoretical foundation first appeared in the literature in the early nineties (Gomes and Lima, 1991). Today, different extensions of the TODIM method are available that can deal with either fuzzy or hybrid data (Chen *et al.*, 2010, Fan *et al.*, 2013; Krohling and Souza, 2012).

Applications of TODIM have covered a wide spectrum of situations such as real estate evaluation (Gomes and Rangel, 2009; Gomes *et al.*, 2009a; Moshkovich *et al.*, 2011; Moshkovich *et al.*, 2012), business planning (Rangel *et al.*, 2009; Rangel *et al.*, 2011), energy resource management (Gomes *et al.*, 2009b; Gomes *et al.*, 2010), hospital management (Nobre *et al.*, 1999), and road planning (Gomes and Lima, 1991). The fact that TODIM is founded on Prospect Theory is reflected in the shape of its value function. This is essentially the same as the gains/losses function of Cumulative Prospect Theory, where gains and losses are always established with respect to a reference point (Tversky and Kahneman, 1992).

Differently from other multicriteria methods, though, TODIM relies on a value function reproducing the gain and loss attitude of a decision maker on each criterion, following the prospect theoretical paradigm (Gomes and Lima, 1991; Gomes and Lima, 1992; Nobre *et al.*, 1999; Gomes and Rangel, 2009; Gomes *et al.,* 2009). A global multiattribute value function aggregates measures of gains and losses over all criteria in the form of an additive difference function, which summarizes arguments in favor and against an alternative when compared to another, similar to what PROMÉTHÉE does (Brans and Mareschal, 1990). Such a function accounts for dominance relations among all pairs of alternatives through a pairwise comparison process. Finally, by normalizing the dominance function the method leads to a global ordering of the alternatives.

4.4 Applying the TODIM Method to our Ranking Problem

Let us consider $C = \{C_1, \dots, C_n\}$ as the set of n countries (usually referred to as *alternatives* in the multicriteria decision analysis literature) to be ordered and $I = \{I, \dots, I_m\}$ the set of m indicators (usually referred to as *criteria* in the multicriteria decision analysis literature). Let us also assume that one of these *indicators* can be considered as the *reference indicator*, as explained below. Although TODIM can be used for qualitative as well as quantitative criteria, the evaluation of the countries in relation to all indicators is a matrix of evaluation, where the values are all numerical. If needed, verbal scales of qualitative criteria are converted to cardinal ones.

Let $P = [P_{nm}]$, where $P_{nm} \in [0,1]$, be the matrix of normalized countries' scores against indicators. TODIM requires the decision-maker to provide inter-criteria information. First, the importance of each indicator I, expressed as w_i, needs to be fixed. Next, a *reference indicator* must be defined as the one with the highest importance, let us say I_r. Then, the relative weight of each indicator I becomes $w_{ir} = w_i/w_r$. Once this information is available, the following utility function is defined:

$$\phi_i(C_j, C_k) = \begin{cases} \sqrt{\frac{w_{ir}(P_{ji}-P_{ki})}{\sum_{i=1}^{m} w_{ir}}} & if\ (P_{ji} - P_{ki}) > 0 \\ 0 & if\ (P_{ji} - P_{ki}) = 0 \\ -\frac{1}{\vartheta}\sqrt{\frac{\sum_{i=1}^{m} w_{ir}(P_{ji}-P_{ki})}{w_{ir}}} & if\ (P_{ji} - P_{ki}) < 0 \end{cases} \qquad (1)$$

This is a piecewise function modelling the decision maker's preference. When $P_{ji} - P_{ki}$ is positive, gains are experienced and the concave form of utility denotes the aversion to risk by the decision maker. On the contrary, for negative differences, losses arise and the convex form of utility reflects propensity to risk, accordingly to prospect theory. In such a case, ϑ is interpreted as an attenuation factor of losses, which shapes the prospect theoretical value function in the negative part of (1).

A net utility may be calculated as a global dominance relation between each pair of countries (C_j, C_k). It is expressed as follows:

$$\delta(C_j, C_k) = \sum_{i=1}^{m} \phi_i(C_j, C_k) \qquad (2)$$

In TODIM, (2) is aggregated in order to obtain a global value, or global utility, for each country, in the following way:

$$\xi_j = \frac{\sum_{k=1}^{n} \delta(C_j,C_k) - min_j \sum_{k=1}^{n} \delta(C_j,C_k)}{max_j \sum_{k=1}^{n} \delta(C_j,C_k) - min_j \sum_{k=1}^{n} \delta(C_j,C_k)} \qquad (3)$$

Expression (3) represents a normalized global performance for the country C_j when compared against all other countries in terms of preferences.

Determining ξ_j leads to the ordering of alternatives. As a consequence, a complete pre-order is then induced, which also means that no incomparability is allowed (Roy, 1996).

5 Ranking Innovation Systems as a MCDA Problem

In this section, we describe our approach to ranking the innovation systems of the countries under study using the MCDA method presented in Section 4.

5.1 The Indicators

We begin by describing the indicators used in our empirical study at each of the three pillars of the CNSE model.

5.2 Financial Pillar

Table 1 describes the set of indicators at the financial pillar (source: Red de Indicadores de Ciencia y Tecnología—Iberoamericana e Interamericana, www.ricyt.org).

Table 1: **Financial pillar indicators**

Indicator	Description
i_1	Bank capital to assets ratio
i_2	Bank nonperforming loans to total gross loans
i_3	Domestic credit by banking sector as a share of GDP
i_4	Credit depth of information index (0=low to 6=high)
i_5	Total reserves in current U.S. dollars as a share of GDP
i_6	Total value of stocks traded in current U.S. dollars as a share of GDP
i_7	Stocks traded turnover ratio
i_8	Market capitalization of listed companies in current U.S. dollars as a share of all listed companies

5.3 Public Pillar

Table 2 describes the set of indicators at the public pillar (source: Red de Indicadores de Ciencia y Tecnología—Iberoamericana e Interamericana, www.ricyt.org).

Table 2: **Public pillar indicators**

Indicator	Description
i_1	Total government expenditures in S&T as a share of GDP
i_2	Expenditure per primary student as a share of GDP
i_3	Expenditure per secondary student as a share of GDP
i_4	Expenditure per tertiary student as a share of GDP
i_5	Total expenditures in S&T per researcher
i_6	Primary pupil-teacher ratio
i_7	Gross primary enrollment ratio
i_8	Gross secondary enrollment ratio
i_9	Gross tertiary enrollment ratio

5.4 Industry Pillar

Table 3 describes the set of indicators at the industry pillar (*source*: Red de Indicadores de Ciencia y Tecnología—Iberoamericana e Interamericana, www.ricyt.org).

Table 3: **Industry pillar indicators**

Indicator	Description
i_1	High-technology exports as a share of all manufactured exports
i_2	High-technology exports in current U.S. dollars as share of GDP
i_3	Patent applications per residents in the country
i_4	Total number of journal publications per million of researchers
i_5	R&D staff per million people
i_6	Receipts for using rights in current U.S. dollars as a share of GDP

5.5 Rough Evaluation Matrix

Since we are ranking the countries for the period from 2000 until 2011, we will have 36 rough evaluation matrices with the form shown in Table 4 (one rough evaluation matrix per year and pillar). Table 4 contains the rough data compiled for each one of these indicators for Argentina, Brazil, Chile, Mexico, Portugal and Spain.

Table 4: **Rough evaluation matrix**

Indicator	i_1	i_2	i_3	…	i_j	…	i_m
w_c	$1/m$	$1/m$	$1/m$	$1/m$	$1/m$	$1/m$	$1/m$
C_1	$R_{1,1}$	$R_{2,1}$	$R_{3,1}$	…	$R_{j,1}$	…	$R_{m,1}$
…	…	…	…	…	…	…	…
C_k	$R_{1,k}$	$R_{2,k}$	$R_{3,k}$	…	$R_{j,k}$	…	$R_{m,k}$
…	…	…	…	…	…	…	…
C_n	$R_{1,n}$	$R_{2,n}$	$R_{3,n}$	…	$R_{j,n}$	…	$R_{m,n}$

$R_{j,k}$, with $1 \leq j \leq m$ and $m = 8$, 9 and 6 in the financial, public and industry pillar, respectively, and with $1 \leq k \leq n$ and $n = 6$, needs to be normalized in order to calculate the dominance function in (2) using a single scale. The value $1/m$ in the matrix above indicates that each indicator has equal importance. Applying (3), we obtain the global dominance ξ_j for each country C_j. As an example, the normalized global performance at the industry pillar for all countries in the year 2000 is shown in Table 5.

Table 5: **ξ_j of countries for industry pillar (ϑ = 1) for the year 2000**

Country	ξ_j
C_1 = Argentina	0,119
C_2 = Brazil	0,943
C_3 = Chile	0,000
C_4 = Mexico	1,000
C_5 = Portugal	0,049
C_6 = Spain	0,876

The normalized global performance expressed in Table 5 leads to the final rankings at the industry pillar in the year 2000, as shown in Table 6.

Table 6: **Ranking of countries for industry pillar for the year 2000**

Country	**Ranking**
Mexico	1
Brazil	2
Spain	3
Argentina	4
Portugal	5
Chile	6

6 Results

In this section, we present the rankings of all the six countries under study at all three pillars. We use the average rankings for the entire period from 2000 until 2011.

6.1 Financial Pillar

The average ranking at the financial pillar is shown in Table 7. Spain and Portugal rank in the first and second place, respectively, while Argentina ranks in the last place.

Table 7: **Average ranking of countries at the financial pillar**

Country	**Ranking**
Spain	1
Portugal	2
Chile	3
Brazil	4
Mexico	5
Argentina	6

Figure 1 shows the dynamic ranking evolution at the financial pilar for the period considered.

Figure 1: **Rankings of countries at the financial pillar (2000-2011)**

The results we obtained for the financial pillar position Argentina in the last place, as we might have expected. Spain held the first position until 2007 and was substituted by Brazil in that position in 2008. In fact, Brazil has been catching up since 2005 and has consistently improved its raking until reaching the first position during 2008. Interesting to note is the consistent decline of Portugal since 2007, although our results suggest that this situation might have come to an end in 2010. Chile and Portugal compete for the second position until 2007 and Chile consolidates its third position in 2008.

6.2 Public Pillar

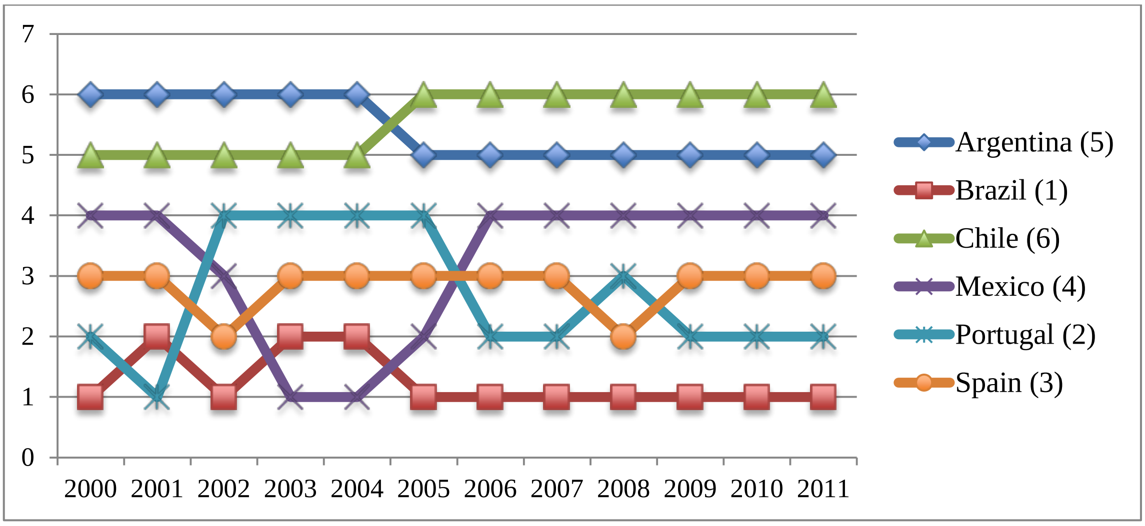
The average ranking at the public pillar is shown in Table 8.

Table 8: **Average ranking of countries at the public pillar**

Country	**Ranking**
Brazil	1
Portugal	2
Spain	3
Mexico	4
Argentina	5
Chile	6

Figure 2 shows the dynamic ranking evolution at the public pilar for the period considered.

Figure 2: **Rankings of countries at the public pillar (2000-2011)**



Brazil ranks consistently in the first place followed by Portugal and Spain, both of which seem to form a cluster for most of the period under study. This comes as no surprise given several indicators that provide evidence of a higher investment of the public sector in key areas for the development of a national innovation system, such as R&D and education, than their counterparts in Latin America (with the exception of Brazil). In Latin America, Mexico and Brazil appear to be leading, with Mexico consistently behind Brazil (except for 2003 and 2004) and behind Portugal and Spain (except for the period from 2002 until 2005).

The fact that Argentina and Chile appear to be disputing the last place, with Chile consistently losing to Argentina in the ranking since 2005 is not all that surprising if we consider the traditionally higher involvement and spending of actors at the public pillar in Argentina in some key areas of their national innovation system such as education, science and technology.

In fact, public spending in education in Argentina more than doubles the spending of Chile in these areas. Conversely, actors at the public pillar in Chile have traditionally played a supervisory and subsidizing role in the Chilean national innovation system. This has led to a more efficient public sector, but also to one less effective that lacks the needed future orientation.

6.3 Industry Pillar

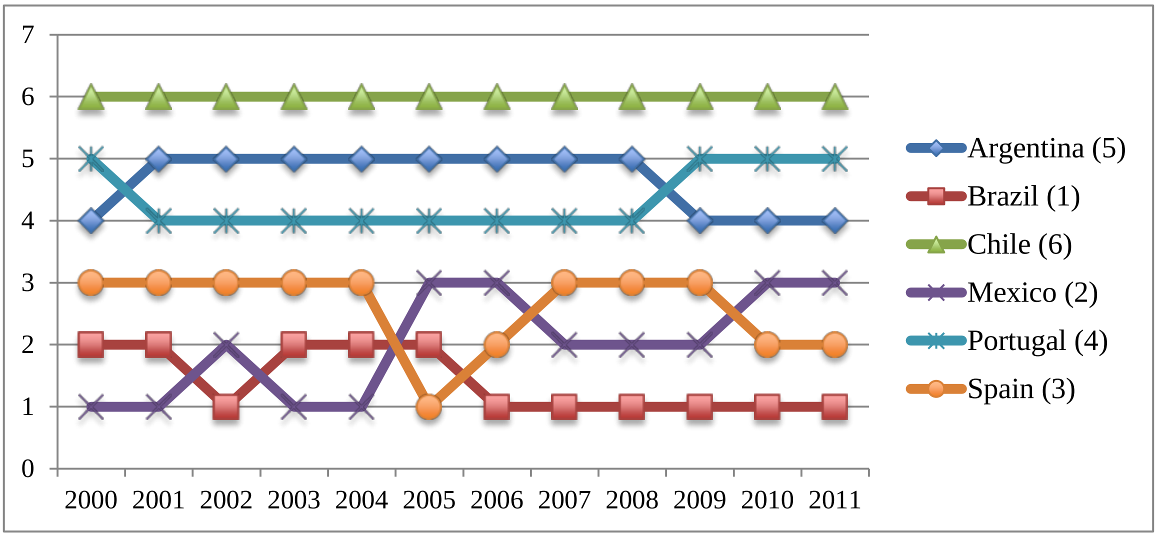
The average ranking at the industry pillar is shown in Table 9.

Table 9: **Average ranking of countries at the industry pillar**

Country	Ranking
Brazil	1
Mexico	2
Spain	3
Portugal	4
Argentina	5
Chile	6

Figure 3 shows the dynamic ranking evolution at the industrial pilar for the period considered.

Figure 3: **Rankings of countries at the industry pillar (2000-2011)**



The results obtained clearly show a dispute for the first place between Brazil and Mexico which is settled in favor of Brazil in 2004. Indeed, Brazil ranks consistently in the first place since 2006. Spain stands alone in third place for most of the period while Portugal and Argentina seem to form a cluster in dispute for the fourth and fifth place, respectively. Chile fills consistently the last position.

7 Discussion

Analyzing the results obtained at the financial, public and industry pillars of the CNSE model, we conclude that Brazil outperforms all countries analyzed in this study at the public and industry pillars for almost the entire period considered in this study and that it also outperforms all other countries at the financial pillar during the period from 2008 through 2011.

Spain outperforms all other countries at the financial pillar until 2006 but lost this position to Brazil in 2007, still outperforming all other countries for the rest of the period considered in our study. While the financial crisis hit both Portugal and Spain at roughly the same time, Portugal appears to have being hit harder than its bigger neighbor, as evidenced by the dive it experimented at the financial pillar starting in 2007 and ending in 2010. Interesting to note in the case of Portugal is disconnect between public spending in education, science and technology and its (poor) performance at the industry pillar.

While its performance stands out in the second and third place at the financial pillar during the period considered, which we find consistent with the robust financial sector of its economy, Chile ranks in the fifth and sixth place at the public pillar and stands alone in the sixth place at the industry pillar. We find evidence to suggest that the poor performance of Chile at the industry pillar is the result of its poor performance in several industry-pillar indicators, including the total value of high-technology exports as a share of all manufactured exports, the total value of high-technology exports in current U.S. dollars as share of GDP, and the total number of patent applications per residents in the country, a category in which Chile only outperforms Portugal.

The case of Mexico constitutes the exact opposite of Chile. With a relatively poor performance at the financial pillar, its performance at the public pillar outperforms Argentina and Chile for the entire period of this study. Its performance at the industry pillar, though, is quite outstanding, disputing the hegemony with Brazil at this pillar until 2004 and losing it to Brazil only in 2005. In fact, in many of the industry-pillar indicators Mexico consistently outperforms Brazil throughout the entire period. These indicators include the total amount of high-technology exports as a share of all manufactured exports, the total amount of high-technology exports in current U.S.

dollars as share of GDP, and the total amount of payments received for the use of IP rights in current U.S. dollars as share of GDP.

We can speculate that the outstanding Mexican performance at the industry pillar has been partly due to a series of free-trading agreements with its neighbor north of the border and the investment of U.S. based technology companies that have disembarked in Mexico not only during the period covered by this study but also prior to it. As a result, Mexico has been able to catch up with Brazil very rapidly and very efficiently as well. Despite this catching-up process, Brazil has a big advantage over Mexico in that the size of its domestic market has consistently attracted and embedded a wide variety of foreign actors at the industry pillar of its economy and this, in turn, has contributed to consolidating its financial sector as well. This situation might be changing, though.

Indeed, Mexico's innovation performance has been positively impacted by the reorientation of actors at the industry pillar since 1994, the year in which Mexico signed the famous North American Free Trade Agreement (NAFTA). Since then the trade balance with the U.S. and Canada has increased dramatically over the last two decades to reach well over 80%. In fact, Mexico's export orientation towards the U.S. and Canada constitutes quite a departure in innovation policy when compared with all other countries considered in this study.

Finally, the results obtained at all three pillars of the CNSE model in our empirical analysis lead to the conclusion that Argentina is being outperformed by all other countries analyzed in this study at the financial pillar and that Chile is being outperformed by all other countries at the public and industry pillars. Although this might come as no surprise in the public pillar, it is somewhat counterintuitive at the industry pillar. As opposed to Argentina, Chile has been consistently implementing policies for the last forty years that facilitate the empowerment of actors at the industry pillar of its economy, a process that has allowed Chile to catch up with its bigger neighbor at the industry pillar for over two decades. Interestingly, despite the financial crisis of 2001 and a track record of government intervention that has proved highly detrimental to the development of its industry pillar, Argentina still shows signs of a more diversified and competitive ecosystem of actors at its industry pillar than that of its western neighbor, as evidenced by the first two industry-pillar indicators in our dataset.

While its policy of non-intervention is often domestically regarded as the big advantage of the Chilean neoclassically inspired economic model, its loyalty to this non-intervention doctrine is a factor that might have become its biggest enemy. In fact, the results obtained at the public pillar position Chile at the bottom as far as the future orientation of the public pillar is concerned. While Argentina needs to reorient its future orientation with a view to making the role of actors at the public pillar more efficient, Chile needs to depart from a doctrine that has left the future orientation of the innovation system largely in the hand of actors at the industry pillar.

This new consciousness is beginning to emerge in Chile. In fact, the need for a future orientation of actors at the public pillar of the Chilean economy, as it relates not only to key areas of the national innovation system such as education but also science and technology, is absolutely of the essence in order for the Chilean economy to transition through the neo-Schumpeterian corridor.

8 Conclusions

From a methodological perspective, multicriteria decision analysis presupposes that the set of criteria, or the dataset of indicators in our case, and their relative weights are already known to the decision analyst. The method will then guide the decision-making process of the decision analyst by providing a ranking of alternatives. Our application domain of national innovation systems poses some interesting challenges in this regard.

Depending on the analysis, such as ranking national innovation system performance in our case, the “right” set of indicators and their relative importance will usually not be entirely known, or at least not entirely agreed upon, beforehand. While there is a vast amount of research on the determinants of innovation performance, especially at the industry pillar (Furman et al., 2002; Wang and Kafouros, 2009), there is comparatively fewer results as to the relative relevance of these determinants. Panels of experts might need to be engaged in order to not only come up with a dataset containing the most relevant set of indicators but also propose their respective relative weights.

Another challenge is data availability. In our empirical study, the final choice of indicators was influenced by the lack of indicators and/or missing data. Some indicators for the countries analyzed and the period considered in this study were not available in datasets compiled by well-established sources such as the OECD, the World Bank, the World Economic Forum, and RICYT (Red de Indicadores de Ciencia y Tecnología Iberoamericana e Interamericana). Both the choice of criteria (indicators) and the definition of their respective weights will have an impact on the definition of utility functions and the resulting rankings of the alternatives (innovation systems of the countries) analyzed.

Methodologically, multicriteria decision analysis offers a wide range of tools that can be used by policymakers to guide strategic decisions regarding the competitive position of innovation systems at regional, national and global level in rapidly evolving industry sectors. One of these areas is robustness analysis, a research area well-established in the multicriteria decision analysis community.

For instance, let such "competitive position" correspond to a "future state" represented by the real order $C_1 \succ \cdots \succ C_k \succ C_n$. Given a set C of countries, a pre-order on it is representable if it exists a utility function $\mathrm{u}: \mathrm{A} \rightarrow \mathbb{R}$ such that $C_j \succcurlyeq C_k \Leftrightarrow \mathrm{u}(C_j) \geq \mathrm{u}(C_k)$, for all countries $C_j, C_k \in \mathrm{C}$ (Pomerol and Barba-Romero, 2000). TODIM, the MCDA method introduced in Section 4, would build such a function using the information coming from evaluations of countries on indicators, the set of weights, and the attenuation factor ϑ.

Therefore, let us assume that the robustness concern in this case refers to the conditions under which the future state (the pre-order induced by the innovation performance of the national innovation systems) is reproduced by the national innovation system. In general, the future and current states will not be the same. Thus, our inquiry will consist in determining how different the orders (rankings) are, which will refer to some distance metrics among rankings calculated using the aggregated global utility metric ξ_j.

Our future work will focus on how to apply such robustness analyses to help guide strategic decisions in this area. From this perspective, analyzing the innovation performance of countries that compete on a regional or global basis within an industry sector is another compelling reason for constraining the number of countries analyzed to "those that matter."

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