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The Dynamics of National Innovation Systems: An Empirical Approach to Economic Growth and Development

Las dinámicas de los sistemas nacionales de innovación: Una aproximación empírica al crecimiento económico y desarrollo

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THE DYNAMICS OF NATIONAL INNOVATION SYSTEMS:

an empirical approach to economic growth and development

LAS DINÁMICAS DE LOS SISTEMAS NACIONALES DE INNOVACIÓN:

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TABLE OF CONTENTS

ABSTRACT

The objective of this doctoral work is to study the dynamic relationships and process of coevolution between innovation, economic growth and development. It analyses a broad sample of national systems in the last three decades by using a time series econometric approach. We aim at contributing to the literature and policy by generating quantitative based evidence of the structures that link the multifaceted dimensions of Innovation Systems (IS) to economic systems over time. This dissertation is composed by a compendium of four interrelated papers. The first one, "*How innovation systems and development theories complement each other*" coauthored with Mario Pansera (2013), aims at relating selected theories of development to IS. We propose that the interaction between IS and development theories provides benefits for both research traditions. Also, rather than focusing on the discussion of IS being or not a theory of development by itself, we believe that making this relational exercise could generate new benefits and frameworks of analysis. The second paper, "*A new panel dataset for cross-country analyses of national systems, growth and development (CANA)*", written with Fulvio Castellacci (2011), opened the door to the econometric methodology: it provided full time series data over the last three decades for 134 countries. The paper offers an alternative to missing data issues for cross-country analyses. It applies a new multiple imputation method that has been developed to estimate time-series cross-section data at the country-level. We constructed a dataset composed by 41 indicators, measuring innovation and technological capabilities, education system and human capital, infrastructures, economic competitiveness, political-institutional factors, and social capital. The last two papers are empirical contributions. The paper "*Innovation, Absorptive Capacity and Growth Heterogeneity: Development Paths in Latin America 1970–2010*", written with Fulvio Castellacci (2013a), carries out an analysis of long-run development paths in 18 Latin American countries. We use time series cointegration to analyze the relationships between absorptive capacity, innovation and economic growth. Two results arose: a) Latin American countries have followed different growth trajectories depending on the combination of policies they have adopted to catch up; b) there is a correspondence between policy strategies and growth performance. Countries that have managed to combine imitation and innovation policy have experienced a higher rate of growth than those economies that have only made efforts to improve their imitation capability. The final paper, "*The dynamics of national innovation systems: a panel cointegration analysis of the coevolution between innovative capability and absorptive capacity*", written with Fulvio Castellacci (2013b), investigates the idea that the dynamics of national IS is driven by the coevolution of innovative capability and absorptive capacity. The empirical analysis employs panel cointegration to a broad set of indicators for 87 countries in the period 1980-2007. The results indicate that the dynamics of national IS is driven by the coevolution of three innovative capability variables (innovative input, scientific output and technological output), on the one hand, and three absorptive capacity factors (infrastructures, international trade and human capital), on the other. This general result does however differ and take specific patterns at different levels of development.

Out of these four papers a central conclusion arises. There is evidence of coevolution between innovative capabilities, absorptive capacity and economic development. This highlights that reductionist approaches that do not consider the multidimensional nature of development are likely to fail to provide pertinent assessments. As a result, two main recommendations come out: first, the combination of innovation and imitation policies is the best practice that could be suggested to policy makers; second, solutions should be country-specific: based on the revealed capabilities and the interactions among them, societies should coordinate and agree on how to construct the competences they need. In any case, evidence up to this point provides a clear message: strong interactions are a common characteristic of developed economies.

Keywords: national systems of innovation; innovative capability; absorptive capacity; economic growth and development; coevolution; panel cointegration analysis.

RESUMEN

El objetivo de esta tesis doctoral es estudiar las relaciones dinámicas y el proceso de co-evolución entre innovación, crecimiento económico y desarrollo. Se analiza una muestra amplia de sistemas nacionales en las tres últimas décadas mediante un enfoque econométrico de series temporales. Este trabajo busca contribuir a la literatura y las políticas públicas al generar evidencia cuantitativa de las estructuras que unen las dimensiones multifacéticas de Sistemas de Innovación (SSII) con los sistemas económicos a través del tiempo. Esta tesis se compone de cuatro artículos científicos interrelacionados. El primero, "*How innovation systems and development theories complement each other*" (¿Cómo los sistemas de innovación y las teorías de desarrollo se complementan entre sí), escrito con Mario Pansera (2013), tiene como objetivo relacionar teorías de desarrollo con los SSII. Propone que la interacción entre los SSII y las teorías de desarrollo proporciona beneficios para ambas líneas de investigación. Además, en lugar de centrarse en la discusión de si los SSII son una teoría del desarrollo por sí mismos, se plantea que este ejercicio relacional generaría nuevos beneficios y marcos de análisis. El segundo artículo, "*A new panel dataset for cross-country analyses of national systems, growth and development (CANA)*" ("Un nuevo conjunto de datos de panel para análisis comparativos de sistemas nacionales, crecimiento y desarrollo (CANA)"), escrito con Fulvio Castellacci (2011), proporcionó datos completos de series temporales de las últimas tres décadas de 134 países. El documento ofrece una alternativa al problema de la falta de datos: aplica un nuevo método de imputación múltiple para estimar datos de corte transversal y series temporales a nivel de país. Se ha construido un conjunto de datos completos compuesto por 41 indicadores, que miden innovación y capacidad tecnológica, sistema educativo y capital humano, infraestructuras, competitividad económica, factores político- institucionales y capital social. Los dos últimos documentos son contribuciones empíricas. El documento "*Innovation, Absorptive Capacity and Growth Heterogeneity: Development Paths in Latin America 1970–2010*" ("Innovación, capacidad de absorción y heterogeneidad del crecimiento: vías de desarrollo de América Latina 1970-2010"), escrito con Fulvio Castellacci (2013a), hace un análisis del desarrollo de 18 países de América Latina, aplicando cointegración de series temporales para estudiar las relaciones entre capacidad de absorción, innovación y crecimiento económico. Dos resultados principales surgieron de esté análisis: a) los países de América Latina han seguido diferentes trayectorias de crecimiento en función de la combinación de políticas que han adoptado; b) los países que han combinado políticas de innovación e imitación han tenido una mayor tasa de crecimiento frente a aquellos que sólo se han mejorado su capacidad de imitación. El último documento, "*The dynamics of national innovation systems: a panel cointegration analysis of the coevolution between innovative capability and absorptive capacity*" ("Las dinámicas de los sistemas nacionales de innovación: un análisis de cointegración de panel de la co-evolución entre la capacidad innovadora y la capacidad de absorción"), escrito con Fulvio Castellacci (2013b), investiga si la dinámicas de los SSII responde a la co-evolución de la capacidad de innovación con la capacidad de absorción. El análisis empírico utiliza cointegración panel para 87 países en el período 1980-2007. Los resultados indican que existe co-evolución entre la capacidad de innovación (inversión en innovación, producción científica y producción tecnológica), por un lado, y tres factores de capacidad de absorción (infraestructuras, comercio internacional y capital humano), por el otro. Este resultado general, no obstante, difiere y toma patrones específicos en diferentes niveles de desarrollo.

De estos cuatro documentos se presenta una conclusión central. Existe evidencia de la co-evolución entre las capacidades innovadoras, la capacidad de absorción y el desarrollo económico. Esto pone de manifiesto que los enfoques reduccionistas que no tienen en cuenta la naturaleza multidimensional del desarrollo son propensos a hacer análisis equivocados. Por tanto, dos recomendaciones principales se pueden esbozar: en primer lugar, la combinación de las políticas de innovación y la imitación es la mejor práctica que podría ser sugerida; en segundo lugar, las soluciones deben ser específicas para cada país: en función a las capacidades reveladas y las interacciones entre ellas, las sociedades deben coordinar y acordar la forma de construir las competencias que necesitan. En cualquier caso, la evidencia hasta el momento ofrece un mensaje claro: las interacciones fuertes son una característica común de las economías desarrolladas.

Palabras clave: sistemas nacionales de innovación, capacidades de innovación, capacidad de absorción, desarrollo y crecimiento económico, co-evolución, cointegración de series temporales y de panel.

CHAPTER 1

INTRODUCTION[1]

There exists a crucial dimension that reveals how countries have used knowledge in their path to economic growth and development: ***time***. Development could only be understood by considering the effect of ***time*** on societies' evolutionary process. This is the main motivation of this doctoral research. In the following pages we will elaborate on how this could be done and the implications of this analysis.

This research project is grounded in the evolutionary economics and innovation systems tradition. In this branch of economic analysis, gradual processes of change are of upmost importance. Heterogeneous agents interact and learn from their interactions. Information is not always freely available and, even when it is, its mere possession does not guarantee that agents will be able to take full advantage of it. Capabilities are needed to exploit the existing knowledge and to create new one. This path dependent process is specific, it determines *how* nations, regions, firms, individuals will react to change, their real possibilities to adapt and evolve or to lock-in and stagnate. This is not a minor issue since innovation is considered the engine of economic growth and development (Nelson and Winter, 1982).

The literature on innovation and economic development is extensive. In the case of this doctoral project, two streams have had a major influence. First, the innovation systems framework (Freeman, 1995; Lundvall et al., 2002) has served as the main approach to study the relationship between innovation and development. By applying a systemic perspective to innovation, we have been able to include much of the complexity that characterizes economic growth and development. The other noteworthy branch has been the capability approach, mainly introduced by Abramowitz (1986) and Lall (1992). Both branches are the milestones that have guided our empirical analyses, in which a

[1] I wish to thank Fulvio Castellacci for helpful comments on a previous draft of this chapter.

multidimensional approach is applied, institutional conditions are considered and the cumulative process of capability building is evaluated over time.

Innovation has been always characterized as a non-stationary process (Dosi, 1982; Metcalfe and Ramlogan, 2008; Perez, 1983; Schumpeter, 1934). However, empirical studies have not fully accompanied such argument. Much of the applied work presents static comparative analyses that might be myopic to patterns and structural changes. We aim at contributing to the literature by closing this gap between theory and empirics. We use time series and panel econometric methods to assess the *dynamics* of innovation and its linkages to economic growth and development. Naturally, we have also put substantial attention on studying how economies differ in their development paths. We consider that, especially for policy action, considering heterogeneity is a must: economic structures vary from one economy to another. The complexity that comes from interactions between agents and their environment should not be neglected in economic assessments.

This introductory chapter contains three additional parts. Section 2 is a review of the literature that has guided the elaboration of this dissertation. The research question and its related objectives, as well as the econometric methodology applied, are also included in this section. Section 3 introduces each of the four papers that compose this doctoral dissertation. The final section offers a summary of the content of this body of research, introducing the main implications of our results, methodological discussions, avenues for future research and limitations to our approach.

1. INNOVATION SYSTEMS: A HISTORICAL PERSPECTIVE

Assessing the relationship between innovation, economic growth and development has been a constant objective of evolutionary economics' research. In fact, some crucial characteristics of this question – such as those related with learning processes and the integration of innovation in productive systems – date back to Adam Smith's labor division discussions in 1776 and Friedrich List's national systems of production and learning in 1841 (Lundvall et al., 2002). Out of the different approaches that could be applied to solve this issue, we have selected the systemic vision as the guiding principle of our research. The possibility of capturing many dimensions of economic development's complexity is behind this decision.

The Innovation Systems framework has been proposed in the end of the 1980s. Freeman, Lundvall and Nelson's contributions can be identified as the three main pillars of this tradition (Fagerberg and Sapprasert, 2011). They have proposed a new research path that has seen a major explosion in the last three decades (Uriona-Maldonado et al., 2012). Christopher Freeman's (1987) seminal work analyzed how the differences in economic performance of Japan, Germany, the URSS, East Asia and Latin America could be explained from a historical point of view. The comparative exercise illustrated the multifaceted nature of the innovation process: the network of scientific institutions, industrial sectors, policies and cultural roots were exposed as the determinants of economic development. Lundvall has put forward that the main phenomenon embedded in this network is *learning*, an evolutionary process in which each agent changes by interacting with other agents and with the environment (Lundvall, 1996, 2004; Lundvall and Johnson, 1994). Nelson's institutional approach (Nelson and Nelson, 2002; Nelson, 2008, 1994, 1986) completes the main characteristics of the Innovation Systems framework: the context determines how agents link up; it contains the *rules of the game* that are generated in a non-linear process. Continuous interactions are the base of established routines that frame relationships and, as a result of this continuity, routines change to adapt to agents' evolution.

Different approaches to Innovation Systems have been developed in order to find the more suitable angle: sectorial (Geels, 2004; Malerba, 2002), regional (Cooke, 2001; Cooke et al., 1997; Uyarra, 2010) and international (Álvarez and Marín, 2010; Carlsson, 2006; Niosi and Bellon, 1994) levels have been added as alternatives to the traditional 'national view'. This multiplicity of viewpoints has been a way of adapting the unit of analysis to investigate how innovation intervenes in the development process. In this dissertation, we have made an effort to understand how development takes place at many different stages: a substantial sample of countries is included in the empirical analysis, giving us a reason to use the national level as the selected unit (Lundvall, 1998).

Nonetheless, finding an adequate approach to apply the innovation system framework is a challenge that goes beyond selecting the unit of analysis. The expansion of this tradition has been nurtured by policy discussion (Godin, 2009) and a variety of visions. Niosi et al. (1993) and Sharif (2006) present discussions regarding the main concerns in this field: its definition and delimitation, the theoretical foundations, the *adequate* degree of flexibility and the possibility of measurement. There remains, nevertheless, one thing that has not been challenged across the different approaches to innovation systems: if historical perspectives are fundamental to explain development, then path dependence and non-reversibility cannot be left out of the analysis (Cowan and Foray, 2002). Case studies have been selected as the preferred methodological tool to accomplish this duty. A great amount of empirical evidence has been collected from qualitative and historical research: Freeman's (1991, 1987) description of agents interactions and the importance of the state in countries' innovation activities set an important reference for the field; Nelson's (1993) comparative analyses pointed out the differences and heterogeneity of the process; more recently Lundvall et al (2009) and Edquist and Hommen (2008) have shown, respectively, insights from developing and developed countries in terms of their policies and institutional settings. Another interesting stream of research, more centered on the sectorial case, has developed around the *history friendly models* (Malerba, 2002; Malerba et al., 1999): they have focused on tracking the evolution over time of specific niches of technologies, identifying the course of key structural changes that have had an impact on the productive systems. In any case, all of these alternatives have not incorporated (at least at a desirable level) econometric evidence.

Econometric approaches to growth and innovation have been trying to integrate the systemic vision in cross-country comparative analyses. Fagerberg (1994) presented a review including more than twenty empirical papers that had assessed –back then– the relationship between economic growth and technology; selected variables combine the share of public sector in the economy, population growth, economic openness, with productivity measures (GDP per capita), and typical innovation activities indicators (like education variables, R&D efforts and patents). Further developments of these approaches have increased the number of the countries analyzed, reaching lower development levels when data was available (Castellacci and Archibugi, 2008; Castellacci, 2008; Fagerberg and Verspagen, 2002; Fagerberg et al., 2007; Lee and Kim, 2009). However, they all still follow a cross section regression approach: they remain static and, most importantly, they do not explicitly acknowledge the two-way relationships between innovation and development.

Empirical exercises closer to the dynamic approaches could be found in Schumpeterian multiple equilibria models, which combine distance-to-the-frontier tradition or technology gap models with different convergence regimes within groups of countries (Castellacci, 2010). In short, they consist in a non-linear characterization of the relationship between innovation, absorptive capacity and economic performance; in which a minimum threshold of countries' ability to incorporate knowledge is a critical factor for catching-up or falling behind: transitions do not happen in a fixed context, but in an evolving environment where technology gaps are constantly changing. Additionally, because of countries' diverse starting points, economic growth does not take place homogenously (Acemoglu et al., 2006; Azariadis and Drazen, 1990; Galor and Weil, 2000; Howitt, 2000). If nonlinear systemic relationships matter, then economies characterized by different initial conditions (e.g. different levels of income per capita) will tend to have diverging growth performances over time (Durlauf and Johnson, 1995): again, some countries will catch-up while others will fall behind and *convergence clubs* will arise as a normal outcome of this process.

Recent empirical studies extend this *convergence clubs* literature and argue that innovation and technology diffusion are the main factors explaining why multiple growth regimes (or different stages of development) exist. This new literature on *technology clubs* investigates how the technology-growth relationship differs across country groups. They also point out the most critical factors of catching up and growth for countries at different stages of technological development (Castellacci and Archibugi, 2008; Castellacci, 2008; Filippetti and Peyrache, 2011). Three groups (clubs) are distinguished according to their capacity to use, adapt and generate technology (Galor, 2005; Howitt and Mayer-Foulkes, 2005; Verspagen, 1991): the most advanced group (high capacity), the catching-up group (developing and increasing capacity) and, the laggard group (low capacity).

For cross-country comparative studies, the multiple equilibria models are also useful because of their consideration of *heterogeneity*. At the very heart of the evolutionary economic principles lies the consideration of agents' specificities, determined by their nature, particular learning process and interactions with the socioeconomic environment

(Dosi and Nelson, 1994). As a matter of fact, the historical perspective highlights heterogeneity as the most important aspect: countries' evolution process could only be understood in the view of their own past. Even when panel analyses have been applied, in order to take heterogeneity into account, country groups were defined according to their institutional and geographical backgrounds.

Closing the gap with empirical exercises requires an operationalization of the innovation systems framework: a capability approach has been selected to evaluate the dynamic linkage between innovation and development. Based on Abramovitz (1986), Kim (1980) and Lall (1992); Fagerberg and Shrolec (2008) identified a set of relevant capabilities that could be representative of national innovation systems: this useful contribution proposes a set of indicators and sources to measure capabilities at country level. Their proposal was used as an initial reference in the empirical analysis here presented: by surveying the literature, other types of capabilities were also added.

On the whole, this brief introduction to the literature on innovation and economic development indicated that most of the empirical literature in the field has adopted a rather static perspective so far. It has focused on cross-country comparisons of national systems in a given period of time and has neglected almost entirely the time series dimension of the growth and development process. This important gap in the literature, between Schumpeterian theoretical models and innovation systems empirical studies, provides the general motivation for this doctoral thesis.

2. OBJECTIVES AND RESEARCH QUESTIONS

The general objective of this doctoral work is to study the dynamic relationships and process of coevolution between innovation, economic growth and development in a broad sample of national systems in the last three decades by using a time series (cointegration) approach. We aim at contributing to the literature and policy by generating quantitative based evidence of the structures that link the multifaceted dimensions of innovation systems to economic systems over time. The general research questions that provides a foundation and links together most of the chapters in this thesis can be formulated as follows:

How do national innovation systems evolve over time? What are their main long-run drivers? How does this evolutionary process differ for countries at different levels of development?

Development processes involve a great deal of complexity. The way structures behave and change can be assessed by looking at time series data and their dynamic properties. Furthermore, heterogeneity is everywhere and the analyses of different cases could show the evolution of the interactions. We propose not to put too strong assumptions and try to see, from the empirical evidence, what types of relationships are taking place and how they could affect economic development. We put forward the idea of including the complementary information that only ***time*** can offer as part of the discussion

In order to answer this question, three specific objectives were defined. They follow a sequential structure: first, there is an effort to understand the theoretical bases of the empirical work; second there is a feasibility check in terms of data availability and; finally, the empirical analyses – ultimate purpose of this dissertation – are targeted. These three objectives are:

1. To analyze the theoretical approaches that link the innovation process with economic growth and development processes.
2. To generate a database to study the innovation systems and the evolution of the economic performance over the last three decades.
3. To investigate the structures that have linked innovation systems, economic growth and development over time. This analysis should be dynamic and rely on the use of the time dimension to incorporate the historical perspective in the econometric exercise.

As Schumpeter (1994) proposed, history, theory and statistics should always be combined in the economic analyses. Organizing the research ideas in this fashion, beyond the main objective of dynamically including time in the empirical exercise, allows us to contribute in two more specific issues. The first one is the on-going debate on the level of theorization of innovation systems. In light of the available development theories and the shortcomings that they might have, we would like to explore the possibility of finding another alternative to look at this issue: focusing on the interactions between them. The other issue is related to innovation measuring from a systemic point of view. Recent proposals have arisen as feasible ways of assessing capabilities at the country level in order to quantify some features of the innovation process. Data availability would be the only constraint in this sense. The possibility of using the existent data and extracting the most out of it is an open question for empirical analyses.

2.1 ECONOMETRIC METHODOLOGY

During the last two decades, the number of econometric analyses investigating evolutionary matters has grown. One reason is data availability: the passage of time has allowed for data collection on key dimensions (like the expenditure on R&D activities, for instance), opening the door for time series and panel econometrics. Also, new methods have been developed to include the effect of precedent events as determinants of the structures and patterns that define economic systems. One of those advanced methods is the vector autoregressive model: it allows for full endogenization and cross effects of the variables in the system, incorporating information from the past to explain current states (Greene and Zhang, 1997). In fact, there is a specific case of this method that has had a major influence in this dissertation: the cointegration methodology, mainly developed by Johansen (1995, 1991), is useful to disentangle the relationships among variables that co-evolve, growing over time as a *system*. If cointegration is confirmed – which means that the vector contains a unit root and that included variables move together – it is possible to distinguish different relationships. On the one hand, the long-run relations, that are at the core of the system, and on the other hand, the short-run structure, that represents how the system reacts to changes (Hendry and Juselius, 2000; Juselius, 2006).

Out of the short-run structure, causality among the variables could be analyzed: this represents the dynamics of the system. The way the variables adapt to the changes in the long-run structure and how they transitorily adjust to the new conditions is a rich source of information (Juselius, 2006). By applying the cointegration methodology we can provide evidence of the driving forces of the economic systems, of the relationships that the time structure reveals, of agents' aggregate interactions. Furthermore, this methodology does not impose strong restrictions: it is oriented to use the information contained in the data to shed light on the systemic relationships. It is an alternative to the rigid model testing approaches in which theories are confirmed or rejected, and it aims at illuminating empirical facts that could help to improve theorizing efforts (Colander et al., 2009; Frydman and Goldberg, 2008; Hoover et al., 2008).

Because of these benefits, the cointegration methodology has been found very suitable for empirical analyses of the innovation systems and economic development. It offers the flexibility that the innovation systems need, it recognizes history as the main source of information and it evaluates the relationships as the result of mutual effects among different dimensions. In this dissertation, this econometric approach is presented as a way of closing the gap between theory and empirics: we regard qualitative analyses as building blocks of the economic research and believe that quantitative approaches are also needed to have a full vision of the related phenomena. In fact, both exercises are fundamental and should be applied in a historical context.

The applied empirical analyses consist of two types of cointegration approaches. Time series cointegration, in which a single country data is evaluated over a given period, is suitable for considering the highest level of heterogeneity in the data: the individual evaluation makes it possible to identify specific events in each country; it is the closest version to using empirical analyses in a case study fashion (Hendry and Juselius, 2000). Also, this approach allows us to analyze the time structure in a deeper level: once the relationships between the variables have been settled, it is possible to investigate the responsiveness of the system (Juselius, 2006).

The other approach is panel cointegration: it combines the information from time series with the cross-section structure of the data, increasing the power of the estimation. By expanding the size of the data, a much more complex exercise could be set: a larger number of variables can be included thanks to the increase of available degrees of freedoms (Breitung and Pesaran, 2006). Heterogeneity, nevertheless, could not be characterized at its highest level (Pedroni, 2001; Persyn and Westerlund, 2008): cluster exercises help to address this issue, by grouping countries according to their similarities in terms of institutional backgrounds and proximity. In any case, it is the mix of both approaches (the panel and the time series case) what enriches the robustness of the conclusions of this PhD dissertation.

3. AN EMPIRICAL APPROACH TO INNOVATION, GROWTH AND DEVELOPMENT

This dissertation is composed by a compendium of four interrelated papers. The first one contains theoretical considerations of the relationships between innovation and economic development. The second paper opened the door to the econometric methodology: it provided full time series data over the last three decades for 134 countries. Finally, the last papers represent two empirical contributions to the analysis of innovation dynamics and the interaction with economic growth and development. In the following lines each of these papers will be summarized.

3.1 DEVELOPMENT: A SYSTEMIC APPROACH

The first paper is called "*How innovation systems and development theories complement each other*"; it is coauthored with Mario Pansera (2013)[2]. Its scientific role in this compendium is to give a definition of *development* and its interaction with Innovation System (IS) approaches, as considered in this thesis. The main objective of this article is to assess how the Innovation System framework could be applied to the most influential theoretical characterizations of development, identifying bidirectional interactions.

This paper proposes a multidimensional definition of *development*: "*it is not only a matter of factor endowments; it implies the interaction of social abilities and productive use of knowledge*" (Natera and Pansera, 2013). Development, then, differs from economic growth since it goes beyond the possession of goods or the correct allocation of resources. In fact, both concepts are not considered antagonistic in nature, but a systemic approach is needed if the objective is to analyze how development takes place. Considering innovation as one of the key factors to foster development, we propose that the IS vision is ideal for this kind of studies.

The characterization of innovation systems includes the agents and their interactions, the learning process that they undertake and the institutional setting in which they are embedded. IS approach is presented as a flexible framework that could shed light on the analysis of development's complex relationships. IS emerges as a tool for action rather

[2] This paper has been submitted to the scientific journal *Prometheus: critical studies on Innovation* (http://www.tandfonline.com/loi/cpro20); it is currently going through the review process.

than a theory that stands alone; it is versatile and therefore suitable to many different theoretical approaches.

Given that the IS framework was born in OECD countries, an appraisal of some considerations from *the South* is part of this paper. We highlight the importance of taking a capability building approach when using IS as a development tool. We also agree with Arocena and Sutz (2000) when they consider that Innovation Systems are an ex-post concept for developing countries, that it carries a normative weigh and that it is a relational model useful for policy making. We have taken these insights as inputs when surveying the literature.

Development as freedom, the Institutional economics, the Neo-Classic theory of growth, the Multiple Equilibrium approach, the Latin American Structuralism and the World System theory are the development theories discussed in the paper, always from a systemic perspective: innovation was centered at the very heart of them, finding a symbiotic relationship in which flexibility and structure are combined. In fact, in light of the on-going debate about the formalization of the Innovation System approach, we argue that its combination with development theories could generate new frameworks of analysis for the scientific community: it is a way to increase the analytical power and constantly update our theoretical assumptions.

In terms of the empirical analyses developed in this dissertation, the Multiple equilibria approach has been the one with the greatest influence. It has been selected because of its suitability to make international comparisons: it takes into account heterogeneity between countries and considers development as a dynamic process. Based on our definition of *development*, we applied a complementary systemic vision to the Multiple equilibria approach: we have augmented the complexity of the dimensions taken into account, allowing for a combination of multifaceted socio-economic and technological factors.

3.2 DATA FOR DEVELOPMENT

The empirical analysis needed to assess development calls for data. Furthermore, if the idea is to be inclusive and not to only focus on the more developed countries, a big challenge arises: missing data harms and sometimes restricts econometric analyses. This was the motivation of the second paper of this compilation: "*A new panel dataset for* *cross-country analyses of national systems, growth and development (CANA)*", co-authored with Fulvio Castellacci (2011), which represents an effort to make data available for time series development studies.

Researchers interested in empirical analyses of development often have had to face the compromise of choosing a selected group of countries – normally OECD and middle income countries – and apply time series techniques or, alternatively, increasing the number of countries in the sample and apply cross-sectional (static) econometrics. We found this very unfortunate: the first option leaves out those countries that experience lower aggregate levels of living standards, in which research activities could have a bigger impact in terms of improving quality of life. The other option does not fully investigate the dynamics and evolution of the economic systems, since they fall short of including evolution over time in the analysis. Particularly for innovation studies, we think that not fully considering the evolutionary process is a big limitation. This paper proposes a way out of this problem.

By applying a novel Multiple Imputation method (Honaker and King, 2010), we constructed a cross-country panel of complete data. The selected method makes use of the existing data to estimate the missing points: it combines the individual time trend with the cross-section observations to produce, through an expectation-maximization algorithm, a complete set of data points that resembles the distribution of the original observed data. The dataset, in its first version, contains 41 indicators to approximate six key country-specific dimensions: innovation and technological capabilities, education system and human capital, infrastructures, economic competitiveness, political-institutional factors, and social capital[3]. It comprises 134 countries and 29 years, from 1980 to 2008.

The quality of the estimation was tested by comparing the distribution of the observed data and the complete data. A correlation analysis was also applied. Only those indicators that were found to be reliable were included in the dataset. An appendix with the details of the estimation process and the data transformation is presented. As part of

[3] A more recent version (constructed in 2012) includes up to 80 indicators. We increased the dataset by adding more indicators to the dimensions already defined and by including two new dimensions: *Productive Structure* and *Internationalization*. The objective behind these additions has been to consider the greater level of the complexity involved in the development process.

the contribution that we wanted to offer to the scientific community, we have made the data entirely available at http://cana.grinei.es.

The method here proposed offers several advantages when compared with other possibilities. First, it includes a bigger share of developing countries, a more representative vision of the world. Second, it makes use of the already available information to produce estimations without imposing any model on the data. Finally, time series techniques are now feasible and the dynamics of the national innovation systems and their interactions with economic development could be assessed.

3.3 TIME STRUCTURES: CAUSALITY AND DEVELOPMENT PATHS

Evolution unfolds over time. Arguably the only way to analyze the revealed structure of an evolutionary process is by incorporating the time dimension in the analysis. The paper, "*Innovation, Absorptive Capacity and Growth Heterogeneity: Development Paths in Latin America 1970–2010*"[4], written with Fulvio Castellacci (2013a), carries out a time series analysis for each of the countries included in the sample.

Latin American countries were selected because of the relevance of their structural changes during the last four decades: the region is basically constituted by middle income countries in which the catching-up process is taking place. Based on the current economic boost of these economies, we find interesting to evaluate how prepared their economic structures are to move to higher development levels. The sample is composed by 18 countries. Years between 1970 and 2010[5] represent the transition from the Import Substitution Industrialization process towards a more global and open economy. Many structural changes have occurred in that period and, therefore could reveal the underlying driving factors that have sustained economic growth.

Based on Verspagen (1991), we present a model that considers the effect of the three dimensions on economic growth: one is related to the innovative activities and the other two are linked to imitation. Openness and industrial structure are the factors that

[4] This paper have been submitted to the scientific journal "Structural change and economic dynamics" http://www.journals.elsevier.com/structural-change-and-economic-dynamics/ ant it is currently under the revision process.

[5] In order to overcome econometric limitations (degrees of freedom on the estimation), a new imputation process was applied following the same methodology described in Castellacci and Natera (2011). The time spam was expanded to include years from 1970 to 2010.

represent countries' abilities to learn from spillovers generated abroad. Two hypotheses accompany this model: first, countries will follow different paths according to the mix of policies that they have adopted to catch up; second, those countries that combine imitation and innovation policies have a higher rate of economic growth.

Results come from a Vector Error Correction model in time series: we used Johansen's system cointegration methodology to analyze the long-run causality that links economic growth with different policy strategies. The indicators selected are: patents per capita (innovation policy), FDI inward flow (imitation – openness) and three different proxies for industrial structure: industry, services and natural resources as percentages of GDP. Indicator selection was a tough process. Using patents in the Latin American context has important limitations, since it does not fairly assess the innovative activity that takes place in the region. Also, for openness and industrial structure we might find similar arguments. These facts open the door for further analysis and place, from the beginning, the outcomes of this exercise as an initial step to empirically describe the Latin American development path.

In the last paper of this dissertation we have carried out a panel exercise to analyse the dynamic relationships between innovation and development. This methodology allowed us to introduce a more complex characterization of the process and to evaluate the differences between the most relevant regions of the world. The paper "*The dynamics of national innovation systems: a panel cointegration analysis of the coevolution between innovative capability and absorptive capacity*", written with Fulvio Castellacci (2013b), is a proposal to investigate the evolution of 87 countries, during the last three decades.

In this paper we highlight the importance of understanding how innovation takes place. Besides the inclusion of time in the analysis, there are three other motivations behind this applied exercise. First, empirical research has mainly focused on the relationship between economic growth and innovation, while efforts to understand the innovation process itself have not been so numerous. We might be running the risk of jumping to the conclusions while still needing to look at the engine of sustainable growth. Recently, some empirical work has revived the interest on the technological aspects: they have centred on countries' technological and innovative capabilities as ways of explaining their economic performance (Castellacci, 2011; Filippetti and Peyrache, 2011). This paper is oriented to contribute in a similar manner.

Second, absorptive capacity normally occupies a secondary role in empirical analyses. For developing countries this could underestimate their possibilities of catching up. This finding is quite surprising since literature has emphasised the role of *spillovers* and imitation activities in the catching-up process, especially in countries' continuous learning process and capabilities accumulation (Aghion et al., 2001; Lee and Lim, 2001; Pérez and Soete, 1988; van Elkan, 1996; Verspagen, 1991). We think that by considering the complexity involved in this concept, much of the dynamics of development could be explained. Instead of considering a control factor in the empirical exercises, we will make this subsystem endogenous in our analysis.

Lastly, these two subsystems co-evolve to drive economic development: more empirical evidence is needed to describe how these relationships occur. We do not assess imitation and innovation as separate activities, but rather we believe that they are intertwined processes that could not be understood separately. We proposed a model composed by three subsystems. *Innovative capabilities* are represented by three factors: innovative input (effort and investment in R&D and related activities); scientific output (results of research and innovation activities from the public S&T system) and; technological output (total output of technological and innovative activities carried out by private firms). *Absorptive capacity* is quite diverse in its composition, it includes: international trade (openness of the national system), human capital (education and skills in the population), infrastructures (network, transportation, distribution, etc.), quality of institutions and governance system (efficiency of the governance system) and, social cohesion and economic inequality (effects of equality in trust and knowledge sharing among individuals). *Income level* (GDP per capita) is the final component of the model: it is a proxy of countries' overall performance and – in the context of systemic interactions – of their development stage.

The proposed configuration of national innovation systems leads us to four propositions (Castellacci and Natera, 2013b):

- The dynamics of the innovative capability is driven by the coevolution of the three factors that define it: innovative input, scientific output and technological output.
- The dynamics of the absorptive capacity is driven by the coevolution of the five dimensions that define it.

- Innovative capability and absorptive capacity co-evolve over time, i.e. these two dimensions are linked together by a set of two-way dynamic relationships.
- The dynamics of innovative capability and absorptive capacity, and the coevolution between them, differ across country groups characterized by different levels of development.

The Vector Error Correction model, in its panel version, is the selected econometric method. It allowed us to examine the causal structure that links together the variables within and between innovative capabilities, absorptive capacity and income level. It shows the structure over time: on one hand, it looks at the long-run equilibrium relationships in which variables move together (as parts of a system); on the other, it describes the causal structure to reveal how variables react when something changes in the system. Our results are organized in terms of these two types of time-structures and of different country groups: heterogeneity has been addressed by clustering countries according to their geographical and institutional background.

4. SUMMARY OF THIS PHD DISSERTATION

Before proceeding to the papers, it is convenient to take a look at Table 1.1, which offers a brief description of the content and current status of each article. Apart from those included in the table, a closing chapter, called "Conclusions, limitations and possible extensions", will expose the main outcomes from this PhD dissertation.

Table 1.1 - An overview of the articles included in the PhD dissertation

Title and co-authors	Publication	Purpose	Methodology
Chapter 2 "How innovation systems and development theories complement each other" (with Mario Pansera)	*Prometheus: critical studies on Innovation* (under review process)	Investigating the interactions between the Innovation Systems approach and development theories	Review of the literature that relates Innovation Systems with Development as freedom, the Institutional economics, the Neo-Classic theory of growth, the Multiple Equilibrium approach, the Latin American Structuralism and the World System theory
Chapter 3 "A new panel dataset for cross-country analyses of national systems, growth and development (CANA)" (with Fulvio Castellacci)	*Innovation and Development,* 1(2), 205–226, 2011	Developing a panel dataset (134 countries and 29 years) suitable for time series analyses of innovation, economic development and growth.	Application of a new Multiple Imputation method that generates estimates of the missing points by extracting the existing information from the observed data.
Chapter 4 "Innovation, Absorptive Capacity and Growth Heterogeneity: Development Paths in Latin America 1970–2010" (with Fulvio Castellacci)	*Structural Change and Economic Dynamics* (under review process)	Identifying the driving forces of Latin American development during the last four decades.	Time series analyses of 18 Latin American countries by using Vector Error Correction models (Johansen's approach) to identify long-run causality estimates between economic growth and innovation and absorptive capacity dimensions.
Chapter 5 "The dynamics of national innovation systems: a panel cointegration analysis of the coevolution between innovative capability and absorptive capacity" (with Fulvio Castellacci)	*Research Policy,* *42*(3), 579–594, 2013	Analyzing the coevolution of the subsystems of innovative capabilities, absorptive capacity and economic growth across different levels of development.	Panel cointegration analyses of 87 countries during the last three decades. Heterogeneity was assessed by defining 5 groups of countries according to their geographical and institutional background.

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CHAPTER 2

HOW INNOVATION SYSTEMS AND DEVELOPMENT THEORIES COMPLEMENT EACH OTHER[ǂ]

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Abstract

The paper aims at comparing some of the most influential theories of development with the notion of Innovation Systems (IS). The objective is to understand if this comparison can be used to delve into the role of innovation within the development process. We start defining the main features that characterizes Innovation Systems. Then we contrast it with different branches of development theories: the Sen's theory of capability building and the Institutionalism, the neo-classic approach and cumulative processes (multiple equilibrium approaches) and finally, the Structures and System Theories (LA structuralism approach, the dependency and world-system theory). We conclude that the interaction between IS and the theories considered represents a mutual benefit. IS, indeed, provide a systemic vision that considers innovation as a holistic process, giving a central role to social and economic factors. Hence, IS might be successfully applied to complement the classic development approach. Innovation Systems could also get benefits from this interaction: development theories shed light on the different ways to think of systemic relationships. Finally, rather than focusing on the discussion of IS being or not a theory for development by itself, we believe that making this relational exercise could generate new benefits and frameworks of analysis for the research community.

Keywords: innovation, innovation systems, development theory.

ǂ This paper has been submitted to ***Prometheus: critical studies in innovation*** http://www.tandfonline.com/toc/cpro20/current#.UieVUDZWySo.

1. INTRODUCTION

Far from being a unique monolithic theoretical block, development theories are rather a conglomeration of theories. They focus on social, economic and technical changes that allow the development of human societies. Since they draw on a huge variety of approaches and scientific disciplines, we will make an effort to present the most influential ones in the following lines. We acknowledge the high diversity that those theories present and the necessity of setting a common criterion to approach development.

When Abramovitz (1986) discusses the relationship between social and technological capabilities with economic growth, he explicitly reveals his intention of incorporating a broader perspective into the economic analysis: it is not only a matter of factors endowments; it implies the interaction of social abilities and productive use of knowledge. This kind of holistic approach to economic progress is what we consider closest to our development vision.

Not without many criticisms, GDP has often been considered as a good proxy to assess the development level of a society . Such an approach has been increasing losing its momentum due to the shortcomings of measuring wellbeing merely through chrematistic indicators (Fioramanti, 2013). The concept of a mere quantitative growth is now thought to harm the concept of development itself (Sen 1999). The typical confusion between "*economic growth*" and "*development*" might often lead to unfortunate conclusions such as increasing inequalities and environmental degradation (Daly 1987). It becomes important, then, to highlight how the notion of development goes beyond the merely possession of economic goods. If this distinction is well established, we do not believe that there is an orthogonal relationship between development and economic growth, since many well developed societies commonly exhibit high levels of GDP per capita. We do believe that what is needed to properly link together these two concepts is a systemic vision of techno-social change dynamics (Clark 2005).

In this sense, IS could shed light on the analysis of the complex economic relationships that constitute *development*. The IS emerges as a tool for action rather than a theory that stands alone, and it is this flexibility that makes it suitable to many different theoretical approaches while increasing their analytical power. The main objective of this paper is to assess how the Innovation System framework could be applied to the most influential theoretical characterizations of development, identifying the bidirectional interactions.

The paper is structured as follow: first, we briefly discuss the basic features of the IS notion; then, we present some of the most relevant development theories and the interactions between them and IS. In the last part, we conclude that this merge might be a valuable tool to understand and foster development by helping to disentangle the enormous level of complexity related to this process.

2. INNOVATION SYSTEMS: FINDING A COMMON GROUND

There are different visions when it comes to define Innovation Systems. There have been heated discussions about treating IS as a concept, a theory or a framework. Rather than discussing the implications of these differences [1], we will present the main characteristics that in our view should be listed when building and IS definition:

- ***The agents and their interactions***: IS are characterized by agents and the mesh of relationships that intertwines each other. Freeman (1995) defines IS as "*the network of institutions in the public and private sectors whose activities and interactions initiate, modify and diffuse new technologies*". A nation's innovation performance depends on the aggregation of these interactions from the micro to the macro level (Nelson 1993). Agent identification has mostly been driven by the Sabato's Triangle (Sábato, Botana 1968) and the closely related concept of the Triple Helix approach (Etzkowitz, Leydesdorff 2000): government, academy and firms are pointed out as the major stakeholders. However, it is important to keep an open door for many other different actors: society may use different configurations in the innovation process; not

[1] The discussion about the implications of IS diverse concepts is not hold here because of its complexity. We prefer to redirect the reader to Shariff (2006) whom, using interviews with the most influent scholars, analyse the evolution and different IS approaches since the concept's inception. Lundvall himself has also presented a deep analysis of IS characterizations (Lundvall 2007b). Another nice contribution in this sense has been made by Godin (2006a). We believe that IS could be used as a concept, when focusing on how to define innovation; as an approach, when different combinations of theories and methods are needed and; as a framework to study policies and ways of organizing societies to produce innovation.

accounting for this might leave important interactions underrepresented (Lundvall 2007a).

- ***The process***: Lundvall stresses the centrality of "*learning*" at the IS core: it is through learning that public and private agents relate to create new and useful objects or services (Lundvall 2007a). Different modes of learning (*learning by doing, learning by using and learning by interacting*) take place at different levels but always reside in people (Lundvall 1988). Describing the IS process as a set of interrelated functions has also been an alternative (Edquist 2005, Bergek, Jacobsson et al. 2008). List of functions mainly includes: knowledge search and formation, market oriented capabilities and managerial skills. This function approach is practical but it might lead to some deterministic considerations of what an IS should or is able to do.
- ***The setting***: the institutional setting (the so-called "*rules of the game*") is one of the main determinants of an IS (Nelson, Nelson 2002). The way routines are organized and its evolution will impel or burden countries economic progress (Nelson 2008). Conflict management, information supply, incentives placement and resource allocation are some of the specific roles that institutions play within the IS (Edquist 1997).

The operationalization of IS has also been a major challenge (Carlsson, Jacobsson et al. 2002). At some extend, the previously discussed "*function approach*" is an attempt to make IS more rational and operative. Other approximations include the establishment of a multilevel perspective (Markard, Truffer 2008), the geographic characteristics (Cooke, Gomez Uranga et al. 1997, Tödtling, Trippl 2005) , as well as IS sectorial analysis (Breschi, Malerba et al. 1997, Malerba 2002).

2.1 INNOVATION SYSTEMS FROM THE SOUTH

Since development requires people involvement, it makes absolute no sense to study the interactions between IS and development without considering the so-called developing world. IS was born in the OECD countries, finding a major success in terms of policy making for Science, Technology and Innovation (Sharif 2006, Godin 2006a). It is reasonable to think that many of their characteristics might be valid only within that context. As a consequence, it is necessary to study if IS can be applied to the South.

During the last decade, recent volumes –promoted by Globelics[2] network– have been devoted to study developing regions under the lens of IS: Africa (Muchie & Gammeltoft, 2003) , Latin America (Cassiolato, Lastres, & Maciel, 2003), Asia (Lundvall, Intarakumnerd, 2006) are currently studying how IS could actually serve to shape their development process.

Lundvall et Al. (2009) focus their attention on the contribution of IS to development economics. Rather than a unique recipe for development, IS suggests investing in endogenous capability through a process of interactive learning. This strategy is often called *competence-building,* or, in other words, *the processes of learning and renewal of skills necessary to innovate* (Lundvall & Borrás, 1999). Investment in capabilities building to increase the local ability to compete is crucial for economic growth in developing countries[3].

According to Ar;ocena and Sutz (2000), when one uses Innovation System in the South, it is decisive to take into account four essential aspects:

1. Unlike developed countries, for developing countries, IS is basically an *ex-ante* concept. In the industrialized countries the study of innovation has been based on empirical analysis that allowed identifying common patterns among different nations and regions. In developing countries it is very difficult to find regular patterns in the economic system at a national level;
2. *"The IS concept carries a normative weight".* That means that there is no *ideal system*. Some measures can be useful in a specific context and may be less effective in other situations.
3. The IS concept is, in its nature, a *relational* model. The good relationships between the actors are often the most important factor of success in the systems. In the case of Latin America, for example, it has been easy to create organizations to boost innovations, but it has been hard to make them work.

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[2] The Global Network for Economics of Learning, Innovation, and Competence Building Systems (Globelics) is a global network of scholars who apply the concept of 'Learning, Innovation, and Competence Building System' (Lics) as their analytical framework. The network is especially dedicated to the strengthening of Lics in countries in the South: http://www.globelics.org/

[3] That strategy may be implemented at regional/national level as well as at community level. Local administrations, indeed, can play a crucial role in increasing the dynamism in the territorial innovation systems even in rural areas (Cummings, 2005).

4. Finally, the IS concept is useful to formulate policies. That implies that it should be possible to act deliberately on the system to achieve real changes in the inn'ovation performances. Since in the majority of developing countries *Science & Technology* policy never occupied a high position in the political agenda, this process of change appears to be quite difficult to achieve without a strong political commitment.

Other authors stress the importance of social aspects uncovered by the IS notion in/u less developed countries. In particular they advocate for an IS which encourages social inclusion and contrasts inequality. According to CEPAL (2009) it is possible to combine the objectives of economic growth, social inclusion and environmental sustainability. In order to achieve those goals, a multilevel decision making approach is needed. It should combine three essential elements to increase efficiency and ownership, crucial for social inclusion: the scientific and technological knowledge, the wisdom and organizational forms with high levels of self-determination and participation.

In the following section, we aim at incorporating this visions in the analysis of the interactions between IS and the mainstream body of development theories. We know the risk of creating "groups of theories" in such complex issue like development is. The objective of this exercise is to highlight their common characteristics in order to organize the most relevant ideas.

3. DEVELOPMENT AS FREEDOM

Nowadays, it is almost impossible to escape from Sen's *freedoms* (Sen 1999) when approaching *development*. The definition of development as the removal of *unfreedoms*, both at the individual and social level, has constituted a major step forward in policy making. It has changed the focus from the highly criticized utilitarianism and libertarian reasoning to a more deep and careful analysis of people's living conditions (Corbridge 2002). Empowering people to decide the lifestyle they want to pursue and how to achieve it encompasses, nevertheless, a great complexity. First of all, because development is something done by people and not done to people: it requires informed and conscious actors in this decision making process. Secondly, it is hard to define the right balance between the individual freedom and the collective freedom, their interactions and their possible clash of interests (Smith, Seward 2009). However, it is important to highlight that the real development only comes when people find their way to use things and act accordingly to their will, meaning an important combination of individual and social knowledge.

Sen defines "*capabilities*" as the different opportunities and the capacity to decide what each person or society wants to do, they are the real enablers to conquer different types of freedoms that constitute development (Sen 1999). This capability approach bridges perfectly to the innovation theory. Deeply rooted in historical analysis of countries performance, Abramovitz (1986) exposed how the interactions between the *technological congruence* and the *social capabilities* explain countries' development level. Technology and firms' operative conditions interact with a broader set of institutions and social characteristics, generating countries ability to catch-up or to fall behind (Abramovitz, David 1996). Lall (1992) presents the concept of *technological capabilities*, both at the firm and national level, as the different characterizations of skills and abilities needed to "*utilize or innovate technologies*". In these two influential proposals there is an obvious link to Sen's vision of development: innovation means an undisputed mixture of different skills, at different levels (individual, firm and aggregated), in order to introduce new solutions. It is not a matter of just having new technologies, but making it useful for society, which implies much more complexity and calls for a systemic view. More recent empirical studies, closely linked to IS, have succeed to demonstrate how a multidimensional vision is required to explain the relationship between technology and economic growth, including social and institutional determinants in the analysis (Dang, Umemoto 2009, Fagerberg, Srholec 2008, Hall, Jones 1999). We second Lundvall when he proposes that explicitly linking this capability approach to Sen's does enhance our understanding of development:

> *"Sen's approach fits well into a system of innovation approach. It is noteworthy however that learning and innovation capabilities generally do not seem to be explicitly included in this capability-based approach to development. Extending capabilities may be the result of changing the setting in which the agent operates, but even more important in the learning economy is whether the setting gives access to and stimulates a renewal and upgrading of the competence of agents"* (Lundvall 2007a).

Sen also refers to the “*agency*” factor, the power that actors have to manage and transform their realities (Sen 1999). This is also a shared feature with IS since, as discussed above, the identification of the multifaceted characteristics of determinant agents is one of its main concerns. This attention to agents comes from the acknowledgment that they are the driving forces of the innovation process. But perhaps the most important point in common has been already pointed out by Arocena and Sutz (2000): the assessment of IS, as a development tool, cannot escape from empowering people to deal with their own reality following their own norms.

4. INSTITUTIONAL ECONOMICS

Institutional economics considers that the way society behaves has a direct effect on economic development. *Organizations*, promoters and main actors of the economic system, regulate their interactions by a set of formal and informal rules, the so-called *institutions* (North 1990). Human beings, interacting continuously with each other and with the environment, have to constantly face the inherent uncertainty of their actions. The main role of institutions is to reduce this uncertainty by providing a code to communicate and to decipher the actions of the subjects involved in a society. The uncertainty reduction diminishes the *transaction costs* that characterize any economic exchange, since it makes easier to enforce agreements and to measure the quality of these enforcements (North 1990). Of course, institutions do not remain unchanged with the pass of time; they evolve as a consequence of new needs or actors preferences’ changes: organizations would use their knowledge, resources and capabilities to drive institutional change and achieve their goals. This change would materialize and feedback into the economy, generating a *learning* process. Development is the result of making things easier for people to interact, a condition that is represented by low transaction costs (good economic performance). North relates transaction costs with the possibility of using information in order to measure the characteristics of the exchange and to enforce agreements.

Under this view, there are many connections to the IS framework. We should start by stating that there is a strong connection between transaction costs and the ability to use technology: the possibility of measuring established agreements is closely linked to the capability of using the right instruments and techniques to do so. By this, we mean that the skills developed to use knowledge are one of the drivers of uncertainty reduction, establishing a crucial bond between society and technological progress.

Additionally, there is a clear parallelism between the main factors that are highlighted by the institutionalism and IS: organizations as the agents that participate in the economic process and that drive institutional change, learning as the central process to explain the evolution of transactions costs and, institutions as the main rules that govern agents' interactions.

Nelson has made an important effort to emphasize the communalities between the two approaches. He presents the concept of *routines*: "*a way of doing something, a course of action*" (Nelson, Nelson 2002). Supported by a set of understanding and beliefs, routines are automatic by nature and admit choice within a limited range of alternatives. Routines are composed by two factors: *physical technologies*, the collection of steps needed to perform an activity and, *social technologies*, the coordination mode needed to organize people's responsibilities in each of those steps (Nelson, Sampat 2001). According to this vision, institutions could be considered as social technologies that have been widely spread within organizations but also between them. In this sense, institutions could and in fact interact with different types of social technologies. They could also play a twofold role: setting the background in which social technologies take place and correspondingly emerging or changing when new social technologies require it (Nelson 2008).

The connections between Nelson's institutional view and the IS approach have been explicitly stated by himself. He theorises that it is the coevolution between physical technologies and social technologies what drives economic development, and institutions are there to define and shape social technologies. In other words, institutions set the background conditions and establish the behavioural rules that agents must follow when interacting. Institutions change as a consequence of a knowledge process: learning.

5. From neo-classical theories to endogenous growth

The neo-classical school has been for long time indifferent to the concept of innovation. One could also argue that the concept of development has suffered the same fate: it has been merely equalled to economic growth, or at least considered as a natural consequence of it. Being both notions out of the discussions, of course, the relationship between innovation and development has been completely neglected. In the pure neo-classical tradition, innovation is just considered and external variable (Ahlstrom 2010). Furthermore, knowledge is always available and free, ready to be adopted by whoever is in need. This implies that technological knowledge can be always perfectly coded without ambiguity. As a consequence, the typical neoclassical firm, in an over simplified version, is assumed to have perfect and complete knowledge about the best technology available at any given time and all the capabilities needed to use it.

Schumpeter's work reversed those assumptions. He states that the very engine of capitalism expansion is innovation that continuously revolutionising the way good and services are produced and delivered. Probably the most important consequence in the neo-classical tradition of Schumpeter work was the fact that he challenged the assumption that growth and development are based only on physical capital accumulation. Other historians, like Moses Abramovitz has also contributed to expose the role of other factor in economic growth. Based on his works on the development of the US industry, he found that something else was missing to really explain the sources of productivity (Abramovitz 1956). Moving in this direction, new scholars attempted to include technological progress in the neo-classical analysis (Fagerberg, Srholec et al. 2010). In the 1950s Solow (1957) introduced the technical change in the function of production finding that innovation accounts for the major part of productivity increase that leads to economic growth. But, once again, under this view development is considered as synonymous of economic growth. Moreover, no other characteristics but labour, physical capital and now technology were part of the equation to explain economic performance.

Later on, further research were carried out by Kenneth Arrow (1962), Paul Romer (1994) and Lucas (1988) who attempted to prove how economic growth was due to indefinite investment in human capital which had spill-over effects on economy through the continuous creation of endogenous innovation. Those model aims at explaining why in the real world the convergence process (based on the law of "*diminishing return*" to capital accumulation) was not taking place. The conclusion was that technical change constantly modifies the production function. This thinking is commonly known as *endogenous development theory* or *new growth theory*. Those theories claim that economic growth is the result of endogenous and not external forces. In Endogenous Growth Theory, investment in human capital, innovation and knowledge are significant contributors to economic growth (Romer 1994). Innovation, thus, can be fostered investing in research, development and education. This approach is also known as "Linear Model" and stress the need of state and private investment in R&D activities and basic scientific research to feed the innovation process (Godin 2006b). As a consequence, economic development occurs more quickly where innovation capability is nurtured properly. In this case, the interactions with the IS approach start to arise. The main role that human capital and knowledge has implicitly recognizes the importance of learning as a main economic process.

About the diffusion and spreading of innovation and economic growth benefits to the rest of the society, neo-classical economists are less explicit. The main argument is that sustained economic growth generates long-term increase in per capita income that is transferred to the base of social pyramid (Barro, Sala-I-Martin 1995). In a nutshell, markets are eventually able to distribute the benefit of economic growth to the entire society and to impulse innovation that spread wealth and create million of new jobs. The basic neo-liberal argument, derived by the neo-classical tradition, is that underdevelopment is simply the result of bad allocation of resources caused by an excessive government intervention and too many obstacles to free circulation of goods. The complex problem of underdevelopment is reduced to the simple recipe of "get the process *right*, get the property rights *right*, get the institutions *right*, get the governance *right* and get the competitiveness *right"*(Cassiolato, Guimarães et al. 2005). Innovation and technological knowledge spill over from advanced to low income countries through international trade, FDI and licencing (Chang 2003). In a free trade world, enterprises in developing world would be able to acquire always the best technology available on the market. But: what does "*right*" mean in this context? We consider that in this approach there is an underestimation of the agents' particular characteristics and society's institutional settings: it does not take into account the effect of the high heterogeneity that characterizes the economic processes around the world or the importance of establishing diverse types of linkages between different actors. Since human capital and knowledge are explicitly indicated as basic driving factors, we consider these omissions a contradiction. Furthermore, the neoclassic or the new growth theories – at best – underestimate the importance of policy interventions for economic development, limiting their scope to an extremely limited research area: the simple case in which just rent redistribution is required. This is a big limit. Though they do not take into account the systemic nature of development, we would at least expect them to accept the importance of policy in fostering S&T. Additionally, the mechanisms exposed to ensure collective benefits, mainly through job creations, neglects the complexity involved in the development process: it closes the door to any other outcome of the economic process that does not produce immediate results, even when the learning processes that supports it could need additional time to reveal its economic value (Arocena, Sutz 2000).

6. MULTIPLE EQUILIBRIUM APPROACHES

Development as a cumulative process has been also applied to explain cross countries differences. The basic idea behind the multiple equilibrium approaches to development is that countries tend to converge to clubs or cluster that share similar macro indicators to. Different groups are defined by similar initial conditions and certain capabilities thresholds. Countries convergence to the similar equilibrium states in the long run is not always linear and does not take place equally around the world (Castellacci 2011). Determining the factors that enable countries to move to a higher development level is one of the key research questions in this approach. Even when human capital and technology have been widely accepted as two of those main factors, there are still some differences among the most influential models in this field.

Verspagen (1991) presented an interesting model in which nonlinear relationships between learning capabilities and the catching-up process vary across country groups: initial absorptive conditions are needed to close the gap and if they are not present, a gap increase could be observed. Aconsistent amount of researches seem to confirm those assumptions, including a narrower perspective in which the interaction of human capital, physical capital and technological (R&D) activities is emphasized (Fagerberg 1994).

The heterogeneous countries' characteristics and their highly diverse starting points lead us to think that economic growth could not take place homogenously. In fact, if nonlinear systemic relationships matter, then economies characterized by different initial conditions (e.g. different levels of human capital) will tend to have diverging growth performances over time: some countries will catch-up while others will fall behind, *convergence clubs* would arise as a normal outcome of this process (Durlauf, Johnson 1995).

Recent empirical studies extend this convergence clubs literature and argue that innovation and technology diffusion are the main factors explaining why there exist multiple growth regimes (or different stages of development). This new literature on *technology clubs* (Castellacci 2008, Castellacci, Archibugi 2008, Filippetti, Peyrache 2011) thus investigates how the technology-growth relationship differs across country groups, and what are the most critical factors of catching up and growth for countries at different stages of technological development.

The Schumpeterian multiple-equilibria growth models offer a basement to these empirical results. Three groups (clubs) are distinguished according to their capacity to use, adapt and generate technology, therefore determining their correspondent development stage (Verspagen 1991, Howitt, Mayer-Foulkes 2005, Galor 2005): the most advance group (high capacity), the catching-up group (developing and increasing capacity) and, the laggard group (low capacity).

Under this view we can see many interactions with IS. First, this literature recognizes the important of the agents' heterogeneity and interaction to produce the aggregate levels of the different thresholds of interest. Second, the initial conditions and the effect of them on the economic performance recognize the institutional setting impact on the development level. Third, since the interaction between human capital and technology are key factors defining countries' capabilities, the learning process is also present.

Nevertheless, we should identify some main differences in which we believe that the IS approach could contribute. The multiple equilibrium models underestimate the systemic vision as an important feature of the economic system development. They are too focused on only two principal characteristics, disregarding many other interactions within the productive system that could have an impact on their performance: for instance, they do not explicitly place the interactions between institutions and technology in any part of the model. If we want to apply a holistic vision to development, we need to identify and augment the complexity of this analysis. The inclusion of systemic relationships to explain growth heterogeneity across the world unravels the necessity of considering innovation, governance, institutions and the international environment when describing countries' economic development (Fagerberg, Srholec 2008). It is there, nevertheless, where IS has a strong interaction with this branch: it is an important complement that could help to better explain the macroeconomic performance. We also consider that this vision is compatible with the capacity building approach that "IS from the South" calls for. From a macro perspective, the multiple equilibrium models could interact with this IS approach to determine the critical competences that should be boost to move forward development levels.

7. LATIN AMERICAN STRUCTURALISM APPROACH

The Latin American Structuralism Approach (LASA) was first developed by Prebisch in the 1950s, when he was required to make an evaluation of the Latin American economic growth. He proposed that *underdevelopment* was not just a merely previous state to (higher) development, but rather a structural pattern persistent in many countries, a different type of development (Prebisch 1949, Prebisch 1986). He argued against the deterministic approach of that pointed out that developing countries should follow a similar path that developed economies have followed before (Ríos 1964). The underlying idea is that development is not a unique state, and that each country should follow its own destiny by constructing internal capabilities. According to this view, one additional constrain to development comes from the capitalist system and the asymmetries that it creates: resources flow from a "*periphery*" (of low income and underdeveloped states) to a "*core*" (of developed and wealthy states) (Furtado 1964, Furtado 1998).

Basically, by this two factors (low internal capabilities and dependent international relationships) are the root causes of development persistence over time. In this sense the importance of usage, production and diffusion of technology as a way to break this circle is evident (Dutrénit, Katz 2005). Many scholars have put forward the idea that combining the evolutionary perspective with the LASA is one way to study development. One of them have been Carlota Pérez, she has made a major contribution to the study of the underlying structural relationships when combining the neo-Schumpeterian approach (the rise and fall of radical innovations and their impacts) and its interactions with the entire economic system structure (Cassiolato, Pagola et al. 2009, Perez 1983, Pérez 1992, Perez 2008).

The IS approach interaction with the LASA has been already studied by Cassiolato et al (2005) and Peixoto (2008). The LASA is also present in Arocena and Sutz (2000) vision of "*IS from the South*". They all make easy to identify the similarities between these two approaches: both emphasize the role of productive system and innovation; they consider innovation as a systemic, dynamic and multidimensional phenomenon; they focus on the interaction between local and aggregate actors at the micro, meso and macro level. The systemic view is a building block of LASA and, of course, of the IS approach: the idea of generating solid capabilities as a way to cope with underdevelopment is completely reasonable in this sense. The tools that could arise from this merge include: the analysis of economic agents and processes as social and political environment embedded actors; the high context dependence of both theory and policy recommendations; and the central policy focus on constant internal and external constrains to development (Cassiolato, Guimarães et al. 2005).

8. DEPENDENCY THEORY AND WORLD-SYSTEM THEORY

Closely related to the Latin American Structuralism Approach, we now target the *dependency theory* as our next subject. The main focus in this case is the effect of current international structures that define those centres and peripheries previously defined by LASA[4]. As a consequence of historical factor accumulation (capital, knowledge and financial resources), countries at the core generates dependent

[4] One important difference between the LASA and the dependency theory should be stressed: the latter does not focus on the internal structures that characterize underdevelopment situations. We could argue that LASA is a more comprehensive approach.

relationships with countries at the periphery, while capturing the resources in which they are interested, a kind of post-colonial relationships. On this process enriches the countries belonging to the "*core*" at the expense of the "*periphery*" (Dietz, 2011).

An evolution of dependency approach was provided by *world-systems theory*. It introduces a third category of countries, the "*semi-periphery*", between the core and periphery. "*The semi-periphery is industrialized, but with less sophistication of technology than in the core; and it does not control finances*" (Velasco, 2002). In the periphery as well as in the core, capitalism is characterized by cyclical fluctuations of expansion and recession. According to this approach, core countries are not simply enriching at the expense of poor but it is a cross national class of rich that is more benefit than low income working classes. In principle under capitalism both rich and poor can growth but they would not benefit equally.

The main contributors to world system theory are Wallerstein and Arrighi who focused on the economic and social transformation that followed the process of globalization. They criticize the positivist approach of modern development that considers economic growth an ameliorative process. In this respect Wallerstein (2004) is enlightening in providing a brilliant description of the origin of the term:

> "*Development, as the term came to be used after 1945, was based on a familiar explanatory mechanism, a theory of stages. Those who used this concept were assuming that the separate units - national societies - all developed in the same fundamental way but at distinct paces (thus acknowledging how different the states seemed to be at present time).*"

Dependency theory and world system theory do not mention explicitly the concept of innovation. However this approach is obvious when they depict an intertwined world where high industrialized countries are able to produce innovative good and services and free to transfer the production process all around the world to minimize resource and labor costs (Arrighi, 2007). The IS approach interactions are more linked to the internationalization of technology: the analysis of the globalization effects on the national innovation systems and its consequent repercussion on local economies. There is an important scientific production that could help to better explain how this interconnection between developed and underdeveloped worlds takes place. Carlsson (2006), in a comprehensive survey, has showed that the internationalization process has been gaining relevance, even considering the main role that the national perspective still possesses. Niosi and Bellon (1994), in an influential paper, reach an important conclusion that is of high relevance when looking at innovation as an international process: the complexity of the innovation systems goes beyond the local and national circumscription and crosses other frontiers, calling for more sophisticated managerial techniques and for a new global institutional dimension that could cope with it. Archibugi is also an important reference in this direction: his work confirms the call for policy action to deal with the global phenomenon (Archibugi, Howells et al. 1999, Archibugi, Iammarino 1999, Archibugi, Pietrobelli 2003). Given our current context, in which the emerging economies are increasing their relative power, we wonder about the implications for global innovation: Is innovation moving from core to periphery? Is the core moving from USA to China?

9. CONCLUSIONS

There is a wide range of theories of development. Development should not be seen as a one-dimensional process in which resources allocation is the only issue to be solved for once and for all. The systemic view is a must when it comes to analyse development. In this paper, we aim at presenting some of the most influential development theories in the literature and their interactions with the IS framework. Our objective has been to show how complementarities arise in order to investigate how this combination could be a powerful tool for development studies. Our fundamental components of Innovation Systems are the agents and their interactions, the learning process they undertake and, the institutional setting that frames the system. A summary of the intersections between the concept of IS and the theories of development considered is reported in Table 2.1

We started with Sen's *development as freedom.* Lundvall (Lundvall 2007b) has explicitly pointed out the relationship with Sen's capabilities; many empirical studies also verify that the social and technological capabilities are suitable to innovation for development. Then, we analyzed *institutional economics.* On this regard, Nelson has remarked a crucial interface between the institutional perspective and the IS approach, using social technologies as a linking concept (Nelson, Nelson 2002). We also highlight how technological capabilities are implicit in transactions costs, opening another door for interactions among both approaches.

We have also included the neoclassic vision of economic growth. It was not possible find any interaction with Innovation Systems. We decided to include it here because it has been considered an implemented as a way of enhancing development across the world, despite of its very limited perspective. In light of the other theories we presented, we believe that the neo-classic approach should not be regarded as a real development theory, but rather a simplified model to deal with particular cases of economic growth.

Table 2.1 - Major intersections between IS and the Development Theories

	How Innovation Systems could benefit from Development Theories?	**How Development Theories could benefit from Innovation Systems?**
Development as freedom	- It identifies many other important types of capabilities to be considered when explaining the systemic interactions. - The agency factor is a useful way of pointing out the how agents are able to drive the system.	- Learning processes are crucial for development, one capability to be added to Sen's list. - More attention to the socio-technical determinants of innovation.
Institutionalism	- Smooth interactions among actors are essential. - It offers a framework of analysis to understand changes in the system versus the stability that it requires to function.	- More attention to the cultural heterogeneity of institutions and their impact on development. - It might explicitly recognize the importance of technology in the determination of the transaction costs.
Neo-Classic theory of growth		Innovation shouldn't be an exogenous variable.
Multiple Equilibrium approach	- Systemic macro interactions ease the process of development. - It sheds light on the accumulative process of the innovation capabilities. - It serves to identify common characteristics among country groups.	- More emphasis in the systemic nature of macro dynamics. - The capabilities considered are very limited to Human Capital. It should rather consider a multidimensional outlook.
Latin American Structuralism	- Development is seen as open process, in which the internal and international factors should be considered.	- It places innovation as the main fundamental factor to achieve a better development.
World System	- Power distributions within the network matter.	No real explanation of technical innovation arising, so it might incorporate it as a crucial factor that explains the power dynamics.

The multiple equilibrium approaches have strong interactions with IS in order to analyse development. First, since it considers the high heterogeneity that characterizes the economic system, it opens the door for the systemic view. Merging these to streams

could lead to a better understanding of the macroeconomic process of development, especially when focusing on international comparisons.
We close this paper considering development and its structural view. The Latin American Structuralism Approach (LASA) could greatly benefit from the use of the IS approach in order to unravel the underlying structures that constitute the underdevelopment phenomenon. Fortunately, at least in Latin America, scholars have realized this opportunity and have taken advantage of it.

The dependency theory and its evolution, the world-system theory, are the final thought stream considered. In this case, to our knowledge, the combination between them and IS has not been explicitly done in any other empirical or theoretical exercise. For this case, we recommend the literature on internationalization and policy implications of it on national IS. We also believe that the interaction with IS approach could expose the way and the degree of dependent relationships between the core and the periphery. Furthermore, structuralists and world system theorists stress the important role of power and its mechanisms in the process of socio-technical change. Who wins and who loses in the innovation process within the system? Such a questions is often neglected by IS advocates.

Innovation Systems are very flexible by nature. They were designed to adapt to different contexts and be always a handy tool for action. This versatility is something of much help when using a specific branch of theories, particularly in such a complex issue like development. Instead of criticizing this malleable characteristic, we would like to push forward the idea of taking advantage of it to incorporate new insights in theoretical and empirical analyses. It could be an opportunity to constantly revisit many of the theoretical milestones while contrasting them with down to earth evidence.

We believe that the interaction between IS and the different development theories represents a mutual benefit. For each of the theories, IS helps to provide a systemic vision that considers innovation as a holistic process, giving a central role to social and economic factors. IS approach could also benefit by interacting, since this theories shed light on different ways to consider the systemic interactions and which should be the most critical relationships to evaluate. Rather than focusing on the discussion if the IS approach should or not be a theory by itself, we believe that making this relational exercise could also bring new light on both ends, generating new benefits and frameworks of analysis for the research community.

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CHAPTER 3

A NEW PANEL DATASET FOR CROSS-COUNTRY ANALYSES OF NATIONAL SYSTEMS, GROWTH AND DEVELOPMENT (CANA)ǂ

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Abstract

Missing data represent an important limitation for cross-country analyses of national systems, growth and development. This paper presents a new cross-country panel dataset with no missing value. We make use of a new method of multiple imputation that has recently been developed by Honaker and King (2010) to deal specifically with time-series cross-section data at the country-level. We apply this method to construct a large dataset containing a great number of indicators measuring six key country-specific dimensions: innovation and technological capabilities, education system and human capital, infrastructures, economic competitiveness, political-institutional factors, and social capital. The CANA panel dataset thus obtained provides a rich and complete set of 41 indicators for 134 countries in the period 1980-2008 (for a total of 3886 country-year observations). The empirical analysis shows the reliability of the dataset and its usefulness for cross-country analyses of national systems, growth and development. The new dataset is publicly available.

The CANA database can be downloaded at the web address:

http://cana.grinei.es

Please contact the authors for any question, or suggestion for future improvements.

Keywords: Missing data; multiple imputation methods; national systems of innovation; social capabilities; economic growth and development; composite indicators.

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"*If you torture the data long enough, Nature will confess*" (Ronald Coase, 1982)

1. INTRODUCTION

A recent strand of research within the national systems literature investigates the characteristics of NIS in developing countries and their relevance for economic growth and competitiveness (Lundvall et al., 2009). Some of this applied research makes use of available statistical data for large samples of countries and carries out quantitative studies of the economic and social capabilities of nations and the impacts of these on the growth and development process (Archibugi and Coco, 2004; Fagerberg et alia, 2007; Castellacci and Archibugi, 2008).

This empirical research faces however one important limitation: the problem of missing data. This problem, and the related consequences and possible solutions, have not been adequately studied yet in the literature. The missing data problem arises because many of the variables that are of interest for measuring the characteristics and evolution of national systems are only available for a restricted sample of (advanced and middle-income) economies and for a limited time span only.

As a consequence, cross-country analyses in this field are typically forced to take a hard decision: either to focus on a restricted country sample for a relatively long period of time, or to focus on a very short time span for a large sample of economies. Both alternatives are problematic: the former neglects the study of NIS in developing and less developed economies, whereas the latter neglects the study of the dynamics and evolution of national systems over time.

This paper proposes a third alternative that provides a possible solution to this trade off: the use of multiple imputation methods to estimate missing data and obtain a complete panel dataset for all countries and the whole period under investigation. Multiple imputation methods represent a modern statistical approach that aims at overcoming the missing data problem (Rubin, 1987). This methodology has received increasing attention in the last decade and has been applied in a number of different fields of research. In particular, Honaker and King (2010) have very recently proposed a new multiple imputation algorithm that is specifically developed to deal with time-series cross-section data at the country-level.

Our paper employs this new method of multiple imputation and shows its relevance for cross-country studies of national systems and development. Specifically, we construct a new panel dataset (CANA) that contains no missing value. The dataset comprises 41 indicators measuring six key country-specific dimensions: innovation and technological capabilities, education system and human capital, infrastructures, economic competitiveness, political-institutional factors, and social capital. The CANA panel dataset that is obtained by estimating the missing values in the original data sources provides rich and complete statistical information on 134 countries for the entire period 1980-2008 (for a total of 3886 country-year observations). Our empirical analysis of this dataset shows its reliability and points out its usefulness for future cross-country studies of national systems, growth and development. We make the new dataset publicly available on the web.

The paper is organized as follows. Section 2 briefly reviews the literature and discusses the missing data problem. Section 3 introduces Honaker and King's (2010) new method of multiple imputation. Section 4 presents the CANA dataset and indicators and carries out a descriptive analysis of some of its key characteristics. Section 5 provides an analysis of the reliability of the new data material obtained through multiple imputation. Section 6 concludes by summarizing the main results and implications of the paper. A methodological Appendix contains all more specific details regarding the database construction, characteristics and quality assessment.

2. CROSS-COUNTRY ANALYSES OF NATIONAL SYSTEMS, GROWTH AND DEVELOPMENT: THE PROBLEM OF MISSING DATA

The national innovation system (NIS) perspective originally developed during the 1990s to understand the broad set of factors shaping the innovation and imitation ability of countries, and how these factors could contribute to explain cross-country differences in economic growth and competitiveness (Lundvall, 1992; Edquist, 1997). Empirical studies in this tradition initially focused mostly on advanced economies in the OECD area (Nelson, 1993). However, the NIS literature has recently shifted the focus towards the empirical study of innovation systems within the context of developing and less developed economies (Lundvall et alia,, 2009)[1].

A well-known challenge for applied research in this field is how to operationalize the innovation system theoretical view in empirical studies and, relatedly, how to measure the complex and multifaceted concept of national innovation system and its relationship to countries' economic performance. Quantitative applied studies of NIS and development have so far made use of two different (albeit complementary) approaches.

The first approach is rooted in the traditional literature on technology and convergence (Abramovitz, 1986; Verspagen, 1991; Fagerberg, 1994). Following a technology-gap Schumpeterian approach, recent econometric studies have focused on a few key variables that explain (or summarize) cross-country differences in the innovation ability of countries as well as their different capabilities to imitate foreign advanced knowledge, and then analyzed the empirical relationship between these innovation and imitation factors and cross-country differences in GDP per capita growth (Fagerberg and Verspagen, 2002; Castellacci, 2004, 2008 and 2011; Fagerberg et alia, 2007). Since one main motivation of this type of studies is to analyze the dynamics and evolution of national systems in a long-run perspective, they typically consider a relatively long time span (e.g. from the 1970s or 1980s onward), but must for this reason focus on a more restricted sample of countries (e.g. between 70 and 90 countries). Due to the lack of statistical data for a sufficiently long period of time, therefore, a great number of developing economies and the vast majority of less developed countries are neglected by this type of cross-country studies.

The second approach is based on the construction and descriptive analysis of composite indicators. In a nutshell, this approach recognizes the complex and multidimensional nature of national systems of innovation and tries to measure some of their most important characteristics by considering a large set of variables representing distinct dimensions of technological capabilities, and then combining them together into a single composite indicator – which may be interpreted as a rough summary measure of a country's relative position *vis-a-vis* other national systems. Desai et alia (2002) and Archibugi and Coco (2004) have firstly proposed composite indicators based on a

[1] For further references and information regarding the flourishing field of innovation systems and development, see the website of the Globelics network: www.globelics.com.

simple aggregation (simple or weighted averages) of a number of technology variables. Godinho et alia (2005), Castellacci and Archibugi (2008) and Fagerberg and Srholec (2008) have then considered a larger number of innovation system dimensions and analyzed them by means of factor and cluster analysis techniques. As compared to the first approach, the composite indicator approach has a more explicit focus on the comparison across a larger number of countries. Consequently, due to the lack of data availability on less developed countries for a sufficiently long period of time, these studies typically focus on a relatively short time span (i.e. a cross-section description of the sample in one point in time, e.g. the 1990s and/or the 2000s).

Considering the two approaches together, it is then clear that researchers seeking to carry out quantitative analyses of innovation systems and development commonly face a dilemma with respect to the data they decide to use. Either, they can focus on a small sample of (mostly advanced and middle-income) economies over a long period of time – or conversely they can study a much larger sample of countries (including developing ones) for carrying out a shorter run (static) type of analysis. Such a dilemma is of course caused by the fact that, for most variables that are of interest for measuring and studying innovation systems, the availability of cross-section time-series (panel) data is limited: data coverage is rather low for many developing economies for the years before 2000, and it improves substantially as we move closer to the present.

Both solutions that are commonly adopted by applied researchers to deal with this dilemma, however, are problematic. If the econometric analysis focuses on the dynamic behavior of a restricted sample of economies, as typically done in the technology-gap tradition, the parameters of interest that are estimated through the standard cross-country growth regression are not representative of the whole world economy, and do not provide any information about the large and populated bunch of less developed countries. In econometric terms, the regression results will provide a biased estimation of the role of innovation and imitation capabilities. Relatedly, by removing most developing countries observations from the sample under study (e.g. by listwise deletion), this regression approach tends to be inefficient as it disregards the potentially useful information that is present in the variables that are (at least partly) available for developing countries.

By contrast, if the applied study decides to consider a much larger sample of countries (including developing ones), as it is for instance the case in the composite indicator approach, the analysis inevitably assumes a static flavor and largely neglects the dynamic dimension. This is indeed unfortunate, since it was precisely the study of the dynamic evolution of national systems that represented one of the key motivation underlying the development of national systems theories.

Surprisingly, such a dilemma – and the possibly problematic consequences of the solutions that are typically adopted in this branch of applied research – has not been properly investigated yet in the literature. This paper intends to contribute to this issue by pointing out a possible solution to the trade-off mentioned above. We construct and make publicly available a new complete cross-country panel dataset where the missing values in the original data sources are estimated by means of a statistical approach that is known as *multiple imputation* (Rubin, 1987). Multiple imputation methods for missing data analysis have experienced a rapid development in the last few years and have been increasingly applied in a wide number of research fields. The next section will introduce this statistical method in the context of time-series cross-section data.

3. THE MULTIPLE IMPUTATION METHOD

Multiple imputation methods were firstly introduced two decades ago by Rubin (1987). They provide an appropriate and efficient statistical methodology to estimate missing data, which overcomes the problems associated with the use of listwise deletion or other *ad hoc* procedures to fill in missing values in a dataset. The general idea and intuition of this approach can be summarized as follows (see overviews in Rubin, 1996; Schafer and Olsen, 1998; Horton and Kleinman, 2007).

Given a dataset that comprises both observed and missing values, the latter are estimated by making use of all available information (i.e. the observed data). This estimation is repeated *m* times, so that *m* different complete datasets are generated (reflecting the uncertainty regarding the unknown values of the missing data). Finally, all subsequent econometric analyses that the researcher intends to carry out will be repeated *m* times, one for each of the estimated datasets, and the multiple results thus obtained will be easily combined together in order to get to a final value of the scientific estimand of interest (e.g. a set of regression coefficients and their significance levels).

Within this general statistical approach, Honaker and King (2010) have very recently introduced a novel multiple imputation method that is specifically developed to deal with time-series cross-section data (i.e. panels). This type of data has in the last few years been increasingly used for cross-country analyses in the fields of economic growth and development, comparative politics and international relations. However, missing data problems introduce severe bias and efficiency problems in this type of studies, as pointed out in the previous section. Honaker and King's (2010) method is particularly attractive because its multiple imputation algorithm efficiently exploits the panel nature of the dataset and makes it possible, among other things, to properly take into account the issue of cross-country heterogeneity by introducing fixed effects and country-specific time trends.

Suppose we have a latent data matrix X, composed of *p* variables (columns) and *n* observations (rows). Each element of this matrix, x_{ij}^{t}, represents the value of country *i* for variable *j* at time *t*. The data matrix is composed of both observed and missing values: $X = \{X^{OBS}; X^{MIS}\}$. In order to rectangularize the dataset, we define a missingness matrix M such that each of its elements takes value 1 if it is missing and 0 if it is an observed value. We then apply the simple matrix transformation: $X^{OBS} = X * (1 - M)$, so that our matrix dataset will now contain 0s instead of missing values (for further details on this framework, see Honaker and King, 2010, p. 576).

Multiple imputation methods typically make two general assumptions on the data generating process. The first is that X is assumed to have a multivariate normal distribution: $X \sim N(\mu; \Sigma)$, where μ and Σ represent the (unknown) parameters of the Gaussian (mean and variance). The useful implication of assuming a normal distribution is that each variable can be described as a linear function of the others.[2]

The second is the so-called *missing at random* (MAR) assumption. This means that M can be predicted by X^{OBS} but not by X^{MIS} (after controlling for X^{OBS}), i.e. formally: $P(M \mid X) = P(M \mid X^{OBS})$. The MAR assumption implies that the statistical relationship

[2] The statistical literature on multiple imputation methods has shown that departures from the normality assumption are not problematic and do not usually introduce any important bias in the imputation model.

(e.g. regression coefficient) between one variable and another is the same for the groups of observed and missing observations. Therefore, we can use this relationship as estimated for the group of observed data in order to impute the missing values (Shapen and Olsen, 1998; Honaker and King, 2010). This condition also suggests that all the variables that are potentially relevant to explain the missingness pattern should be included in the imputation model.[3]

The core of Honaker and King's (2010) new multiple imputation method is the specification of the estimation model for imputing the missing values in the dataset:

$$x_{ij}^{MIS} = \beta_j \, x_{i;-j}^{OBS} + \gamma_j \, t + \delta_{ij} + \delta_{ij} \, t + \varepsilon_{ij} \tag{1}$$

where x_{ij}^{MIS} are the missing values to be estimated, for observation *i* and variable *j*, and $x_{i;-j}^{OBS}$ are all other observed values for observation *i* and all variables excluding *j* (we have for simplicity omitted the time index *t*). The parameter β_j represents the estimate of the cross-sectional relation between the variable *j* and the set of covariates – *j*; γ_j is an estimate of the time trend; δ_{ij} is a set of individual fixed effects; δ_{ij} t is an interaction term between the time trend and the fixed effects, which provides an estimate of the country-specific time trends (i.e. a different time trend is allowed for each observation); finally, ε_{ij} is the error term of the model.[4] For clarity of exposition, it is useful to rewrite this model in its extended form:

$$\begin{cases} x_{i1}^{MIS} = \beta_1 \, x_{i;-1}^{OBS} + \gamma_1 \, t + \delta_{i1} + \delta_{i1} \, t + \varepsilon_{i1} \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ x_{ip}^{MIS} = \beta_p \, x_{i;-p}^{OBS} + \gamma_p \, t + \delta_{ip} + \delta_{ip} \, t + \varepsilon_{ip} \end{cases} \tag{2}$$

[3] The MAR assumption should not be confused with the more restrictive MCAR condition (*missing completely at random*). According to the latter, missing values are assumed to be pure random draws from the data distribution, and cannot therefore be systematically different from the observed data.

[4] For simplicity, the model specification in equation 1 assumes a linear trend for all variables and all observations. Honaker and King's method, however, makes it also possible to specify more complex non-linear adjustment processes in order to achieve a better fit of the estimated series to the observed data.

The formulation in (2) makes clear that our imputation model is composed of *p* equations, one for each variable of the model. Each variable is estimated as a linear function of all the others. In each of these *p* equations, missing values for a given variable are estimated as a function of the observed values for all the other variables.

The model is estimated through the so-called EM algorithm. This is an iterative algorithm comprising two steps. In the first (E-step), missing values are replaced by their conditional expectation (obtained through the estimation of (2)) – given the current estimate of the unknown parameters μ and Σ. In the second (M-step), a new estimate of the parameters μ and Σ is calculated from the data obtained in the first step. The two steps are iteratively repeated until the algorithm will converge to a final solution.

As pointed out above, the key idea common to all multiple imputation methods is that the imputation process is repeated *m* times, so that *m* distinct complete datasets are eventually obtained – reflecting the uncertainty regarding the unknown values of the missing data.[5] Honaker and King's method implements this idea by setting up the following bootstrap procedure: *m* samples of size *n* are drawn with replacement from the data X; in each of these *m* samples, the EM algorithm described above is run to obtain μ, Σ and the complete dataset. Thus, *m* complete datasets are obtained ready for the subsequent analyses.[6]

In summary, this new multiple imputation method presents two main advantages. First, similarly to other related methods, it avoids bias and efficiency problems related to the presence of missing values and/or the use of *ad hoc* methods to dealing with them (e.g. listwise deletion). Secondly, it is specifically developed to deal with time-series cross-section data. In particular, it is well-suited to deal with the issue of cross-country heterogeneity, since it allows for both country fixed effects as well as country-specific time trends.

[5] The multiple imputation literature indicates the existence of a proportional relationship between the method's efficiency and the number of imputed datasets (*m*) for any given share of missing data. It is usually recommended to set $m = 5$ (at least) in order to reach an efficiency level close to 90%. In our application of this method for the construction of the CANA dataset , we have set $m = 15$ and estimated fifteen complete datasets, which implies an efficiency level of 97%.

[6] Honaker, King and Blackwell (2010) have also developed the statistical package Amelia II that can be used to implement this new multiple imputation method and analyse the related results and diagnostics.

Despite these attractive features, it is however important to emphasize that this type of missing data estimation procedures should be applied with caution. Specifically, when the percentage of missing data is high, the imputation procedure tends to be less precise and reliable, and it is therefore important to carefully scrutinize the results. We will discuss this important issue in section 5 and provide all related details in the Appendix.

4. A NEW PANEL DATASET (CANA)

We now present the main characteristics of the CANA panel dataset, which has been constructed by applying the method of multiple imputation described in the previous section. The complete dataset that we have obtained contains information for a large number of relevant variables, and for a very large panel of countries. Specifically, for 34 indicators we have obtained complete data for 134 countries for the whole period 1980-2008 (3886 country-year observations); for seven other indicators we have instead achieved a somewhat smaller country coverage (see details below). On the whole, this new dataset represents a rich statistical material to carry out cross-country analyses of national systems, of their evolution in the last three decades, and of the relationships of these characteristics to countries' social and economic development.

Given that the concept of national systems is complex, multifaceted and comprising a great number of relevant factors interacting with each other, our database adopts a broad and multidimensional operationalization of it. Our stylized view, broadly in line with the previous literature, is presented in figure 1.[7] We represent national systems as composed of six main dimensions: (1) Innovation and technological capabilities; (2) Education and human capital; (3) Infrastructures; (4) Economic competitiveness; (5) Social capital; (6) Political and institutional factors. The underlying idea motivating the construction of this database is that it is the dynamics and complex interactions between these six dimensions that represent the driving force of national systems's social and economic development, and it is therefore crucial for empirical analyses in this field to

[7] Other empirical exercises in the NIS literature have previously made use of (at least some of) these dimensions and indicators. See in particular Godinho et alia (2005), Castellacci and Archibugi (2008) and Fagerberg and Srholec (2008).

have availability of statistical information for an as large as possible number of indicators and country-year observations.[8]

Figure 3.1: National systems, growth and development – A stylized view

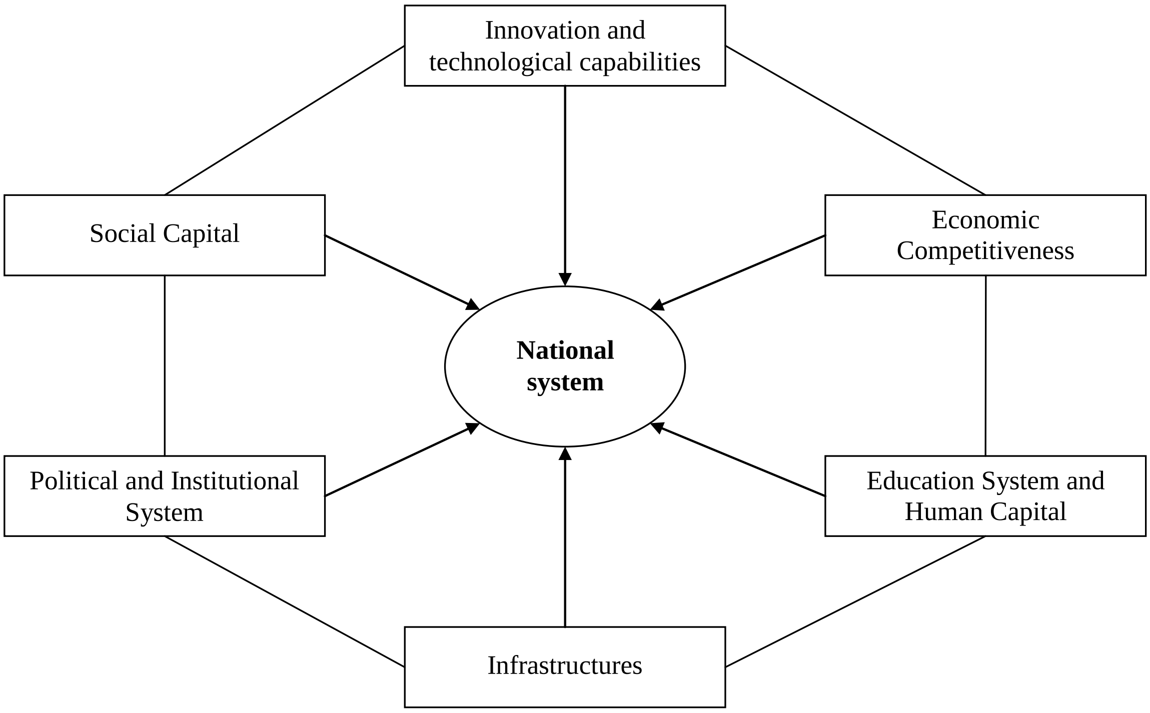

Table 1 presents a list of the 41 indicators included in the CANA database, and compares some descriptive statistics of the new (complete) panel dataset with those of the corresponding variables in the original (incomplete) data sources. The last column of the table shows the share of missing data present in the original data sources, which is in many cases quite high. A comparison of the left and right-hand sides of the table indicates that the descriptive statistics of the complete version of the data (containing no missing value) are indeed very close to those of the original sources – which gives a first and important indication of the quality and reliability of the new CANA dataset (this aspect will be analysed in further details in the next section).

The methodology that we have followed to construct the complete dataset and indicators has proceeded in four subsequent steps (see figure A1 in the Appendix). In the first, we have collected a total number of 55 indicators from publicly available databases and a variety of different sources (see the Appendix for a complete list of indicators and data sources). This large set of indicators covers a wide spectrum of

[8] In another paper (Castellacci and Natera, 2011), we study the interactions among these dimensions and carry out a time series multivariate analysis of their co-evolutionary process.

variables that are potentially relevant to measure the six country-specific dimensions pointed out above. This initial dataset contains as well-known a great number of missing values for many of the countries and the variables of interest. In the remainder of the paper, we will for simplicity refer to it as the *observed* (or the original) dataset.

In the second step, we have run Honaker and King's (2010) multiple imputation procedure as described in section 4 above. We have carried out the imputation algorithm for each of the six dimensions separately.[9] In order to achieve a high efficiency level, we have set $m = 15$, i.e. fifteen complete datasets have been estimated for each of the six dimensions. We have then combined these fifteen datasets into a single one, which is our *complete* CANA dataset. This is a rich rectangular matrix containing information for all relevant variables for 3886 observations (134 economies for the whole period 1980-2008).

Thirdly, we have carried out a thorough evaluation of each of these 55 variables in order to analyze the quality of the imputed data and the extent to which the new complete dataset may be considered a good and reliable extension of the original data sources. This evaluation process is discussed in details in the next section. In short, the main result of this assessment work is that the multiple imputation method has been successful for 34 indicators, which we have then included in the final version of database for the whole range of 3886 country-year observations (134 countries).

Fourthly, in the attempt to increase the number of "accepted" indicators, we have repeated the imputation procedure for all the remaining indicators and for a smaller number of countries – i.e. excluding those countries that have a very high share of missing data in the original sources. After a careful quality check of this second round of multiple imputations, we have decided to include seven more indicators in the final version of the CANA database: R&D (for 94 countries) and six social capital variables (for 80 countries).

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[9] For each of the six dimensions, we have included in the imputation model all the indicators belonging to that group plus four more variables: (1) GDP per capita, (2) mean years of schooling, (3) electricity consumption, and (4) corruption. These additional four variables were included in the specification following the recommendations of the multiple imputation literature, i.e. with the purpose of improving the precision of the imputation results for those variables with a high missingness share.

Table 3.1: CANA Database, the new complete dataset versus the original (incomplete) data – Descriptive Statistics

(for the exact definition and source of these indicators, see the Appendix)

		CANA dataset					**Original (incomplete) data**					
Dimensions and indicators	**Variable code**	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Missingness**
Innovation and technology												
Royalty and license fees	di1royag	3886	0.0022752	0.0066858	-0.0006418	0.1124235	2304	0.0026847	0.0083678	-0.0006418	0.1124235	40.71%
Patents	di6patecap	3886	0.0000134	0.0000369	0	0.0003073	3448	0.0000138	0.0000392	0	0.0003073	11.27%
Scientific articles	di7articap	3886	0.0001247	0.0002433	0	0.0012764	2439	0.0001463	0.0002614	0	0.0011837	37.24%
R&D	di16merdt	2726	0.7707415	0.8098348	0	4.864	1186	1.121976	0.9393161	0.001336	4.864	56.49%
Economic competitiveness												
Enforcing contract time	ec8contt	3886	-613.6034	274.3453	-1510	-120	645	-594.6899	282.5664	-1510	-120	83.40%
Enforcing contract costs	ec9contc	3886	-32.5055	23.71088	-149.5	0	648	-32.49522	24.69621	-149.5	0	83.32%
Domestic credit	ec14credg	3886	57.38872	63.73561	-121.6253	1255.16	3436	60.27133	63.47005	-72.99422	1255.16	11.58%
Finance freedom	ec15finaf	3886	51.81987	19.99745	10	90	1279	53.1509	19.03793	10	90	67.09%
Openness	ec16openi	3886	0.6026762	0.4797221	0.0222238	9.866468	3607	0.6116892	0.491836	0.0622103	9.866468	7.18%
Education and human capital												
Primary enrollment ratio	es1enrop	3886	96.47109	20.08273	13.69046	169.4129	1813	98.74914	19.01171	16.51161	169.4129	53.35%
Secondary enrollment ratio	es2enros	3886	62.90153	33.22149	0.7405149	170.9448	1740	67.28427	33.57044	2.498812	161.7809	55.22%
Tertiary enrollment ratio	es3enrot	3886	21.79418	20.32524	0	101.4002	1065	30.41785	24.79067	0.2897362	96.07699	72.59%
Mean years of schooling	es10schom	3886	6.736687	2.712745	0.2227	13.0221	732	6.681627	2.847444	0.2227	13.0221	81.16%
Education public expenditure	es12educe	3886	4.345558	2.17516	0.4347418	41.78089	1311	4.477923	2.183884	0.4347418	41.78089	66.26%
Primary pupil-teacher ratio	es14teacr	3886	-28.86118	13.21903	-92.84427	-6.782599	1570	-29.40752	14.36682	-92.84427	-8.680006	59.60%
Infrastructure												
Telecommunication revenue	i3teler	3886	2.515669	2.016845	0.0148	30.89729	3001	2.326596	1.654389	0.0148	21.10093	22.77%
Electric power consumption	i4elecc	3886	2953.605	4037.924	3.355309	36852.54	3007	3227.218	4350.007	10.45659	36852.54	22.62%
Internet users	i5inteu	3886	6.19008	15.16012	0	90.00107	2205	10.87692	18.82151	0	90.00107	43.26%
Mobile and fixed telephony	i6telecap	3886	288.7624	410.6129	0.1092133	2254.531	3790	293.22	414.3786	0.1166952	2254.531	2.47%
Paved roads	i7roadp	3886	47.87835	32.6202	0	100	1526	50.9243	33.54946	0.8	100	60.73%
Carrier departures	i8carrd	3886	6.093646	11.2161	0	111.3109	3343	6.379399	11.44183	0	111.3109	13.97%

Table 3.1 (cont.) - CANA database, the new complete dataset versus the original (incomplete) data – Descriptive Statistics
(for the exact definition and source of these indicators, see the Appendix)

		CANA dataset					Original (incomplete) data					
Dimensions and indicators	**Variable code**	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Missingness**
Political-institutional factors												
Corruption	pf1corri	3886	4.310959	2.161876	0.1121457	10	1274	4.540502	2.373167	0.4	10	67.22%
Freedom of press I	pf6presf	3886	-47.06303	23.66474	-99	0	2010	-46.05323	22.6873	-99	0	48.28%
Freedom of press II	pf7presr	3886	-23.19181	18.39877	-101.7329	0	896	-24.1132	20.09846	-97	-0.5	76.94%
Freedom of speech	pf8presh	3886	1.010362	0.7224378	0	2	3570	1.014566	0.7397838	0	2	8.13%
Human rights	pf10physi	3886	4.497512	2.558727	0	8	3618	4.498894	2.569385	0	8	6.90%
Women's rights	pf11womer	3886	3.976016	1.991885	0	9	3420	3.977778	2.008341	0	9	11.99%
Political rights	pf12polir	3886	-3.726385	2.126546	-7	-1	3666	-3.66012	2.146002	-7	-1	5.66%
Civil liberties	pf13civil	3886	-3.774798	1.790849	-7	-1	3666	-3.711129	1.807751	-7	-1	5.66%
Freedom of association	pf14freea	3886	1.078315	0.8209096	0	2	3569	1.081535	0.8389471	0	2	8.16%
Electoral self-determination	pf19demos	3886	1.118305	0.8268154	0	2	3569	1.123004	0.8455571	0	2	8.16%
Democracy vs. autocracy	pf20demoa	3886	2.081987	7.049185	-10	10	3486	2.394722	7.193271	-10	10	10.29%
Intensity of armed conflicts	pf22confi	3886	-0.2179619	0.5144967	-2	0	3886	-0.217962	0.5144967	-2	0	0.00%
Electoral competitiveness I	pf23legic	3886	5.675433	1.919987	0	7	3589	5.740039	1.968286	0	7	7.64%
Electoral competitiveness II	pf24execc	3886	5.433728	2.01466	0	7	3589	5.472137	2.071984	0	7	7.64%
Social capital												
Importance of friends	sc1friei	2320	2.268226	0.196071	1.625	2.766	193	2.270788	0.2485897	1.625	2.766	91.68%
Importance of family	sc2famii	2320	2.862629	0.069405	2.569	2.99	193	2.856347	0.0904246	2.569	2.99	91.68%
Importance of marriage	sc3marro	2320	0.8340359	0.0691305	0.083	0.986	204	0.8304902	0.0863815	0.083	0.986	91.21%
Gini index	sc8ginii	2320	38.26996	10.77369	12.1	77.6	1153	36.19132	10.93449	12.1	77.6	50.30%
Trust	sc20trust	2320	0.2763512	0.1279273	0.028	0.742	211	0.2987915	0.1553472	0.028	0.742	90.91%
Happiness	sc24happf	2320	2.034554	0.2310578	1.264	2.577	210	2.043133	0.2739787	1.264	2.577	90.95%

In summary, the final version of the CANA database that we make available contains a total number of 41 indicators (34 with full country coverage and seven for a smaller sample), whereas the remaining 14 indicators have been rejected and not included in the database because the results of the imputation procedure has not led to imputed data of a sufficiently good and reliable quality.

A simple descriptive analysis of the CANA dataset and indicators illustrates the relevance and usefulness of this new data material to gain new empirical insights on some of the main characteristics of national systems in such a broad cross-section of countries, and particularly on their dynamic processes over the period 1980-2008. Figures 2 to 7 show the time path of some of the key variables of interest. For each of the six dimensions, we also report a composite indicator and its time trend. The composite indicators, calculated for illustrative purposes only, have been obtained by first standardizing all the variables included in a given dimension (and for any given year), and then calculating a simple average of them. The upper part of figures 2 to 7 depicts the time trend for some selected countries, whereas the lower part plots the cross-country distribution of each dimension at the beginning and the end of the period (1980 and 2008). In each figure, we report the composite indicator on the left-hand panel, and two of the selected indicators used to construct it on the middle and right-hand panels.

Figure 2 focuses on countries' innovation and technological capabilities. The lower part of the figure shows that the cross-country distribution of innovative capabilities has not changed substantially over the period, indicating that no significant worldwide improvement has taken place in this dimension (Castellacci, 2011). However, the pattern is somewhat different for the R&D variable, since this focuses on a smaller number of countries. The upper part of the figure suggests that the technological dynamics process has been far from uniform and that different countries have experienced markedly different trends. In particular, the US and Japan are the leading economies that have experienced the most pronounced increase over time, whereas South Korea and China are the followers that have experienced the most rapid technological catching up process. Most other middle-income and less developed economies have not been able to catch up with respect to this dimension.

A worldwide and relatively rapid process of convergence is instead more apparent when we shift the focus to figures 3 and 4, which study the evolution of the human capital and infrastructures dimensions respectively. The kernel densities reported in the lower part of these figures show that the cross-country distributions of these two dimensions have visibly shifted towards the right, thus indicating an overall improvement of countries' education system and infrastructure level. The time path for some selected economies reported in the upper part of these figures also show the rapid catching up process experienced by some developing countries (and many others not reported in these graphs) with respect to these dimensions.

As for the remaining three dimensions – economic competitiveness (figure 5), social capital (figure 6) and political-institutional factors (figure 7) – the worldwide pattern of evolution over time is less clear-cut and depends on the specific indicators that we take into consideration. For instance, the graphs for social capital (figure 6) indicate that the indicator of happiness has on average increased over time, whereas the trust variable has not.

In order to provide a more synthetic view of the main patterns and evolution of NIS, figure 8 shows a set of radar graphs for some selected countries: four technologically advanced economies (US, UK, Japan, South Korea) plus the BRICS countries (Brazil, Russia, India, China and South Africa). For each country, the standardized value of each composite indicator is reported for both the beginning and the end of the period (1980 and 2008), so that these radar graphs provide a summary view of some key characteristics of NIS and their dynamic evolution in the last three decades. The graphs are rather informative. More advanced countries have on average a much greater surface than the catching up BRICS economies, indicating an overall greater level of the set of relevant technological, social and economic capabilities. Japan and South Korea are those that appear to have improved their relative position more visibly over time. By contrast, within the group of BRICS countries, the catching up process between the beginning and the end of the period has been more striking for China, Brazil and South Africa, and less so for Russia and India. It is however important to emphasize that the dynamics looks somewhat different for each of the six dimensions considered in figure 8, so that our summary description here is only done for illustrative purposes.

The descriptive analysis of cross-country patterns and evolution that has been briefly presented in this section will be extended and refined in a number of ways in future research. However, as previously pointed out, our purpose here is not to carry out a complete and detailed analysis of the characteristics and evolution of national systems, but rather to provide a simple empirical illustration of the usefulness of the new CANA panel dataset, and of how it can be used for cross-country studies of national systems and development.

Figure 3.2 - Innovation and technological capabilities (1980 – 2008)

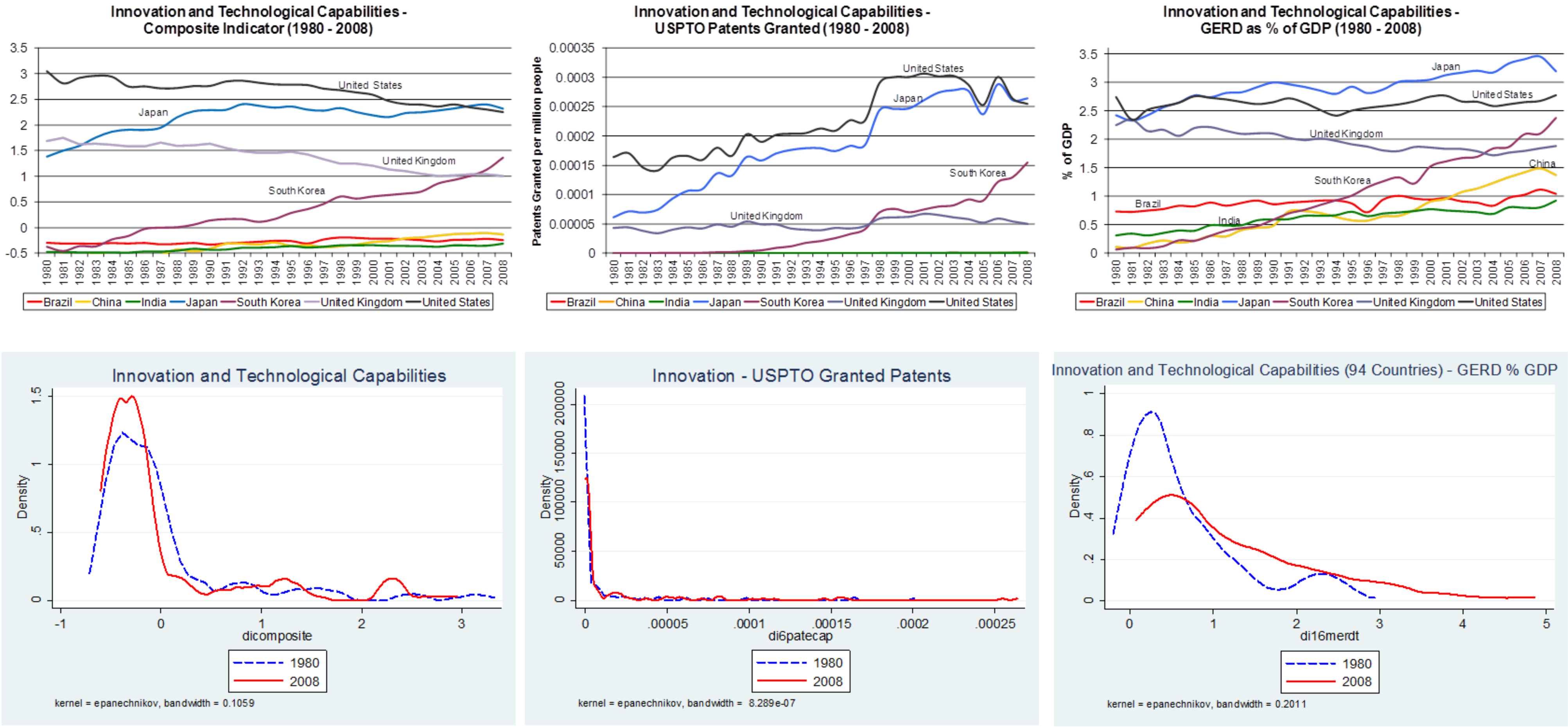


Figure 3.3 - Education system and human capital (1980 – 2008)

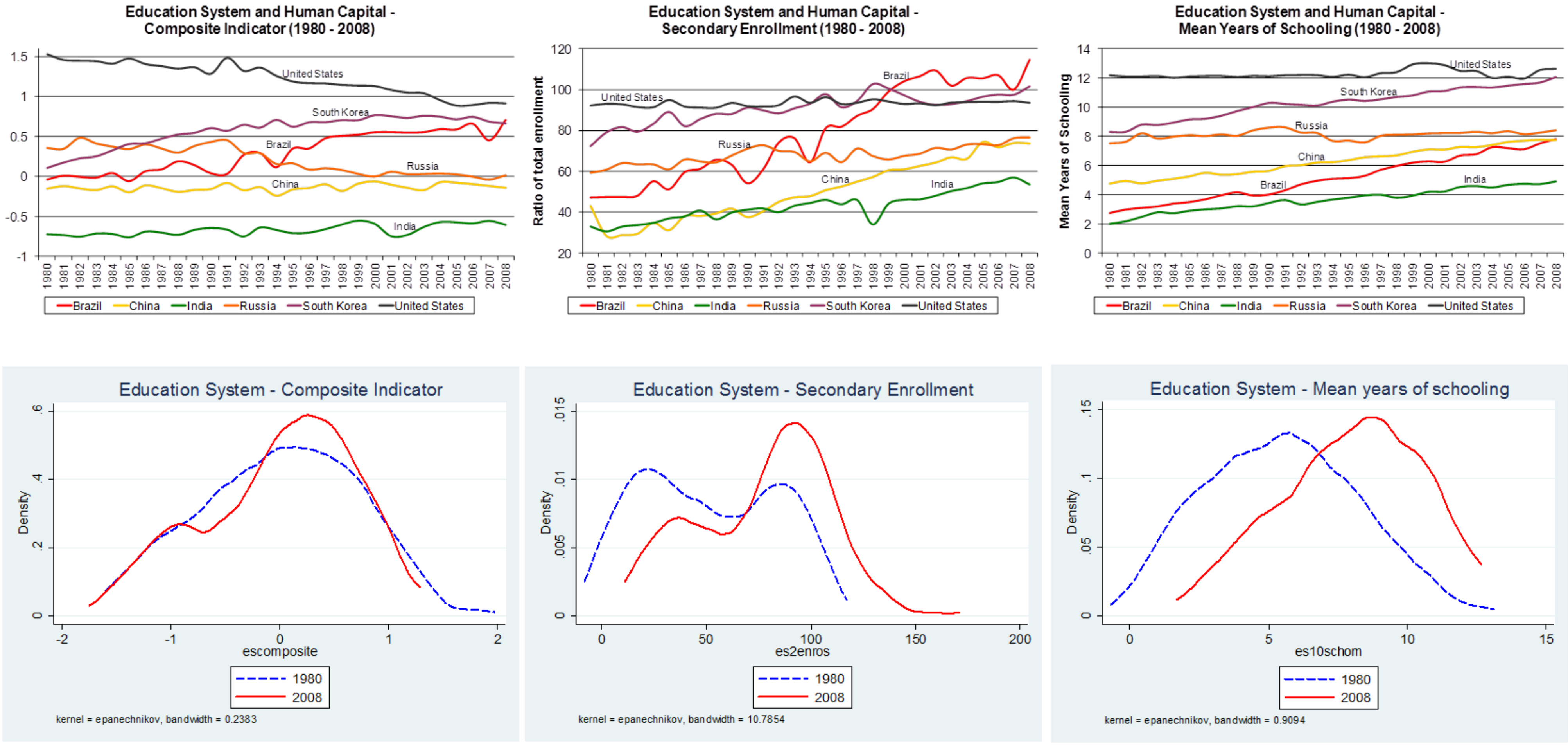


Figure 3.4 - Infrastructures (1980 – 2008)

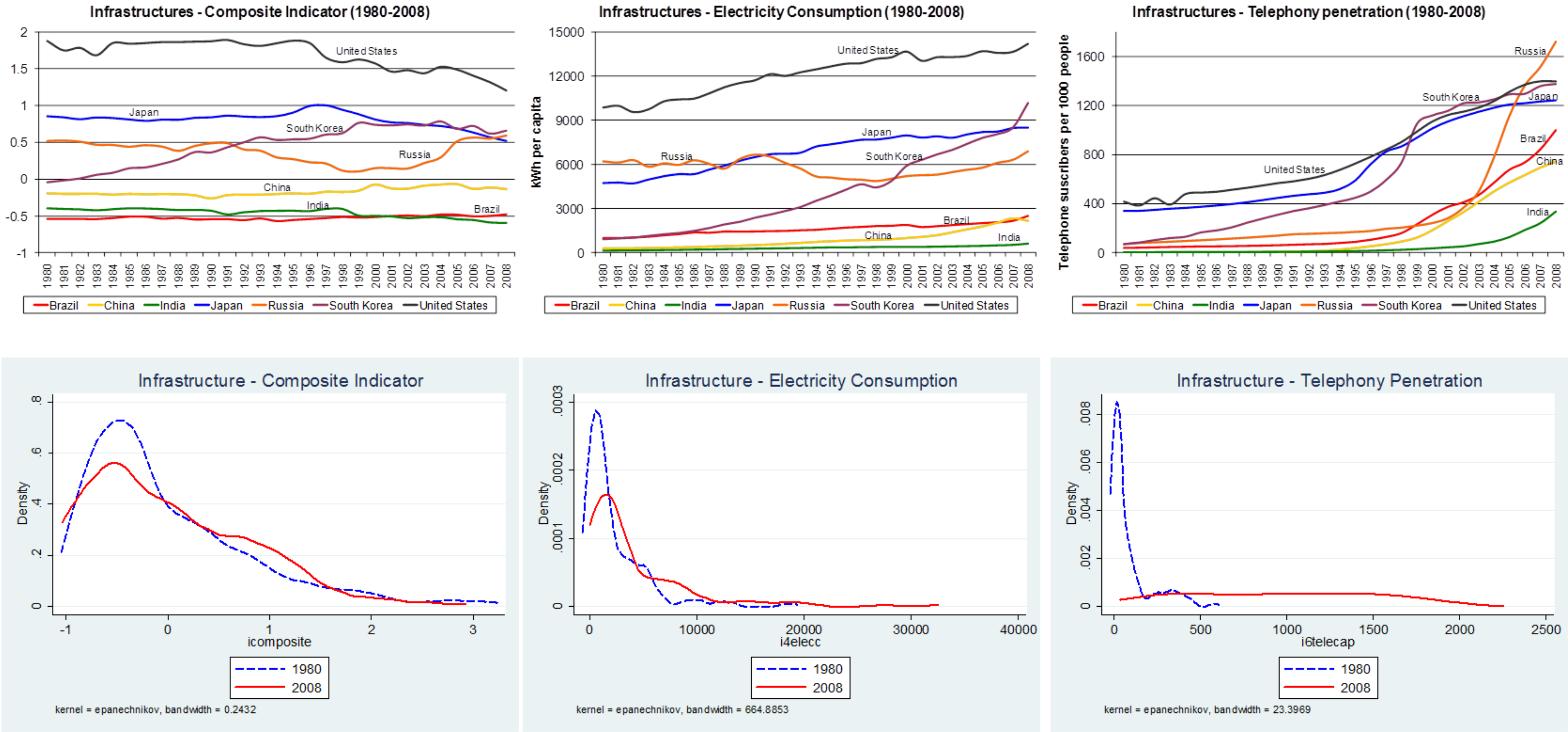


Figure 3.5: Economic competitiveness (1980 – 2008)

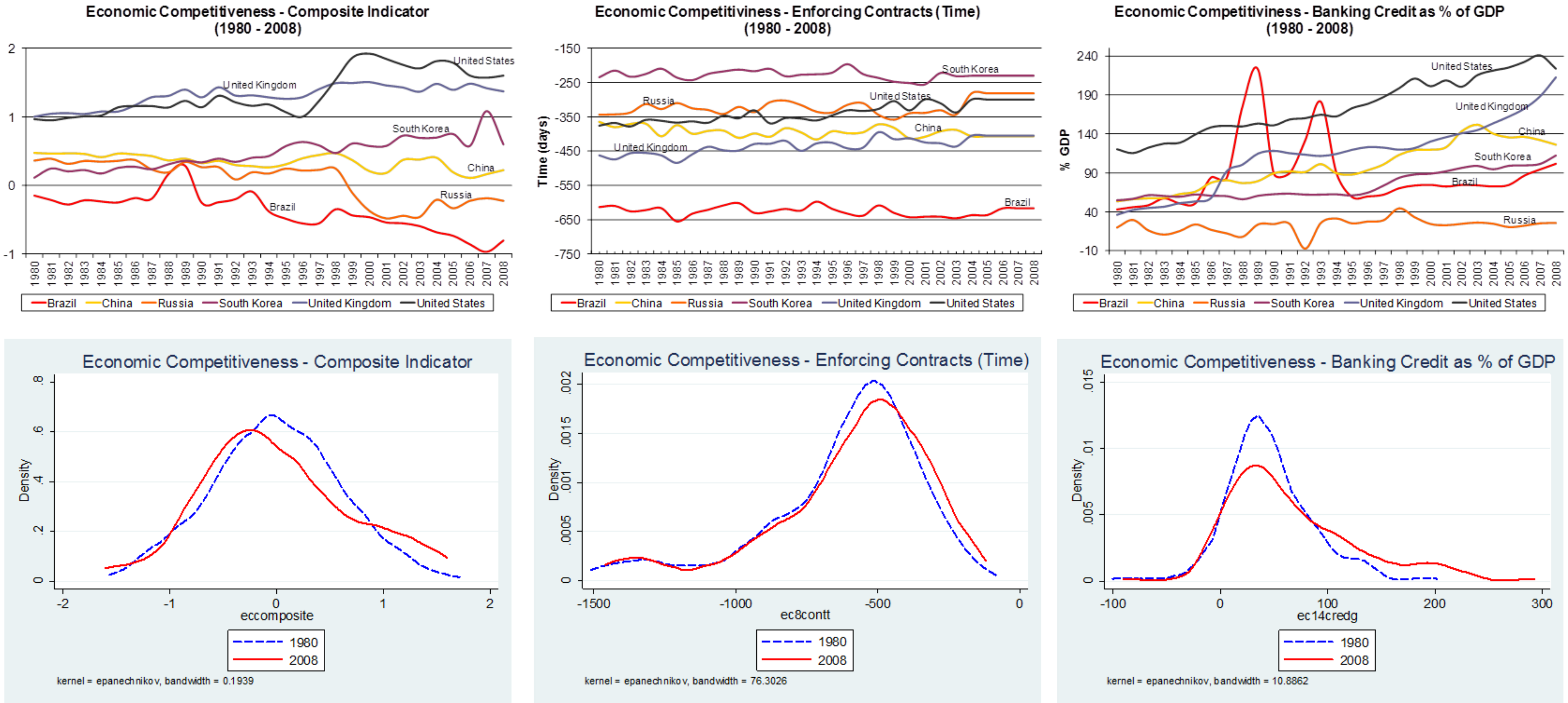


Figure 6: Social capital (1980 – 2008)

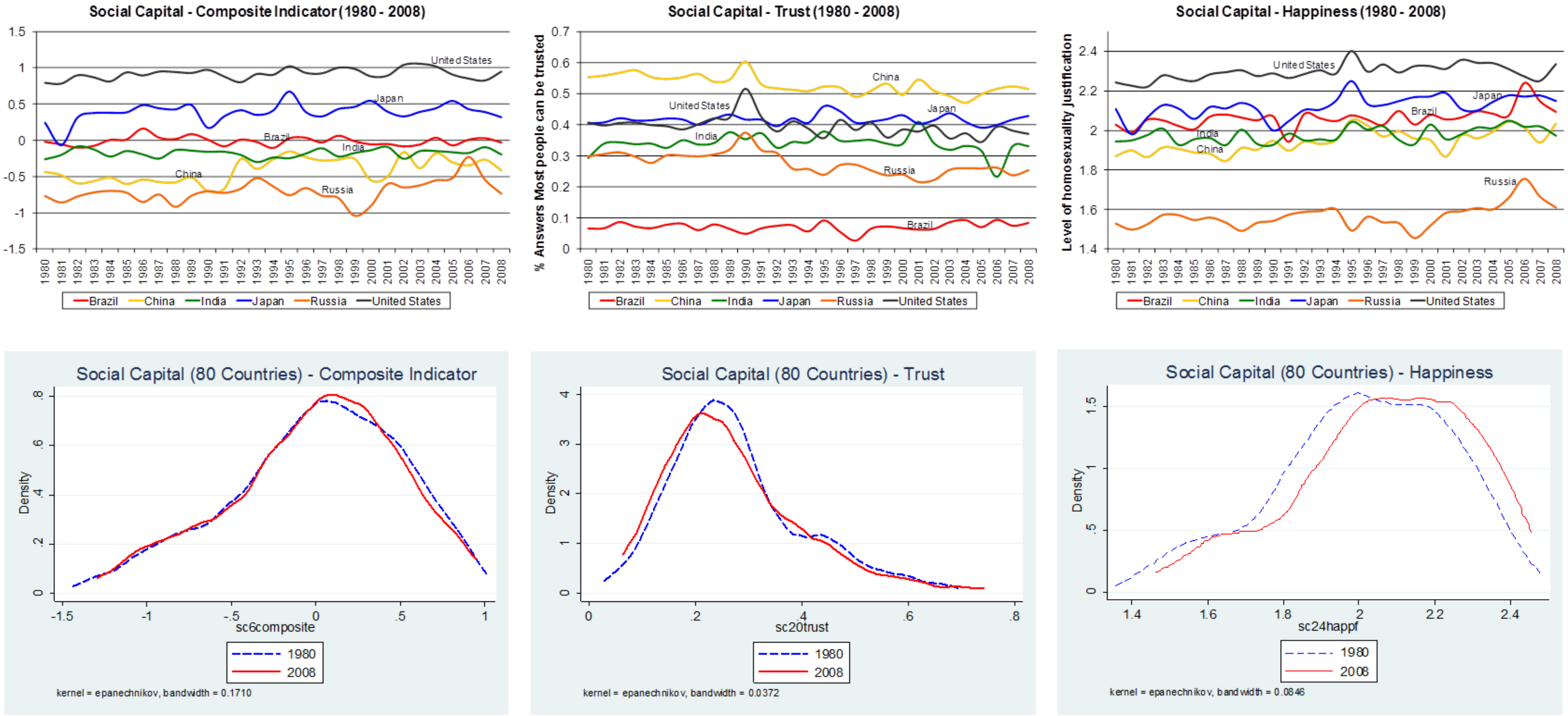


Figure 3.7 - Political-institutional factors (1980 – 2008)

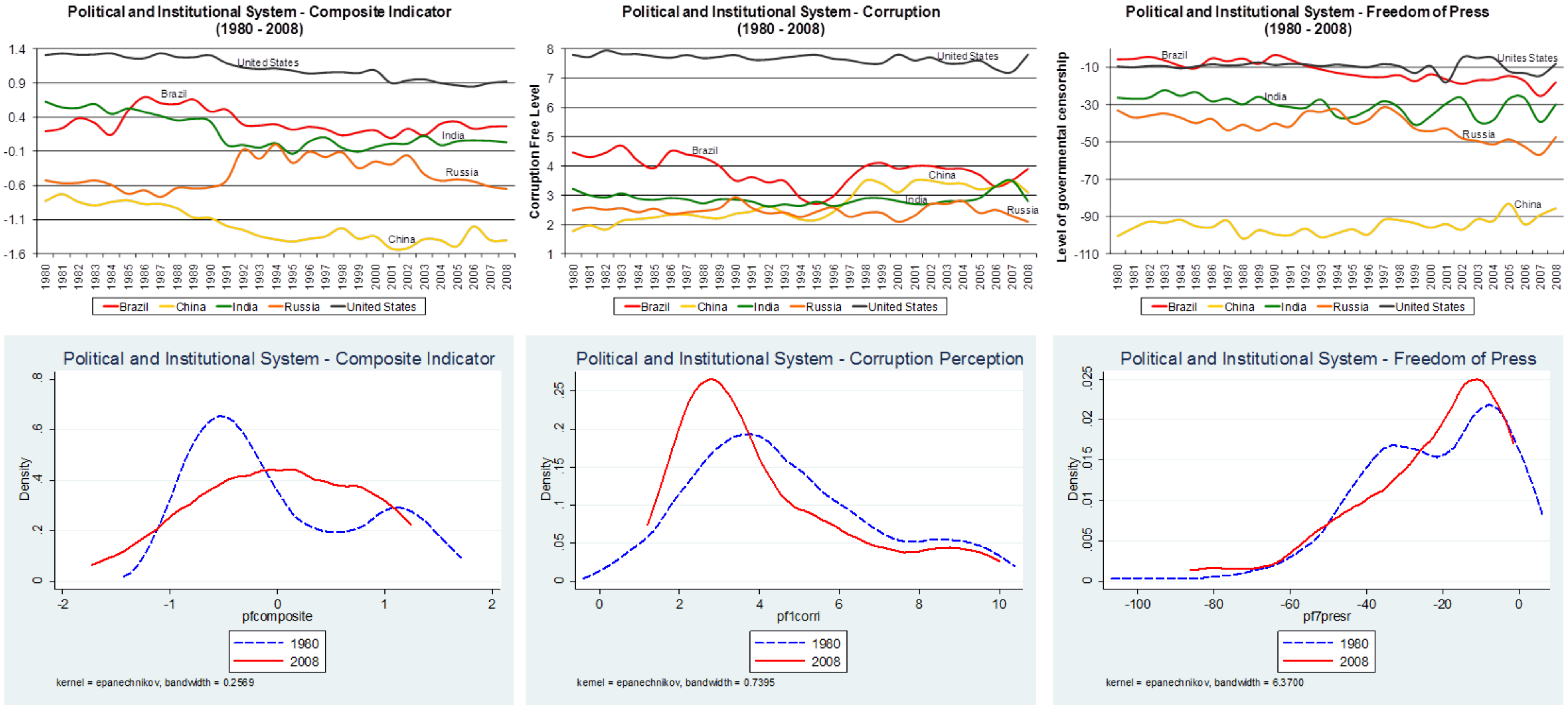
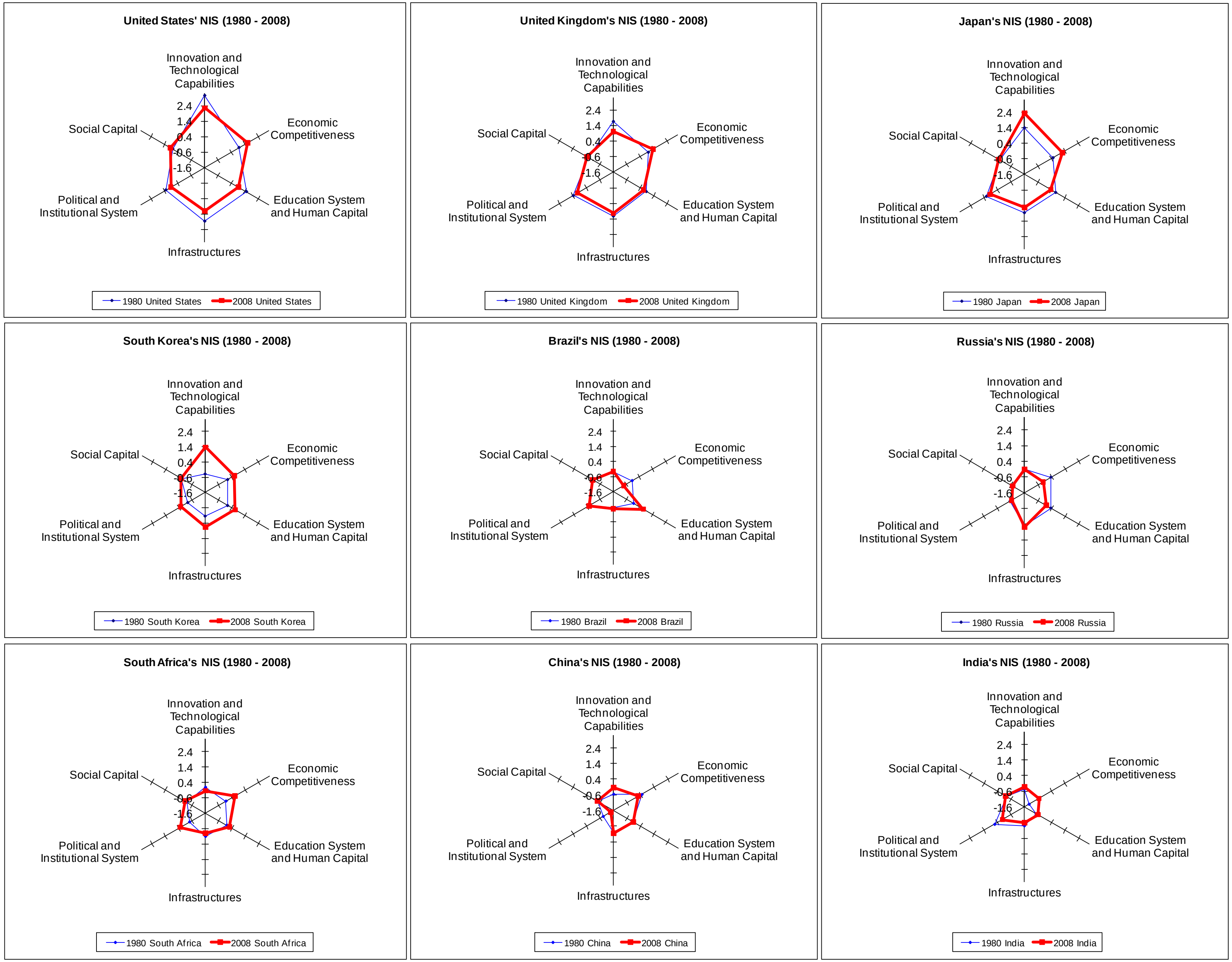


Figure 3.8 - Dynamics and evolution of national systems (1980 – 2008), selected countries



5. An analysis of the reliability of the CANA dataset and indicators

The illustration presented in the previous section has shown some of the advantages of adopting a method of multiple imputation to estimate missing values and obtain a rich complete dataset for the cross-country empirical investigation of national systems and development. However, at the same time as emphasizing the usefulness of the CANA dataset and indicators that we have constructed, it is also important to assess the quality of this newly obtained data material and investigate the possible limitations of the multiple imputation method that has been used to construct it.

As mentioned in the previous section, during the construction of the CANA database we have initially collected a total number of 55 indicators, which are intended to measure six different dimensions of countries' social, institutional and economic development. We have then carried out a first main round of multiple imputations in order to estimate the missing values in the original sources. After this first set of imputation estimations, we have carried out a thorough evaluation of each of these 55 variables in order to analyse the quality of the imputed data and the extent to which the new complete dataset may be considered a good and reliable extension and estimation of the original data sources. We have concluded that the multiple imputation method has been successful for 34 indicators, which we have then included in the final version of database for the whole range of 3886 country-year observations (134 countries).

Next, in the attempt to increase the number of "accepted" (reliable) indicators included in the dataset, we have repeated the imputation procedure for all the remaining indicators and for a smaller number of countries – i.e. excluding those countries that have a very high share of missing data in the original sources. After a second round of quality and reliability check, we have decided to include seven more indicators in the final version of the CANA database: R&D (for 94 countries) and six social capital variables (for 80 countries). Therefore, the final version of the CANA database contains a total number of 41 indicators (34 with full country coverage and seven for a smaller sample), whereas the remaining 14 indicators have been rejected and not included in the database because the results of the imputation procedure has not led to imputed data of a sufficiently good and reliable quality.

In order to illustrate our data assessment procedure and the reliability of the indicators that we have included in the final version of the database, we summarize the main steps here and report further material in the Appendix (see section A.3). Our evaluation process has made use of three main tools: (1) a comparison of the descriptive statistics of the complete versus the original data; (2) a graphical inspection of their kernel density graphs; (3) a comparison of the respective correlation tables.

First, table 1 (see previous section) reports a comparison of the main descriptive statistics for the CANA (complete) dataset *versus* the observed (original) data sources. The table shows that, for the 41 indicators included in the final version of the database, the means of the two distributions are rather similar in nearly all cases. On average, the means are however slightly lower for the complete version of the dataset, since this includes data for a larger number of developing economies that is only partly available in the original datasets.

A second and more detailed assessment exercise is reported in figure A2 (see the Appendix). The various graphs in figure A2 compare the statistical distributions (kernel densities) of the *observed* and the *complete* datasets for all the 41 indicators that we have included in the final version of the CANA database. As previously specified, the *observed* dataset is the original database that we have constructed by combining together indicators from different publicly available data sources (i.e. the one containing missing values for some of the variables and some of the country-year observations), whereas the *complete* dataset is the one that we have obtained by estimating missing values through Honaker and King's (2010) multiple imputation procedure.

The idea of comparing the two distributions is to provide an easy and effective visual inspection of the reliability of the multiple imputation results: if the statistical distribution of the complete dataset is substantially the same (or very similar to) the one for the observed data, we may be confident about the quality and reliability of the imputation results; by contrast, if the two distributions turn out to be quite different from each other, this would imply that the new data that have been estimated depart substantially from the original ones, and hence the results of the multiple imputation procedure may be less reliable.[10]

The comparison among the kernel densities reported in the various panels of figure A2 is rather informative and provides an interesting quality check of the data material. For four of the key dimensions considered in this paper, the distributions of the complete data seem to provide a very close approximation to those of the original sources – see the indicators measuring the dimensions of economic competitiveness, education system and human capital, infrastructure, and political-institutional factors. This represents an important validation of our multiple imputation exercise, particularly considering that some of the indicators considered here have a relatively high share of missing values in the original data sources (e.g. over 80% for the indicators measuring enforcing contracts time and costs, and the one of mean years of schooling). This means that our multiple imputation procedure has been able to estimate a substantial amount of missing values with a relatively good precision.

For the other two dimensions, as previously mentioned, the first round of multiple imputation has not been equally successful for all the indicators, and we have then carried out a second set of estimations in which we have focused on a somewhat smaller number of countries for those variables whose imputation results did not work as well as for the other indicators. The results of the graphical inspection are again reported in figure A2. For the innovation and technological capability dimension, the three indicators of patents, articles and royalties have been estimated for the whole 134 countries sample, and their distributions appear to be quite skewed and roughly resemble those of the original variables. For the R&D indicator, however, we have had to focus on a smaller 94 countries sample in order to obtain a more satisfactory fit to the origin[2]al distribution.

[10] Some other papers in the multiple imputation literature actually compare the *observed* data to the *imputed* (estimated) data, instead of the *complete* dataset as we do in this section (see e.g. Honaker and King, 2010; Schafer and Olsen, 1998). The reason for our choice is that, within the context of cross-country data on national systems and development, it is of course reasonable to expect that a large share of the missing values will have a different statistical distribution from the observed data, i.e. they are likely to have a lower mean because they belong to less developed economies and/or to observations referring to previous years. We therefore consider more appropriate and reasonable within our context to compare the observed data to the whole complete dataset, in order to inspect whether the latter's distribution has similar characteristics as the former.

Analogously, for the social capital dimension, we initially included a total of 12 variables in the multiple imputation algorithm. However, the first set of imputation results was not successful for this dimension, and most of these indicators had in fact complete data distributions that were quite different from those of the original data. The reason for this is that most of our social capital indicators have a very high share of missingness (above 90%), since the original data sources (e.g. the World Value Survey) are only available for a limited sample of countries and for a relatively short time span. For this reason, we repeated the multiple imputation procedure for this dimension by focusing on a smaller 80 countries sample (i.e. keeping only those economies with better data coverage for these indicators). At the end of this procedure and further quality check, we have decided to disregard six social capital variables with low reliability and poor data quality, and include only six indicators in the final version of the CANA database. Figure A2 shows the statistical distributions of these six "accepted" variables, and indicate that these have on the whole a relatively good fit of the complete data to the original (incomplete) data sources (particularly considering the high share of missingness that was present in the latter).

Finally, the fourth exercise that we have carried out to analyze the reliability of the CANA dataset is based on the comparison of the correlation tables for each of the six dimensions, and it is reported in table A2 in the Appendix. For each dimension, table A2 reports the coefficients of correlation among its selected indicators. Next to each correlation coefficient calculated on the (original) *observed* dataset, the table reports between parentheses the corresponding coefficient calculated on the *complete* dataset. The rationale of this exercise is that we expect that the more similar two correlation coefficients are (for the observed *versus* the complete data), the closer the match between the two statistical distributions, and hence the more reliable the results of the imputation procedure that we have employed. In other words, if the CANA (complete) dataset and its set of indicators are reliable, then we should observe correlation coefficients among the various indicators that are quite similar to those that we obtain from the original data sources. By contrast, if the correlation coefficients are substantially different (in sign and/or in magnitude), this would imply that our imputation procedure has introduced a bias in the dataset that is likely to affect any subsequent analysis (e.g. a regression analysis run on the complete dataset).

The results reported in table A2 are largely in line and corroborate those discussed above in relation to figure A2. In general terms, the overall impression is that the correlation patterns within each dimension are substantially preserved by the multiple imputation procedure: the sign of the correlation coefficients are in nearly all cases the same after imputing the missing values, and the size of the coefficients are also rather similar for most of the variables. Some of the correlation coefficients, though, change their size somewhat, e.g. those between R&D and royalties, finance freedom and openness, and enforcing contract time with openness. Despite these marginal changes for a very few coefficients, the results reported in table A2 do on the whole indicate that the data imputation procedure that we have employed does not seem to have introduced a systematic bias in the correlation structure of the variables of interest.

6. CONCLUSIONS

The paper has argued that missing data constitute an important limitation that hampers quantitative cross-country research on national systems, growth and development, and it has proposed the use of multiple imputation methods to overcome this limitation. In particular, the paper has employed the new multiple imputation method recently been developed by Honaker and King (2010) to deal with time-series cross-section data, and applied it to construct a new panel dataset containing a great number of indicators measuring six different country-specific dimensions: innovation and technological capabilities, education system and human capital, infrastructures, economic competitiveness, social capital and political-institutional factors. The original dataset obtained by merging together various available data sources contains a substantial number of missing values for some of the variables and some of the country-year observations. By employing Honaker and King's (2010) imputation procedure, we are able to estimate these missing values and thus obtain a complete dataset (134 countries for the entire period 1980-2008, for a total of 3886 country-year observations).

The CANA database provides a rich set of information and enables a great variety of cross-country analyses of national systems, growth and development. As one example of how the dataset can be used within the context of applied growth theory and cross-country development research, we have carried out a simple descriptive analysis of how these country-specific dimensions differ across nations and how they have evolved in the last three decades period.

The methodological exercise presented in this paper leads to two main conclusions and related implications for future research. The first general conclusion is that the multiple imputation methodology presents indeed great advantages *vis-a-vis* all other commonly adopted *ad hoc* methods to deal with missing data problems (e.g. listwise deletion in regression exercises), and it should therefore be used to a much greater extent for cross-country analyses within the field of national systems, growth and development. Specifically, the construction of a complete panel dataset through the multiple imputation approach presents three advantages: (1) it includes many more developing and less developed economies within the sample and thus leads to a less biased and more representative view of the relevance of national systems for development; (2) it exploits all data and available statistical information in a more efficient way; (3) it makes it possible to enlarge the time period under study and thus enables a truly dynamic analysis of the evolution of national systems and their relevance for the catching up process.

However, multiple imputation methods do not represent a magic solution to the missing data problem, but rather a modern statistical approach that, besides filling in the missing values in a dataset, does also emphasize the uncertainty that is inherently related to the unknown (real) values of the missing data. The second conclusion of our paper, therefore, is that it is important to carefully scrutinize the results of any multiple imputation exercise before using a new complete dataset for subsequent empirical analyses. In particular, we have carried out an analysis of the reliability of the new complete CANA dataset, which has shown that, in general terms the method seems to work well, since for most of the indicators the statistical distribution of the complete dataset (after the imputation) resembles closely the one for the original data (before the imputation). We have therefore included this set of 41 more reliable indicators in the final version of the CANA panel dataset, and have instead disregarded the other 14 variables for which our imputation results seemed to be less reliable.

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APPENDIX

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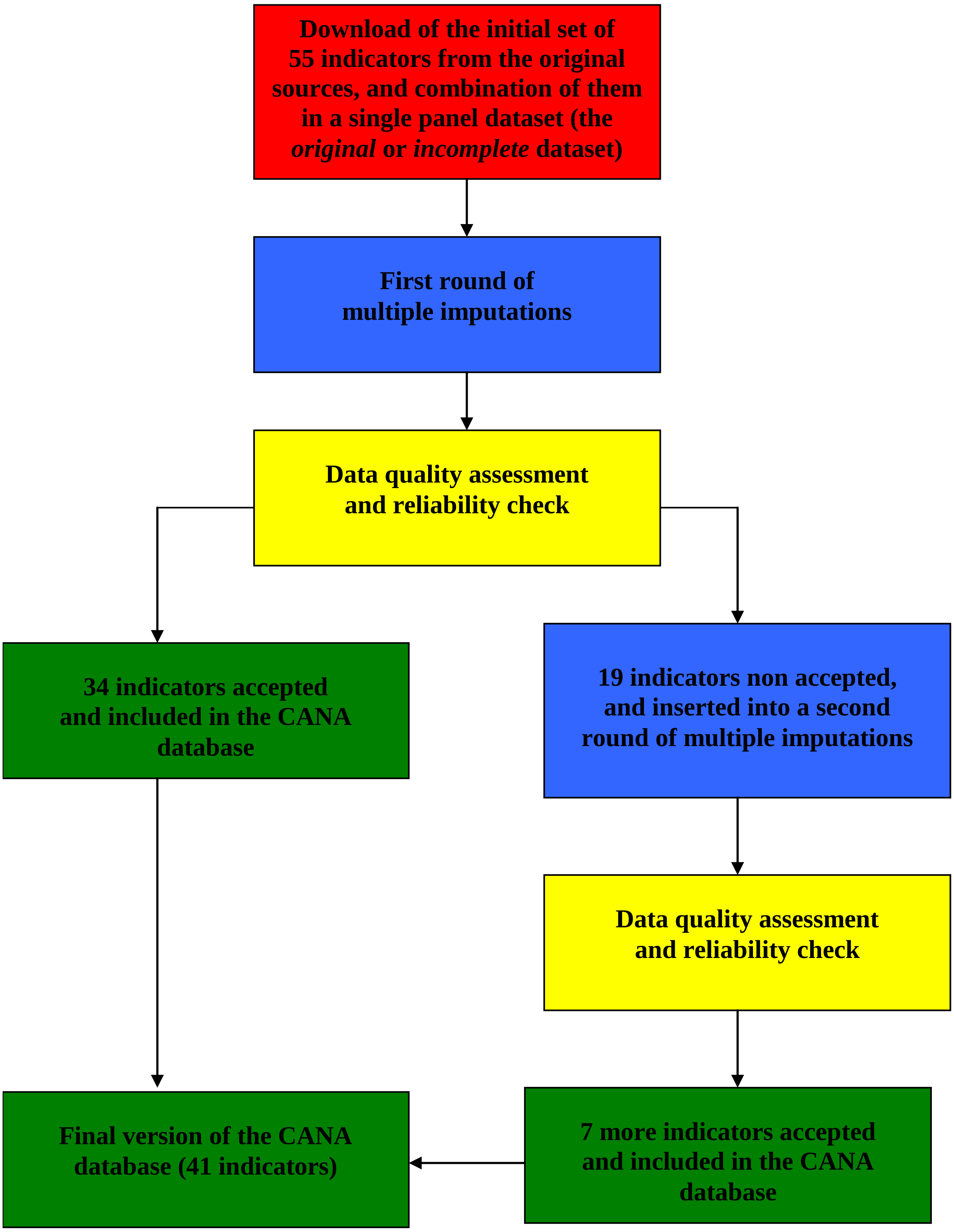
THE CANA DATABASE:

METHODOLOGY, INDICATORS AND RELIABILITY

A.1. THE CONSTRUCTION OF THE CANA DATABASE

Figure 3A.1- Methodological steps in the construction of the CANA Database



A.2. The CANA indicators

A.2.1 List of indicators and data sources

Table 3A1 - List of the whole set of 55 indicators used in the multiple imputation estimations

I. Innovation and Technological Capabilities

	Code	Indicator	Source	% Missingness	CANA Estimation Assessment
Innovation and Technological Capabilities	di1royag	**Royalty and license fees payments.** Payment per authorized use of intangible, non-produced, non-financial assets and proprietary rights and for the use, through licensing agreements, of produced originals of prototypes, per GDP.	World Bank	40.71%	Accepted
	di6patecap	**US Patents granted per Country of Origin.** Number of utility patents granted by the USPTO by year and Inventor's Country of Residence per inhabitant.	USPTO	11.27%	Accepted
	di7articap	**Scientific and technical journal articles.** Number of scientific and engineering articles published in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences, per million people.	World Bank; National Science Foundation	37.24%	Accepted
	di16merdt	**R&D.** R&D expenditures as a percentage of GDP.	UNESCO; OECD; RICYT	69.48%	Accepted *

* Only for 94 countries

II. Economic Competitiveness

	Code	Indicator	Source	% Missingness	CANA Estimation Assessment
Economic Competitiveness	ec1start	**Starting a Business: Time.** Number of days required to follow all procedures needed to start a new business.	World Bank. Doing Business	83.40%	Rejected
	ec2starc	**Starting a Business: Cost**. Cost of starting a new business, as a percentage of GDP per capita. It includes all official fees and fees for legal or professional services if such services are required by law.	World Bank. Doing Business	83.40%	Rejected
	ec8contt	**Enforcing Contracts: Time.** Number of days needed to enforce a contract. Days are counted from the moment the plaintiff files the lawsuit in court until payment. Low (high) values of the variable indicate high (low) competitiveness.	World Bank. Doing Business	83.40%	Accepted
	ec9contc	**Enforcing Contracts: Cost**. Percentage of the claim needed to proceed with it. Low (high) values of the variable indicate high (low) competitiveness.	World Bank. Doing Business	83.32%	Accepted
	ec11reguq	**Regulation Quality**. Index that measures administrative regulations, tax systems, import barriers, local competition, easiness to start a business and anti-monopoly laws.	World Economic Forum	76.87%	Rejected
	ec14credg	**Domestic Credit by Banking Sector.** Includes all credit to various sectors on a gross basis, with the exception of credit to the central government, which is net, as a share of GDP.	World Bank	11.58%	Accepted
	ec15finaf	**Finance Freedom**. Subjective assessments of Heritage staff, comparable over time. These indicators are scored on a 100-point scale.	Heritage Foundation	67.09%	Accepted
	ec16openi	**Openness Indicator**. (Import + Export)/GDP. PPP, 2000 USD	UNCTAD	7.18%	Accepted

III. Education System and Human Capital

	Code	Indicator	Source	% Missingness	CANA Estimation Assessment
Education System and Human Capital	es1enrop	**Gross Enrollment Ratio, Primary**. Ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the primary level.	UNESCO	53.35%	Accepted
	es2enros	**Gross Enrollment Ratio, Secondary**. Ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the secondary level.	UNESCO	55.22%	Accepted
	es3enrot	**Gross Enrollment Ratio, Tertiary.** Ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the tertiary level.	UNESCO	72.59%	Accepted
	es10schom	**Mean years of schooling.** Average number of years of school completed in population over 14.	Barro and Lee (2001); World Bank	81.16%	Accepted
	es11liter	**Literacy Rate**. Percentage of population aged 15 and above who can understand, read and write a short, simple statement on their everyday life.	UNESCO	90.63%	Rejected
	es12educe	**Public Expenditure on Education**. Current and capital public expenditure on education.	UNESCO	66.26%	Accepted
	es14teacr	**Primary pupil-teacher ratio (inverse)**. Ratio: (number of pupils enrolled in primary school) / (number of primary school teachers) multiplied by (-1)	UNESCO	59.60%	Accepted

IV. Infrastructure

	Code	Indicator	Source	% Missingness	CANA Estimation Assessment
Infrastructure	i3teler	**Telecommunication Revenue. R**evenue from the provision of telecommunications services such as fixed-line, mobile, and data, % of GDP.	World Bank	22.77%	Accepted
	i4elecc	**Electric power consumption.** Production of power plants and combined heat and power plants less transmission, distribution, and transformation losses and own use by heat and power plants.	World Bank	22.62%	Accepted
	i5inteu	**Internet users per 1000 people.** People with access to the worldwide web network divided by the total amount of population.	World Bank	43.26%	Accepted *
	i6telecap	**Mobile and fixed-line subscribers.** Total telephone subscribers (fixed-line plus mobile) per 1000 inhabitants.	World Bank	2.47%	Accepted
	i7roadp	**Paved Roads.** Paved roads are those surfaced with crushed stone (macadam) and hydrocarbon binder or bituminized agents, with concrete, or with cobblestones, as a percentage of the whole roads' length of the country.	World Bank	60.73%	Accepted
	i8carrd	**Registered carrier departures worldwide.** Domestic takeoffs and takeoffs abroad of air carriers registered in the country, per 1000 inhabitants.	World Bank	13.97%	Accepted

***** For all missing values for the years before 1995, zero values were imputed.

V. Political and Institutional Factors

	Code	Indicator	Source	% Missingness	CANA Estimation Assessment
Political and Institutional Factors	pf1corri	**Corruption Perception Index**. Transparency International Index, ranging from 0 (High Corruption) to 10 (Low Corruption)	Transparency International	67.22%	Accepted
	pf6presf	**Freedom of Press**. This index assesses the degree of print, broadcast, and internet freedom in every country in the world, analyzing the events of each calendar year. Index from -100 (no freedom) to 0 (high freedom)	Freedom House	48.28%	Accepted
	pf7presr	**Freedom of Press**. It reflects the degree of freedom that journalists and news organizations enjoy in each country, and the efforts made by the authorities to respect and ensure respect for this freedom. Index from -115 (no freedom) to 0 (high freedom)	Reporter Without Borders	76.94%	Accepted
	pf8presh	**Freedom of Speech.** Extent to which freedoms of speech and press are affected by government censorship, including ownership of media outlets. Index from 0 (Government censorship) to 2 (No Government Censorship).	Cingranelli and Richards (2008)	8.13%	Accepted
	pf10physi	**Physical integrity human rights**. Index constructed from the Torture, Extrajudicial Killing, Political Imprisonment, and Disappearance indicators. It ranges from 0 (no Government respect) to 8 (full Government respect).	Cingranelli and Richards (2008)	6.90%	Accepted
	pf11womer	**Women's rights**. Index constructed the sum of three indices: Women's Economic Rights, Women's Political Rights and Women's Social Rights. It ranges from 0 (low women rights) to 9 (high women rights).	Cingranelli and Richards (2008)	11.99%	Accepted
	pf12polir	**Political Rights**. People's free participation in the political process. It ranges from -7 (low freedom) to -1 (total freedom).	Freedom House	5.66%	Accepted
	pf13civil	**Civil Liberties**. People's basic freedoms without interference from the state. It ranges from -7 (low freedom) to -1 (total freedom).	Freedom House	5.66%	Accepted
	pf14freea	**Freedom of Association**. Extent to which freedom of assembly and association is subject to actual governmental limitations or restrictions. Index from 0 (Total restriction) to 2 (no restriction).	Cingranelli and Richards (2008)	8.16%	Accepted

V. Political and Institutional Factors (cont.)

	Code	Indicator	Source	% Missingness	CANA Estimation Assessment
Political Factors and Institutional System	pf18demoe	**Electoral Democracy**. Dummy variable assigning the designation "electoral democracy" to countries that have met certain minimum standards.	Freedom House	32.01%	Rejected
	pf19demos	**Electoral Self-Determination**. Indicates to what extent citizens enjoy freedom of political choice and the legal right to change the laws and officials through free and fair elections. It ranges from 0 (no freedom) to 3 (high freedom).	Cingranelli and Richards (2008)	8.16%	Accepted
	pf20demoa	**Index Democracy and Autocracy**. *Democracy*: political participation is full and competitive, executive recruitment is elective, constraints on the chief executive are substantial. *Autocracy*: it restricts or suppresses political participation. The index ranges from +10 (democratic) to -10 (autocratic).	Marshall and Jaggers (2003)	10.29%	Accepted
	pf21conft	**Total Armed Conflicts**. Total magnitudes of all (societal and interstate) major episodes of political violence. It ranges from 0 (no violence) to 60 (high violence).	Marshall and Jaggers (2003)	19.97%	Rejected
	pf22confi	**Intensity of Armed Conflicts.** The index assesses the magnitude of conflicts developed within the territory (internal or external). It varies between 0 (no conflict) to -2 (war).	PRIO	0%	Accepted
	pf23legic	**Legislative Index Electoral Competitiveness.** Competitiveness of elections into legislative branches. The index ranges from 7 (countries in which multiple parties compete in elections and the largest party receives less than 75% of the vote) to 1 (countries without or with unelected legislature).	Beck et al. (2001)	7.64%	Accepted
	pf24execc	**Executive Electoral Competitiveness**. Competitiveness for post in executive branches in government, taking into account the balance of power between legislature and executive. It ranks from 1 (low competitiveness) to 7 (high competitiveness).	Beck et al. (2001)	7.64%	Accepted
	pf26rulel	**Rule of Law**. PRS's assessment of the strength and impartiality of the legal system and of the popular observance of the law. It ranks from 0 (low) to 1 (high).	PRS Group	65.77%	Rejected
	pf27propr	**Property Rights**. Subjective assessments made by the Heritage staff, comparable over time. These indicators are scored on a 100-point scale.	Heritage Foundation	67.09%	Rejected

VI. Social Capital

	Code	Indicator	Source	% Missingness	CANA Estimation Assessment
Social Capital	sc1friei	**Friends important in life**. Index ranging from 3 (very important) to 0 (not important).	World Values Survey	95.16%	Accepted *
	sc2famii	**Family important in life**. Index ranging from 3 (very important) to 0 (not important).	World Values Survey	95.16%	Accepted *
	sc3marro	**Marriage is an outdated institution**. Percentage of respondents who "Disagree" with this statement.	World Values Survey	94.85%	Accepted *
	sc4natip	**How proud of nationality**. Index ranging from 3 (very proud) to 0 (not proud).	World Values Survey	94.70%	Rejected
	sc8ginii	**Gini Index**	United Nations	65.18%	Accepted *
	sc9womej	**Jobs scarce: Men should have more right to a job than women**. Percentage of respondents who "Disagree" with this statement.	World Values Survey	95.19%	Rejected
	sc10inmij	**Jobs scarce: Employers should give priority to (nation) people than immigrants.** Percentage of respondents who "Disagree" with this statement.	World Values Survey	95.24%	Rejected
	sc13homoj	**Justification of Homosexuality**. Index ranging from 0 (never justifiable) to 9 (always justifiable).	World Values Survey	94.75%	Rejected
	sc19relii	**Religion important in life**. Index ranging from 3 (very important) to 0 (not important).	World Values Survey	95.16%	Rejected
	sc20trust	**Most people can be trusted**. Percentage of respondents who "agree" with this statement.	World Values Survey	94.67%	Accepted *
	sc24happf	**Feeling of Happiness**. Index ranging from 3 (very happy) to 0 (not happy).	World Values Survey	94.70%	Accepted *
	sc25freed	**Freedom of choice and control**. Index ranging from 0 (no freedom) to 9 (total freedom).	World Values Survey	94.80%	Rejected

* Only for 80 countries

A.2.2 References to the original data sources

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- PRIO: Armed Conflict Dataset:
- http://www.prio.no/CSCW/Datasets/Armed-Conflict/UCDP-PRIO/
- Red Iberoamericana de Indicadores de Ciencia y Tecnología (RICYT): http://bd.ricyt.org/explorer.php/query/submit?excel=on&indicators[]=GASPBI&syear=1990&eyear=2008&
- Reporters Without Borders: http://en.rsf.org/
- Transparency International: Corruption Perception Index: http://www.transparency.org/policy_research/surveys_indices/cpi
- UNCTAD: http://unctadstat.unctad.org/ReportFolders/reportFolders.aspx?sRF_ActivePath=P,3&sRF_Expanded=,P,3
- UNESCO: http://stats.uis.unesco.org/unesco/TableViewer/document.aspx?ReportId=136&IF_Language=eng&BR_Topic=0
- USPTO: http://www.uspto.gov/web/offices/ac/ido/oeip/taf/h_at.htm#PartA1_1a
- World Bank Development Indicators: http://data.worldbank.org/indicator/
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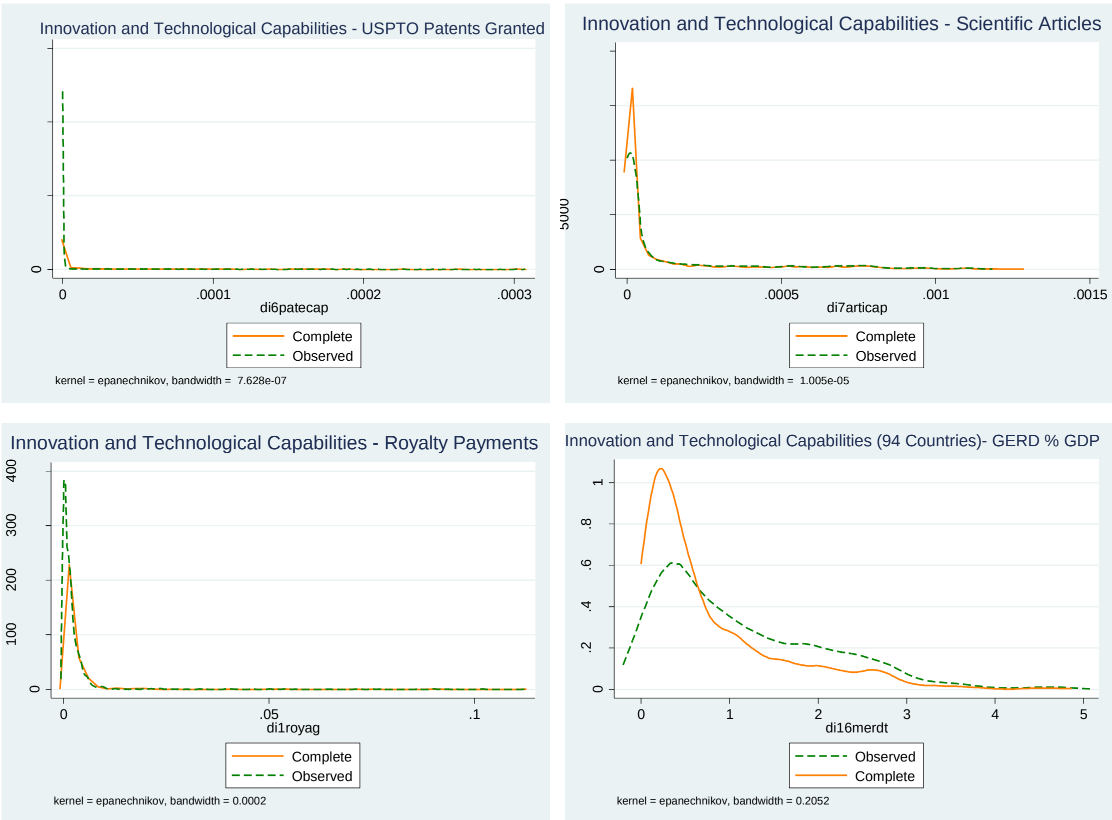
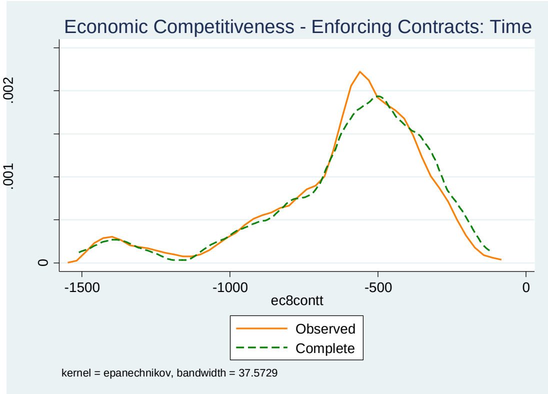
- World Economic Forum: http://www.weforum.org/
- World Values Survey, **1981-2008 OFFICIAL AGGREGATE v.20090901, 2009. World Values Survey Association:** www.worldvaluessurvey.org

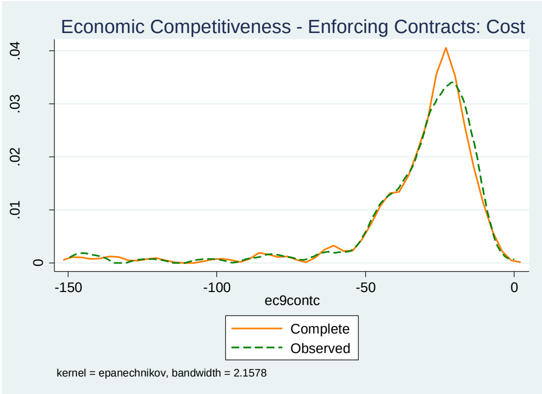
Figure 3A2 - A comparison of the kernel density of the observed data versus the complete CANA dataset

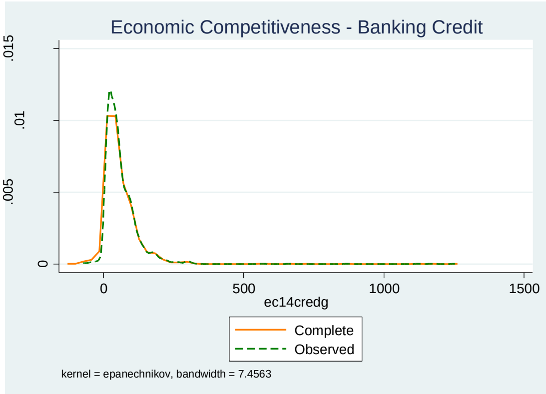
I. Innovation and Technological Capabilities

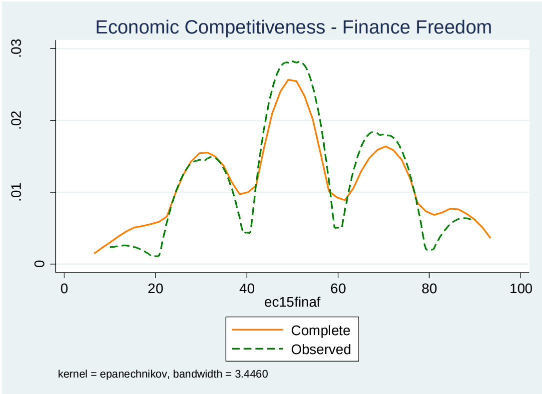


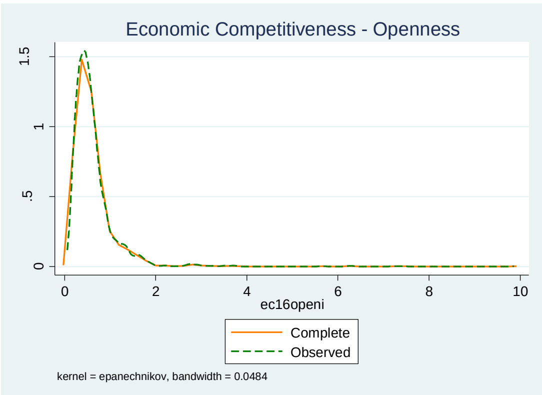
II. Economic Competitiveness



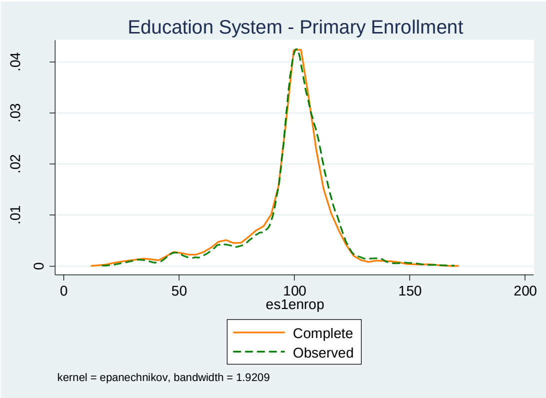


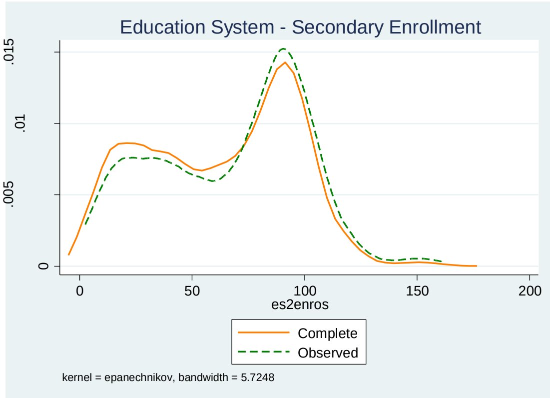


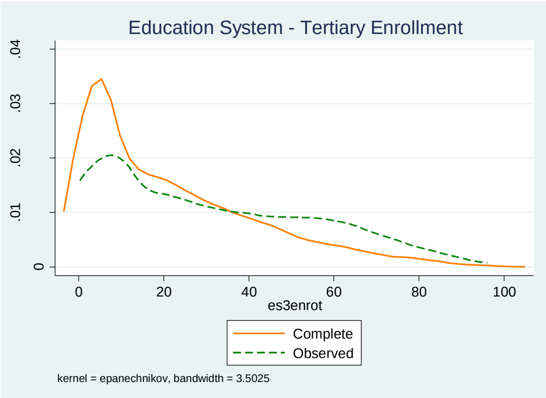


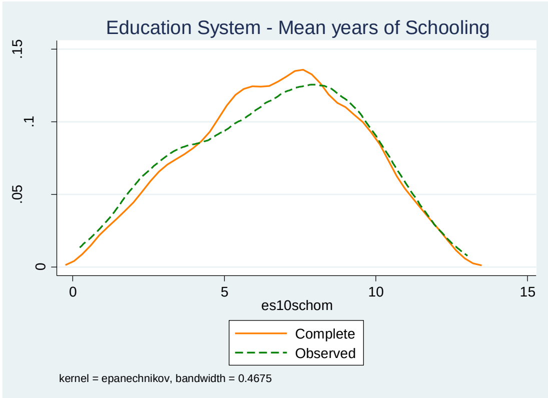


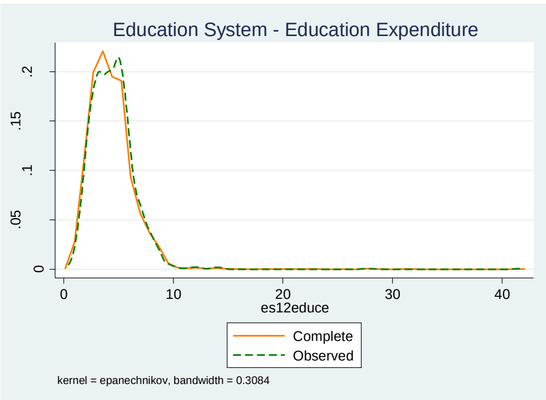
III: Education System and Human Capital

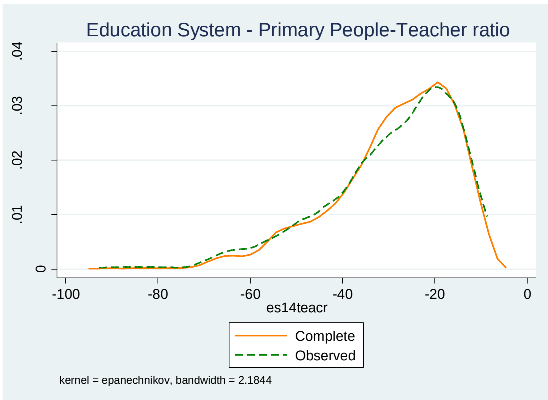




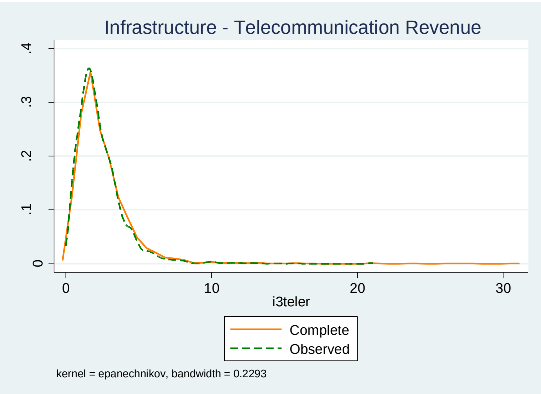


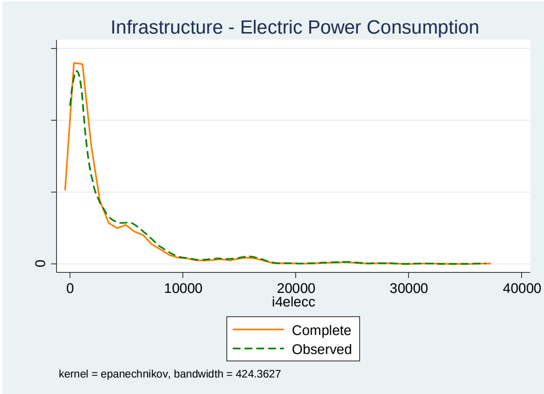


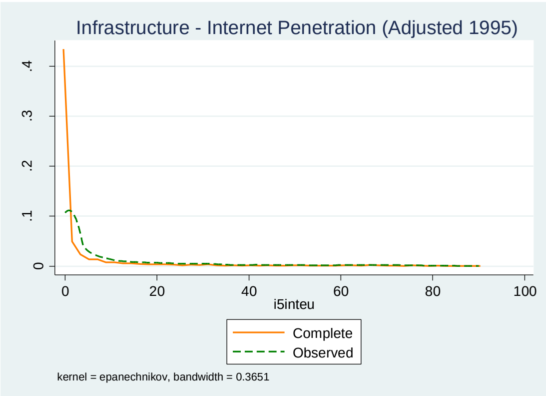


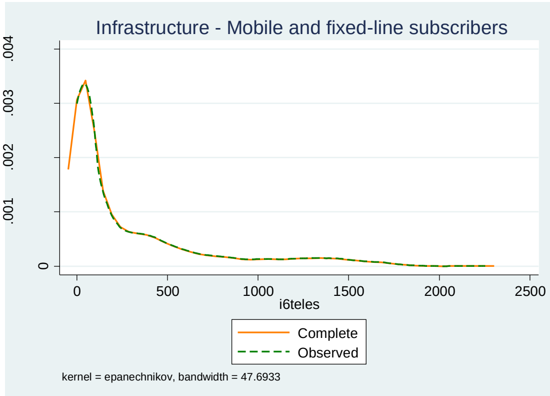


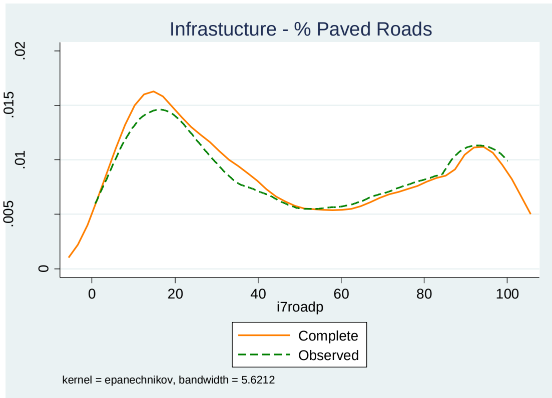
IV. Infrastructure

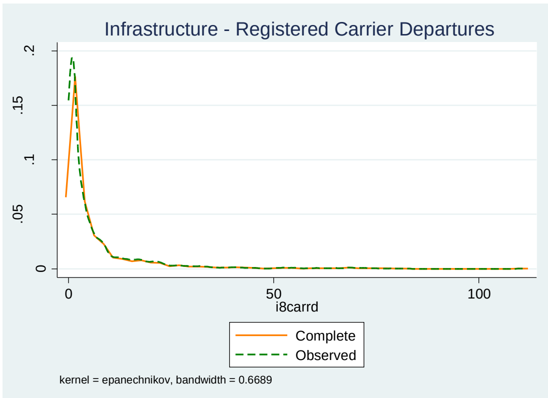




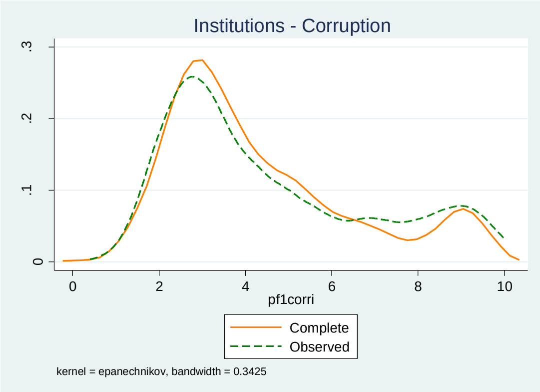


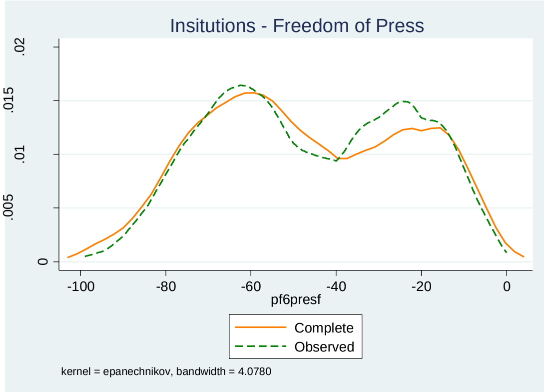


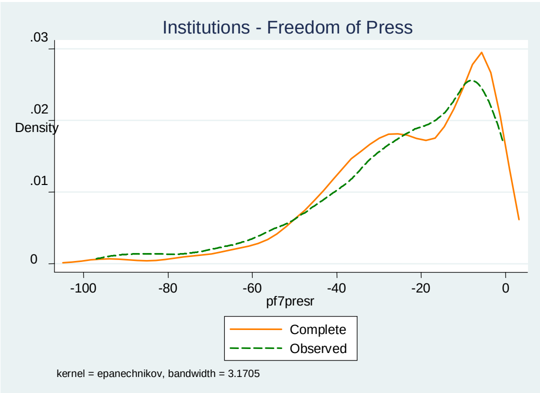


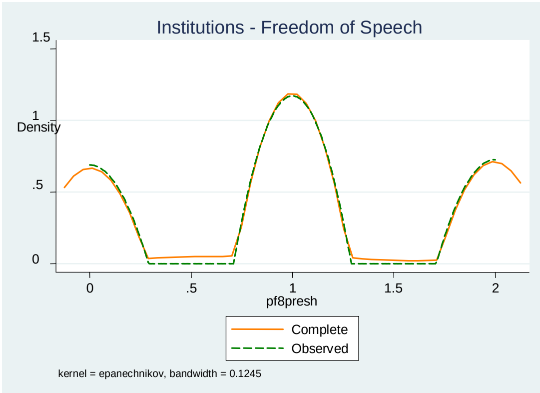


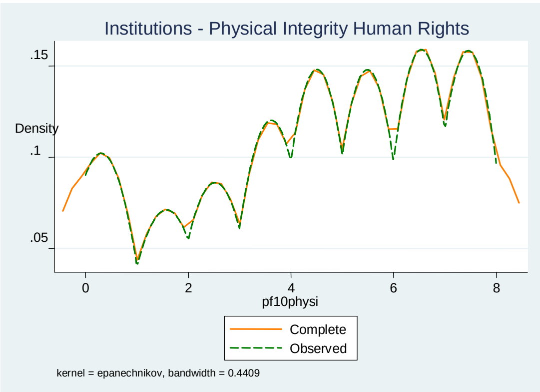
V. Political-institutional factors

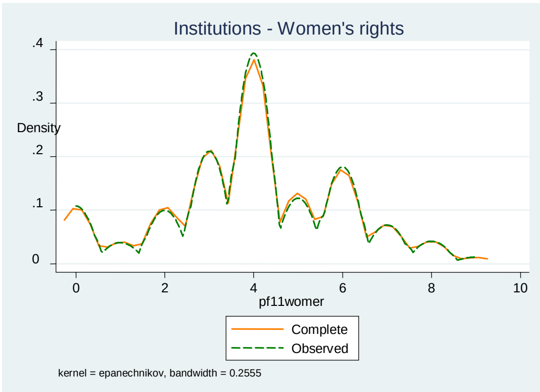


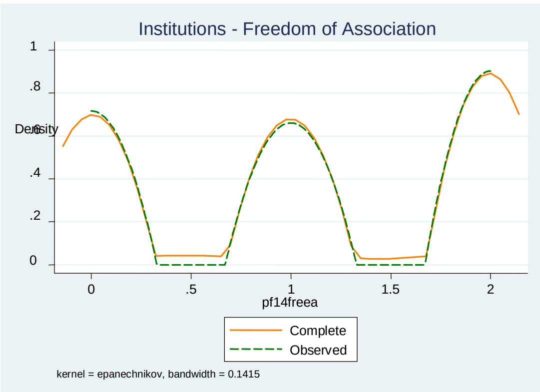


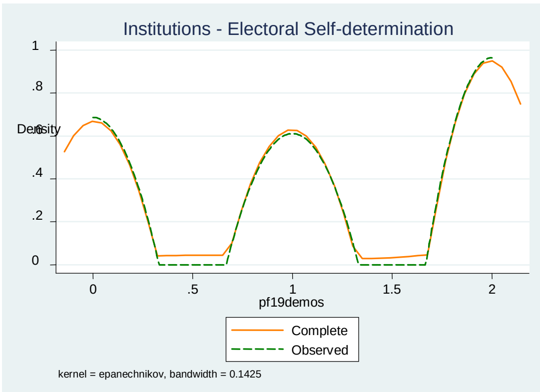




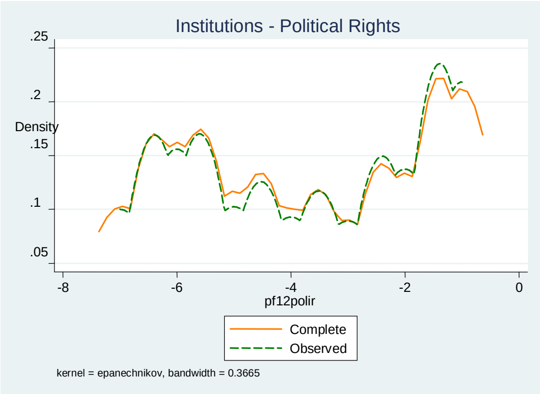


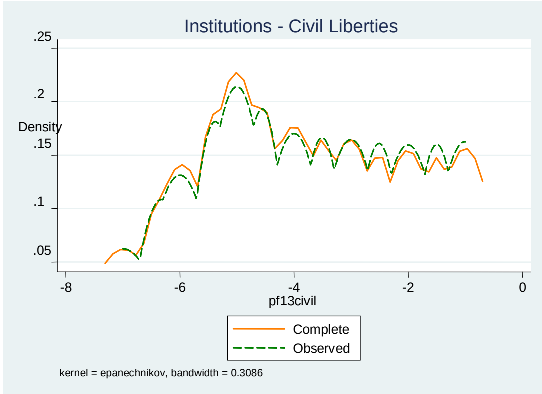


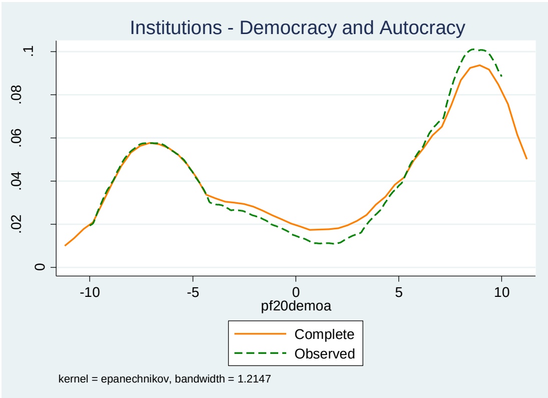


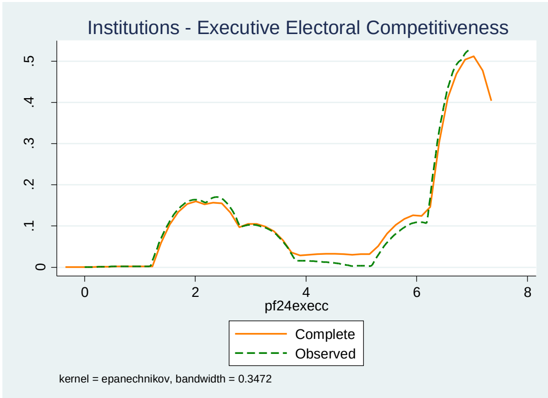


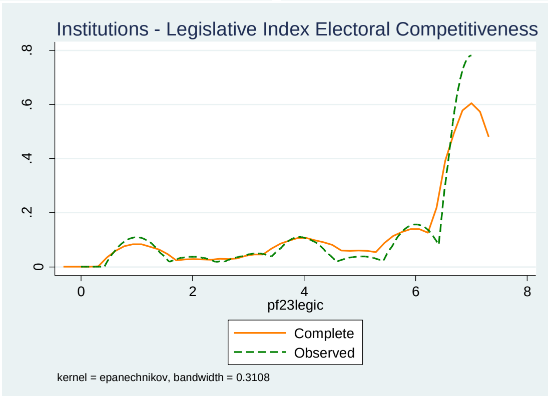
V. Political-institutional factors (cont.)



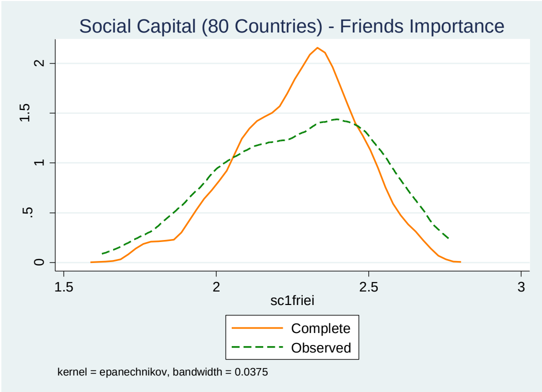


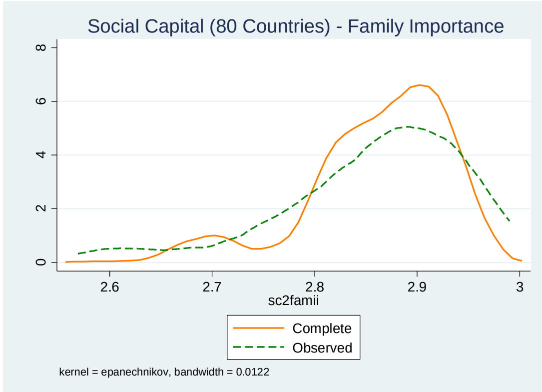


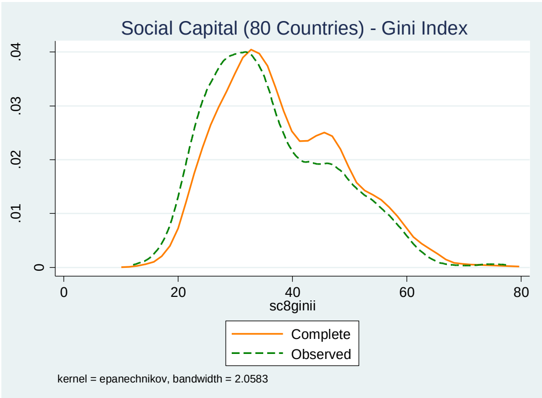


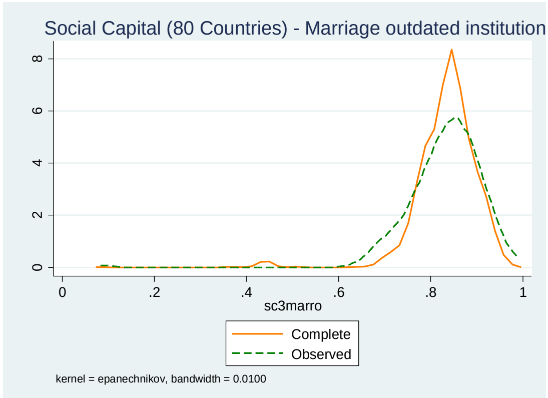


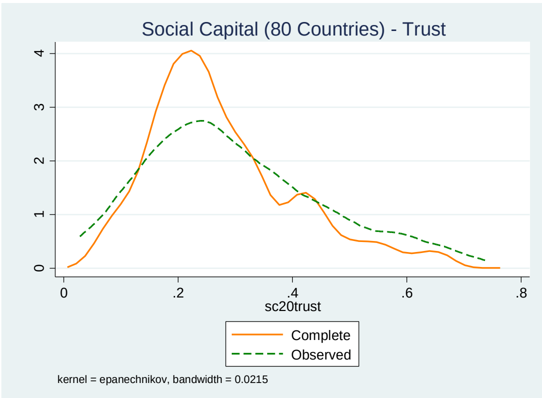
VI. Social Capital











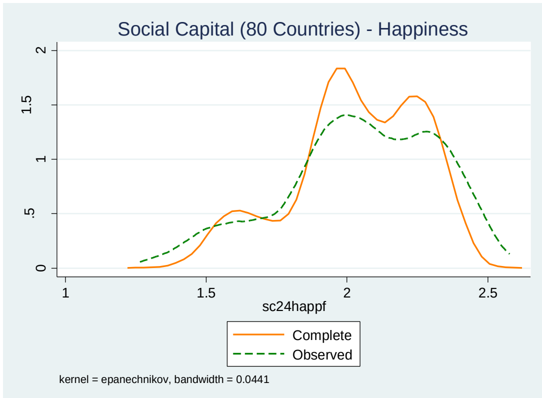


Table 3A2 - Correlation matrix: complete versus original datasets

(the coefficients of correlation for the complete CANA dataset are reported in parentheses)

I. Innovation and Technological Capabilities

	di1royap	di6pateo	di7artis
di6pateo	0.1055 (0.1224)	1	
di7artis	0.1948 (0.1993)	0.7451 (0.7399)	1
di16merdt	0.0983 (0.1786)	0.818 (0.8065)	0.8356 (0.8338)

II. Economic Competitiveness

	ec8contt	ec9contc	ec14credg	ec15finaf
ec8contt	1			
ec9contc	0.1286 (0.0916)	1		
ec14credg	0.1782 (0.0552)	0.3176 (0.2016)	1	
ec15finaf	0.1738 (-0.0074)	0.1719 (0.1844)	0.3659 (0.2079)	1
ec16openi	0.1371 (0.0241)	0.1613 (0.1724)	0.3766 (0.4078)	0.1249 (0.1196)

III. Education System and Human Capital

	es1enrop	es2enros	es3enrot	es10schom	es12educe
es2enros	0.4093 (0.4766)	1			
es3enrot	0.1512 (0.2671)	0.8002 (0.7778)	1		
es10schom	0.4637 (0.4584)	0.8743 (0.8537)	0.7771 (0.7418)	1	
es12educe	0.1081 (0.0782)	0.3366 (0.3229)	0.3334 (0.227)	0.2679 (0.2343)	
es14teacr	0.2229 (0.3239)	0.7905 (0.7927)	0.6834 (0.6511)	0.6777 (0.68)	0.2823 (0.2963)

IV. Infrastructure

	i3teler	i4elecc	i5inteu	i6teles	i7roadp
i4elecc	0.1189 (0.0343)	1			
i5inteu	0.178 (0.2438)	0.5666 (0.5159)	1		
i6teles	0.3272 (0.2878)	0.6385 (0.6222)	0.86 (0.8578)	1	
i7roadp	0.0561 (-0.0029)	0.34 (0.3799)	0.2895 (0.2613)	0.5227 (0.4394)	1
i8carrd	0.1209 (0.0609)	0.7826 (0.7184)	0.3869 (0.387)	0.4396 (0.4647)	0.2234 (0.242)

V. Political-institutional factors

	pf1corri	pf6presf	pf7presr	pf8presh	pf10physi	pf11womer	pf12polir	pf13civil	pf14freea
pf6presf	0.685 (0.6004)	1							
pf7presr	0.5065 (0.4264)	0.8111 (0.7415)	1						
pf8presh	0.5161 (0.414)	0.7149 (0.6674)	0.6627 (0.5986)	1					
pf10physi	0.65 (0.5269)	0.6195 (0.5472)	0.6683 (0.4746)	0.5374 (0.5333)	1				
pf11womer	0.6488 (0.468)	0.5963 (0.5151)	0.425 (0.4025)	0.554 (0.5464)	0.5668 (0.5654)	1			
pf12polir	0.5813 (0.5242)	0.8867 (0.8397)	0.7808 (0.6833)	0.7 (0.6977)	0.5237 (0.5288)	0.5442 (0.542)	1		
pf13civil	0.6661 (0.5786)	0.8953 (0.8444)	0.7929 (0.6969)	0.7044 (0.7029)	0.5814 (0.5821)	0.5717 (0.5666)	0.9238 (0.9203)	1	
pf14freea	0.402 (0.3429)	0.6624 (0.6628)	0.623 (0.5693)	0.6699 (0.6725)	0.4969 (0.4947)	0.5589 (0.5506)	0.7534 (0.7454)	0.7526 (0.7483)	1
pf19demos	0.4166 (0.3871)	0.7238 (0.6972)	0.6421 (0.5918)	0.6808 (0.6832)	0.4883 (0.4875)	0.5861 (0.5824)	0.804 (0.7931)	0.7654 (0.7605)	0.7383 (0.7396)
pf20demoa	0.4273 (0.3671)	0.7845 (0.7259)	0.7178 (0.5783)	0.6703 (0.6469)	0.3895 (0.3917)	0.5254 (0.5049)	0.9035 (0.8821)	0.8558 (0.8308)	0.7453 (0.7194)
pf22confi	0.205 (0.1916)	0.2782 (0.2344)	0.3066 (0.177)	0.151 (0.1509)	0.435 (0.4305)	0.1031 (0.1095)	0.2145 (0.1956)	0.2755 (0.2536)	0.1192 (0.1181)
pf23legic	0.1584 (0.1813)	0.4195 (0.4838)	0.405 (0.3937)	0.4833 (0.4809)	0.2496 (0.2766)	0.4357 (0.4288)	0.6426 (0.6389)	0.6042 (0.5994)	0.5781 (0.5725)
pf24execc	0.2021 (0.2153)	0.4819 (0.5246)	0.4754 (0.3973)	0.5203 (0.505)	0.2979 (0.301)	0.4561 (0.4357)	0.699 (0.685)	0.66 (0.6429)	0.6062 (0.588)

V. Political-institutional factors

	pf19demos	pf20demoa	pf22confi	pf23legic
pf20demoa	0.809 (0.7814)	1		
pf22confi	0.1231 (0.1272)	0.1258 (0.1275)	1	
pf23legic	0.6362 (0.6189)	0.7048 (0.6908)	0.0899 (0.0791)	1
pf24execc	0.7022 (0.6714)	0.7839 (0.7513)	0.1121 (0.1037)	0.8342 (0.8283)

VI. Social Capital

	sc1friei	sc2famii	sc3marro	sc8ginii	sc20trust
sc2famii	0.3221 (0.2912)	1			
sc3marro	0.0708 (0.1111)	0.0413 (0.0102)	1		
sc8ginii	-0.1536 (-0.1568)	0.3301 (0.4)	-0.225 (-0.1444)	1	
sc20trust	0.3557 (0.4308)	-0.1552 (-0.1589)	0.1163 (0.1039)	-0.4337 (-0.5809)	1
sc24happf	0.4675 (0.4717)	0.3769 (0.3911)	-0.098 (-0.1271)	0.1603 (0.1113)	0.2956 (0.2844)

CHAPTER 4

INNOVATION, ABSORPTIVE CAPACITY AND GROWTH HETEROGENEITY: DEVELOPMENT PATHS IN LATIN AMERICA 1970–2010ǂ

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Abstract

The paper carries out an analysis of long-run development paths in Latin America in the period 1970-2010. We focus on three main dimensions – openness, industrial structure and innovation – and analyze how changes in these factors, and the specific combination of them adopted by each country, have affected its income per capita growth. We apply Johansen cointegration approach to time series data for 18 Latin American countries. The analysis leads to two main results. First, we show that Latin American countries have followed different growth trajectories depending on the combination of policies they have adopted to catch up. Secondly, we find a clear correspondence between policy strategies, on the one hand, and growth performance, on the other. Countries that have managed to combine imitation and innovation policy have experienced a higher rate of growth than those economies that have only made efforts to improve their imitation capability.

Keywords: innovation; absorptive capacity; economic growth; heterogeneity; development paths; long-run causality; Latin America

JEL codes: O1, O3, O4

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1. Introduction

In Latin America, the period from the early 1970s onwards marks a sharp rupture with the previous era of State-led industrialization, and the introduction of a new economic model according to which free market mechanisms represent the major force driving economic development (Bulmer-Thomas et al., 2006; Ocampo and Ros, 2011). Latin American economies, though, have responded differently to the opportunities and challenges of globalization, adopting different policy strategies and following distinct growth trajectories. Some of the countries in the region have more actively embraced the new market-oriented model, whereas others have opted for a more cautious mixed approach, building on the path of the import-substitution era (Cimoli and Porcile, 2011; Hausmann, 2011).

How can the development paths followed by Latin American countries during the last decades be explained in the light of the literature on innovation and economic growth? Schumpeterian research has extensively investigated the role of innovation and international knowledge diffusion for the process of economic growth and development. The literature has so far greatly emphasized the cross-country comparative dimension of this process. One strand of research has carried out cross-country econometric studies of empirical data (e.g. Fagerberg and Verspagen, 2002; Castellacci, 2008). Another line of research has presented Schumpeterian models of innovation and growth, and studied the steady state properties of these theoretical frameworks (Howitt and Mayer-Foulkes, 2005; Acemoglu et al., 2006).

While providing an in-depth analysis of the main factors shaping the catching up process of developing economies, Schumpeterian research on innovation and economic growth does however open up new questions, which are particularly relevant in the light of the Latin American experience summarized above. The first question refers to cross-country heterogeneity. Existing research provides a stylized uni-dimensional view of the catch up process, according to which developing countries either catch up or fall behind (depending on their initial conditions and structural characteristics). However, economic history and political economy analyses suggest that economic development is a complex process, and that countries can adopt distinct policy strategies and follow markedly different growth trajectories over time. This is a crucial aspect that deserves further research in order to shed new light on the long-run development paths of Latin American economies.

The second open question relates to the time series dimension. The Schumpeterian literature has so far largely focused on the cross-country comparative dimension of the growth process. By contrast, the time series patterns of the growth process have often been neglected (Castellacci and Natera, 2013). The Latin American experience indicates that countries undergo important economic transformations in the long-run, and that individual economies differ in the specific policy strategy they adopt when faced with the same changing economic and institutional environment. Therefore, time series analysis is crucial in order to shed further light on the different policy strategies and growth trajectories followed by developing economies.

Motivated by these two research issues, our study intends to provide an investigation of Latin America's growth experience with a focus on heterogeneity patterns and the related time series properties. First, we present a simple theoretical model of growth and catching up, based upon, and extending further, Verpagen's (1991) seminal model. The model focuses on three main dimensions – openness, industrial structure and innovation – and analyzes how changes in these factors affect the growth of income per capita of developing economies along their transitional dynamics. We then investigate the empirical evidence of this model by carrying out a time series analysis of 18 Latin American countries in the period 1970-2010. We make use of Johansen cointegration approach, which makes it possible to disentangle short-run and long-run causality effects, and it is then well-suited to estimate the effects of policy changes in terms of openness, industrial structure and innovation on the rate of income per capita growth.

This analysis leads to two main results. First, we show that Latin American countries have followed different growth trajectories depending on the combination of policies they have adopted to catch up (openness, industrial transformation and/or innovation policy). Secondly, we find a clear correspondence between policy strategies, on the one hand, and growth performance, on the other. Countries that have managed to combine imitation policy and innovation policy have experienced a higher rate of growth than those economies that have only made efforts to improve their imitation capability.

The paper is organized as follows. Section 2 describes the background and introduces the relevant literature; section 3 presents the theoretical model; section 4 outlines the time series data and indicators; section 5 explains the econometric method; section 6 presents the results; section 7 summarizes the main results and implications of the work.

2. BACKGROUND

2.1 ECONOMIC GROWTH AND DEVELOPMENT IN LATIN AMERICA

In Latin America, the period spanning from approximately 1940 up to 1970 is commonly defined as the era of "State-led industrialization" (or "import substitution industrialization"; see Bulmer-Thomas et al., 2006; Ocampo and Ros, 2011). Many countries in the region experienced a shift from primary export-led growth towards domestic industrialization, and a growing role of the State in economic development. Economic performance in this period was in general positive, and various Latin American countries managed to catch up and reduce the technology and income gap vis-a-vis other regions in the world (Cimoli and Porcile, 2011).

The subsequent decades, however, marked a much more turbulent era, characterized by important policy changes and a more heterogeneous growth dynamics. The period 1970-2010 – often referred to as "the era of market reform" or "the globalization model" – saw three major changes as compared to the previous phase of long-run growth. First, there were substantial changes in macroeconomic policies (financial stabilization, fiscal restructuring) in order to manage crisis and financial instability. Secondly, most Latin American countries increased the openness of the economy through trade liberalization (lower tariffs and trade agreements) and increased FDI. Thirdly, the new doctrine of market-led economic development rapidly became the mainstream view, and the State started to have a much less active role to foster economic growth. Industrial and technology policies, among others, lost momentum.

The new economic model did not easily lead to the expected economic outcomes. Economic growth performance was not as good as in the previous era, and some Latin American countries were unable to continue the convergence process they had undertaken in previous decades (Cimoli and Porcile, 2011). At the same time, this was an era of great heterogeneity, in which national economies responded differently to the opportunities and challenges of globalization, adopting different policy strategies and following distinct growth trajectories (Ocampo and Ros, 2011). Some of the economies in the region actively embraced the new market-oriented model (e.g. Argentina, Chile and Colombia), whereas others opted for a more cautious mixed model, which built on the path of the import-substitution approach (e.g. Brazil, Mexico, Perú and Venezuela; see Bulmer-Thomas et al., 2006).

Three major dimensions are relevant to investigate the long-run drivers of economic growth in Latin America in the period 1970-2010. The first is the increased openness of the economies in the region. International trade has increased substantially, although according to some recent meta-analysis (see Lora, 2011) the effects of trade policy on the growth of GDP per capita and productivity have so far been modest and transitory. Inwards FDI has also increased substantially, becoming a central, though highly debated, dimension of Latin America's development (Ferraz et al., 2011)[1]. Inward FDI are potentially an important channel of international knowledge diffusion and catching up. However, their impact on economic growth depends largely on the sectors on which they focus, and the spillover effects that they may induce throughout the whole economy through the set of vertical linkages in the host economy.

Industrial structure and sectoral specialization patterns represent a second major dimension to explain heterogeneous policy strategies and growth trajectories in Latin America. In general terms, the ability of a national system to shift resources from traditional and low-productivity sectors (e.g. agriculture, public services) towards more advanced and dynamic industries (such as manufacturing and business services) is an important driver of aggregate growth, as it may support the country's capability to imitate and implement foreign advanced technologies (Fagerberg, 2000; Castellacci, 2010). However, in recent decades structural change has been slower in Latin America than in other developing countries and some of the economies in the region have actually increased their production and employment shares in lower productivity sectors (Cimoli and Porcile, 2011). This is also reflected in the export specialization patterns of Latin American economies, which is often focused on a narrow product range (except the cases of Brazil and Mexico) and on weakly dynamic industries (Hausmann, 2011).

[1] The causal impact of FDI on economic growth is far from clear. Recent time series analyses shed new light on the complexity of this causal effect, e.g. on Chile (Chowdhury and Mavrotas, 2006; Herzer et al., 2008).

For instance, some Central American countries have strengthened their specialization in manufacturing industries, but focusing on assembling activities to serve export-platform FDI of foreign multinationals (e.g. car industry in Mexico, textile in Central America & Caribbean, ICT hardware in Costa Rica; see Ferraz et al., 2011). Sectors related to the exploitation of natural resources are also important in the region, and South American countries have attracted a substantial amount of resource-seeking FDI, mostly in energy and mining (Pineda and Rodriguez, 2011). Although these industries are potentially important for economic development, productive activities in these branches must be accompanied by industrial policies and investments in infrastructures and technological capabilities (e.g. the oil industry in Venezuela and Mexico).

The third crucial dimension refers precisely to innovation and technological capability building, which is the key aspect that catching up countries should try to foster in order to make the jump to the innovation stage. During the period of State-led industrialization, industrial policies and active State interventions created favorable conditions for the development of domestic technological capabilities in Latin America. However, the new market-oriented paradigm undertaken since the early 1970s marked a sharp rupture with the previous phase, so that public support to R&D and innovation policies weakened (at least until the 2000s, see Cimoli and Porcile, 2011). In the last decades, in fact, the innovation gap of Latin America vis-a-vis other regions of the world has increased (Castellacci and Archibugi, 2008; Castellacci, 2011). However, the innovation intensity and performance of national systems varies substantially across the region, and some Latin American countries have indeed undertaken major efforts to place technology and innovation policies on top of their policy objectives.

2.2 THE LITERATURE ON INNOVATION AND ECONOMIC GROWTH

How can the development paths followed by Latin American countries during the last decades be explained in the light of the literature on innovation and economic growth? Schumpeterian research has made major progress and extensively investigated the role of innovation and international knowledge diffusion for the process of catching up of developing economies (Fagerberg, 1994).

A large empirical literature has focused on the process of international knowledge diffusion and investigated the set of factors that affect the extent to which a national system is able to grow and catch up with the technological frontier by means of international learning and imitation activities. This approach was originally inspired by the work of economic historians such as Landes, Gerschenkron and Abramovitz, which, by focusing on historical case studies of the technological catch up process, pointed out that international knowledge diffusion is a complex and demanding process, and investigated the set of factors that are necessary for imitation-based technological development. This set of factors, in a nutshell, defines the absorptive capacity, or imitation capability, of a country (Abramovitz, 1986; 1994).

Empirical works in this tradition have typically followed a growth-regression econometric approach, and shown the large variety of factors, of both a techno-economic and socio-institutional nature, that affect convergence and divergence patterns in broad cross-country samples (e.g. Fagerberg and Verspagen, 2002; Fagerberg and Srholec, 2008; Castellacci, 2008 and 2011). Most of this empirical research, however, has so far focused on the cross-country comparative aspect ("why growth rates differ") and mostly neglected the time series dimension and the analysis of the dynamics of the technological catch up and economic growth process for individual countries (or specific regions) over time.

Theoretical models in the technology-gap (or distance-to-frontier) tradition have tried to formalize some of these ideas into stylized growth models, in which developing countries catch up with the frontier if they are endowed with a sufficient level of absorptive capacity and imitation capability, and fall behind otherwise. Absorptive capacity is in these models affected by countries' level of human capital, their openness to the international economy, as well as their industrial specialization patterns (Verspagen, 1991; Benhabib and Spiegel, 1994; Papageorgiou, 2002; Stokke, 2004).

A more recent class of theoretical models in the distance-to-frontier tradition puts greater emphasis on the innovative capabilities of catching up countries, and points out that the existence of threshold externalities may explain the cumulative nature of the process of technological accumulation and economic growth in the long-run. Specifically, threshold externalities models are based on the idea that the interactions between countries' R&D and innovation activities, on the one hand, and imitation activities, on the other, may generate different country clubs, and explain the transition of each national system from the imitation stage of development to the innovation stage (Howitt, 2000; Howitt and Mayer-Foulkes, 2005; Acemoglu et al., 2006).

Schumpeterian research on innovation and economic growth – while providing an in-depth analysis of the main factors shaping the catching up process of developing economies – does however open up new questions, which are particularly relevant in the light of the Latin American experience summarized above. The first question refers to cross-country heterogeneity. Existing research provides a stylized uni-dimensional view of the catch up process, according to which developing countries either catch up or fall behind (depending on their initial conditions and structural characteristics). However, economic history and political economy analyses suggest that economic development is a complex process, and that countries can adopt distinct policy strategies and follow markedly different growth trajectories over time. This is a crucial aspect that deserves further research in order to shed new light on the long-run development paths of Latin American economies.

The second open question relates to the time series dimension. The Schumpeterian literature has so far largely focused on the cross-country comparative dimension of the growth process, e.g. by carrying out cross-country econometric studies of empirical data, or by studying the steady state properties of growth models. By contrast, the time series patterns of the growth process have largely been neglected (Castellacci and Natera, 2013). The Latin American experience indicates that countries undergo important economic transformations in the long-run, and that individual economies differ in the specific policy strategy they adopt when faced with the same changing economic and institutional environment. Therefore, time series analysis – and specifically time series econometrics, and theoretical analyses of the transitional dynamics properties of growth models – is crucial in order to shed further light on the different policy strategies and growth trajectories followed by developing economies. Motivated by these two broad questions, our study intends to provide an investigation of Latin America's growth experience with a focus on heterogeneity patterns and the related time series properties.

3. MODEL

Our theoretical framework is based on Verspagen's (1991) seminal model of growth and catching up, and subsequent extensions of it by Papaegeorgiou (2002) and Stokke (2004). We extend these previous models and study their time series properties focusing on the effects of policy shocks on the growth rate of catching up countries along the transitional dynamics. The model studies the economic growth of two countries, a leader (L) and a follower (F) economy. The technology gap, or technological distance, between the two countries can be defined as:

$$G = \ln (K_L/K_F) \quad (1)$$

The knowledge stock of the leader country (K_L) is assumed to grow at a constant growth rate IL:

$$\Delta K_L/K_L = I_L \quad (2)$$

This growth rate depends on the amount of resources that country L invests in R&D activities (RD_L) as well as the productivity of its research sector (β_L). Since the focus of the model is the process of growth and catching up of the follower country F, we assume for simplicity that both RD_L and β_L are constant and exogenous, reflecting the assumption that the leader country is growing at a constant speed along its steady state.

$$I_L = \beta_L \bullet RD_L \quad (3)$$

The knowledge stock of the follower country (K_F) depends on two factors: innovation activities (I_F) and international spillovers (S_F) that the country benefits from by imitating foreign advanced knowledge:

$$\Delta K_F/K_F = I_F + S_F \quad (4)$$

The innovation term depends again on the amount of resources that country F invests in R&D activities (RDF) as well as the productivity of its research sector (β_F):

$$I_F = \beta_F \bullet RD_F \quad (5)$$

It is reasonable to assume that the follower country's R&D intensity and the productivity of its research sector are lower than those in the leader economy ($RD_F < RD_L$; $\beta_F < \beta_L$). This implies that $I_F < I_L$, i.e. the innovation rate in the follower country is lower than the one in the leader country.

The international spillovers term S_F represents imitation activities that catching up countries behind the technological frontier can undertake in order to adopt, import and implement foreign advanced technologies. We follow Verspagen's (1991) original formulation and assume a non-linear process of diffusion according to which international spillovers vary with the technological distance G between the leader and the follower country:

$$S_F = \varphi\, G \bullet \exp\,(-G/\delta) \tag{6}$$

The intuition behind this non-linear spillover function is well-known. The term φ G represents the potential spillovers, which depend positively on the size of the gap G as well as on the parameter φ. The latter ($0 < \varphi \leq 1$) measures the openness of the economy (e.g. in terms of international trade and FDI activities), indicating that the more open an economy is, the larger the scope for imitation activities through international knowledge flows.

However, imitation activities can only be successfully undertaken if the follower country has a sufficient level of absorptive capacity that enables to implement and adapt foreign advanced technologies into the domestic system of innovation (Abramovitz, 1986; Fagerberg, 1994). This absorptive capacity, or imitation capability, is noted by the parameter δ (with $\delta > 0$). The higher the parameter δ is, the greater the ability of country F to catch up through international spillovers.

Most previous models of growth and international knowledge diffusion typically assume absorptive capacity to be an exogenous country-specific factor, which depends on the level of human capital of an economy (Verspagen, 1991; Papaegeorgiou, 2002; Benhabib and Spiegel, 2005). We depart from these previous formalizations, and assume that the absorptive capacity does not depend on the level of human capital as such, but rather on the sectors of activity in which a country's human capital is employed. Specifically, suppose there are two sectors in the economy: a traditional sector T (e.g. agriculture) and a technologically progressive sector P (e.g. manufacturing and services). Hence, we point out that:

$$\delta = \lambda \bullet HK_P \tag{7}$$

i.e. the absorptive capacity δ of country F is a linear function of the share of human capital employed in the progressive sector of the economy (HKP), where the parameter λ represents for instance the infrastructures and physical capital that it is necessary to support imitation activities. This formulation points out an important link between human capital and the industrial structure (or specialization pattern) of an economy, and the relevance of this for the catch up and development process. We argue that it is not the level of human capital as such that shapes absorptive capacity, but rather the shares of human capital that are employed in different sectors. For any given level of education and human capital, countries with a higher share of workers employed in technologically progressive industries will in general have stronger absorptive capacity than economies in which labor resources are employed in traditional sectors. This idea is particularly relevant when applied to the Latin American context, in which cross-country differences in human capital levels are not substantial, whereas the differences in terms of industrial structure and specialization patterns among countries in the region are considerable.

In order to study the dynamic properties of this model, we take the time derivative of equation 1:

$$dG/dt = d(K_L/K_F)/dt = \Delta K_L/K_L - \Delta K_F/K_F \quad (8)$$

Using equations 2 to 6, the dynamics of the technology gap in equation 8 can be expressed as:

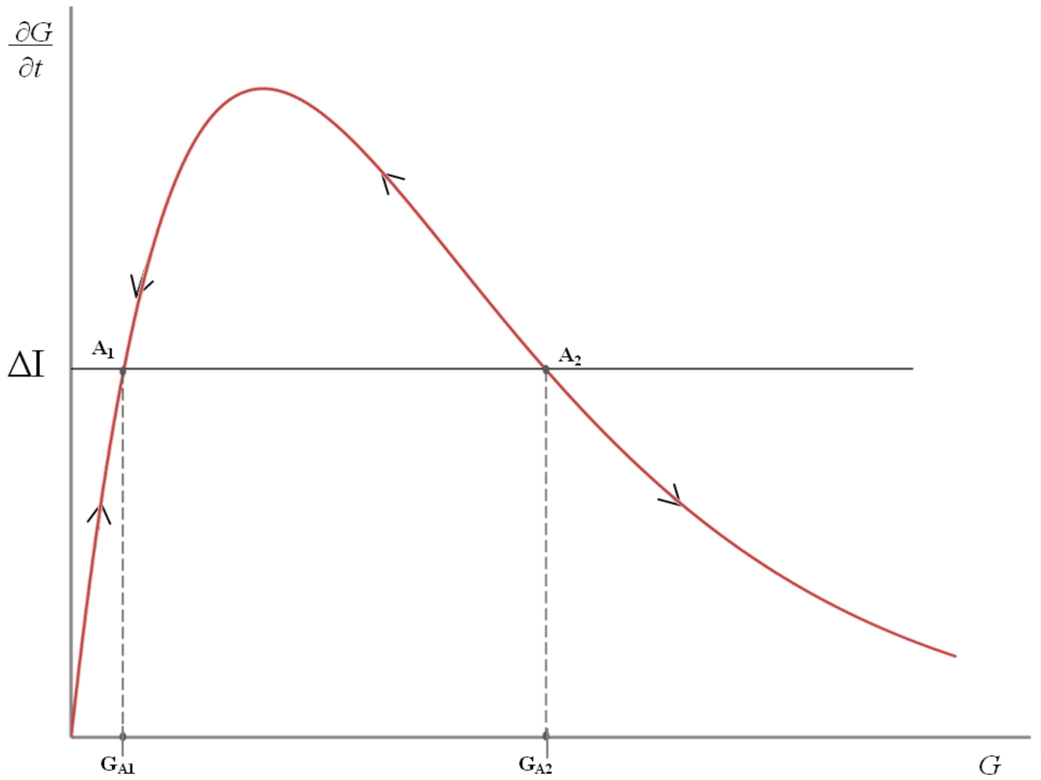
$$dG/dt = (\beta_L \bullet RD_L - \beta_F \bullet RD_F) - \varphi\, G \bullet \exp(-G/\delta) \quad (9)$$

This differential equation is solved by imposing the condition:

$$dG/dt = 0 \quad \Rightarrow \quad \beta_L \bullet RD_L - \beta_F \bullet RD_F = \varphi\, G \bullet \exp(-G/\delta) \quad (10)$$

Figure 1 depicts the dynamics of the technology gap and the equilibrium points (resembling figure 1 in Verspagen, 1991). The left-hand side of equation 10 represents the difference ($I_L - I_F$), i.e. the difference between the rate of innovation in the leader and the follower country. Figure 1 denotes this as ΔI, which, as noted above, is a positive constant. The right-hand side of the equation does instead represent the non-linear process of knowledge imitation, which is affected by the size of the gap, the openness of the economy, and its absorptive capacity (i.e. the country's industrial specialization pattern in our formulation). If [$\Delta I < (\varphi \bullet \delta)/e$] (i.e. if the horizontal line measuring the innovation advantage of the leader country is not higher than the maximum of the spillover term), there exist two equilibrium points, A_1 and A_2. The equilibrium point A_1 is stable whereas A_2 is unstable. The reason for this is that when the RH_S of equation 10 is greater (lower) than the LH_S, the gap tends to decrease (increase). Therefore, countries whose absorptive capacity is too low, lying on the right of point A_2, will not be able to catch up and diverge, whereas national economies above this threshold level will be able to exploit international knowledge spillovers and converge towards the equilibrium point A_1.

Figure 4.1 - The dynamics of the knowledge gap



Source: Verspagen, 1991

Let us now extend this simple framework to carry out some comparative analysis on the effects of policy shocks on the dynamics of growth and catching up of the follower country. Figure 2 presents this comparative exercise by showing equation 10 for different values of the absorptive capacity parameter δ and/or openness parameter φ (curves A and B) and for differential innovation terms ΔI (horizontal lines ΔI_A and ΔI_C). Focusing only on the stable equilibrium points, the figure outlines four different scenarios.

- The point A is the same stable equilibrium outlined in Figure 1 above, and it represents our benchmark scenario in the absence of policy shocks.
- The point B is the equilibrium corresponding to a policy shock that increases the absorptive capacity parameter δ and/or the openness parameter φ, shifting the spillover curve upwards.
- The equilibrium C_A corresponds to a situation in which country F undertakes an innovation policy (e.g. increasing its innovation intensity RD_F, or the productivity of its research sector β_F), which shifts the horizontal line downwards from ΔI_A to ΔI_C.
- The point C_B is the equilibrium corresponding to a combination of the previous cases, i.e. in which country F simultaneously increases its imitation capabilities (through an improved absorptive capacity and/or openness policy) and its innovation ability.

Comparing the level of the technology gap G among these four policy scenarios, it is easy to see that: $G_{CB} < G_{CA} < G_B < G_A$, meaning that the more active the imitation and innovation policies undertaken by a follower country are, the smaller will be the distance between the country and the technological frontier at the end of the catch up process (although the gap will always be positive as long as we assume that $\Delta I > 0$).

Differently from previous related exercises, our main interest is not to analyze the steady state solutions of the model, but rather to focus on the properties of the transitional dynamics that catching up countries follow along their development process, and how this is affected by the different policy shocks outlined above. To do this, we study the effects of changes in our policy parameters on the transitional dynamics term dG/dt. The partial derivatives of dG/dt with respect to φ, δ and RD_F outline three main properties.

$$\partial(\Delta K_F/K_F)/\partial\varphi = G \cdot \exp(-G/\delta) > 0 \quad (11)$$

The first is that an increase in φ (openness policy) leads to an increase in the rate of growth of country F along the transitional dynamics.

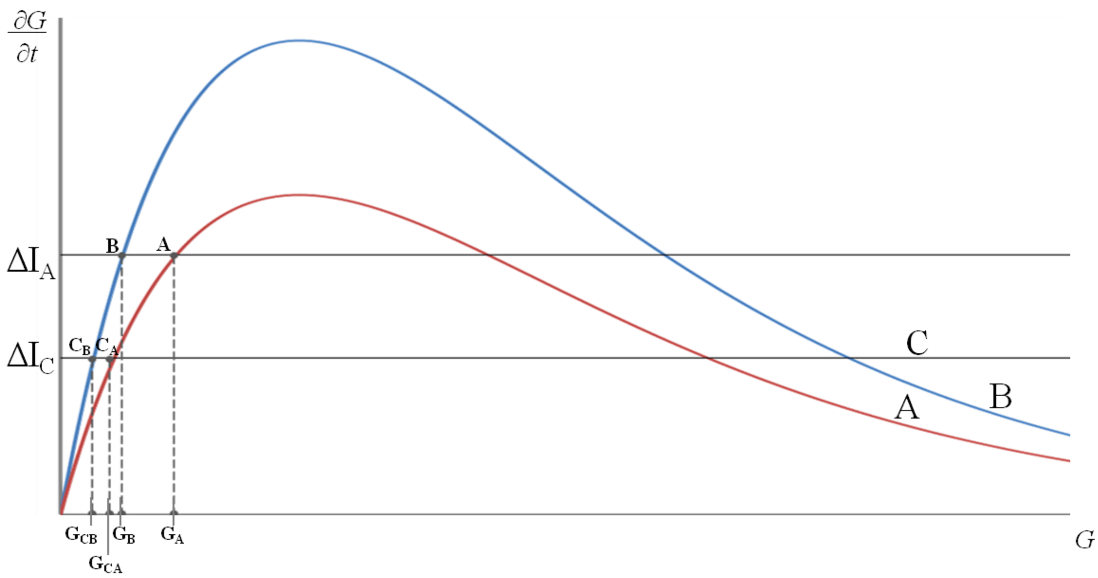
$$\partial(\Delta K_F/K_F)/\partial\delta = [\varphi\, G^2 \exp(-G/\delta)] / \delta^2 \quad (12)$$

The second is that an increase in δ (shifting resources from traditional to technologically progressive sectors) leads to an increase in the rate of growth of country F along the transitional dynamics.

$$\partial(\Delta K_F/K_F)/\ \partial RD_F = \beta_F > 0 \qquad (13)$$

The third property is that an increase in RD_F (through innovation policy) leads to an increase in the rate of growth of country F along the transitional dynamics.

Figure 4.2 - Effects of policy changes on the dynamics of the knowledge gap



In short, a policy shock increasing φ, δ or RDF (openness, structural change or innovation policy) has a positive effect on the growth rate of a catching up economy along the transitional dynamics. These links between policy variables and rates of economic growth during the catch up phase represent the key aspect that our empirical analysis will focus on in a time series context. In turn, these model's properties can be summarized by the following two propositions, which we will test in the empirical part of the paper.

First, we point out that catching up is a complex process, which could be achieved through different policy strategies and following different growth trajectories. The modeling literature has so far focused on a uni-dimensional process, according to which developing economies either catch up or fall behind. To refine and extend this standard approach, we emphasize the existence of different roads and policy strategies to catch up, which is an obvious, though neglected, aspect of the growth and catch up process. Even in a relatively homogenous context as the Latin American region, countries have followed substantially different growth paths, as it will be shown in the empirical part of the paper.

Proposition 1: *Countries follow different growth trajectories depending on the combination of policies they adopt to catch up (openness, structural change and/or innovation policy).*

Table 1 outlines all possible combinations that can be generated by changing the policy parameters of our model. Imitation and innovation policies can be combined in different ways, and each combination determines a specific growth trajectory along the transitional dynamics that characterizes the development path of the economy. Specifically, table 1 points out eight distinct policy strategies, which lead to different growth trajectories.

To consider the effects of different policy strategies on the growth rate of catching up economies, let us suppose that country F undertakes an effort to simultaneously increase both its imitation capability (openness and industrial transformation policies) and innovation ability (i.e. increasing both φ, δ and RDF), i.e. like the last configuration outlined at the bottom of table 1. The corresponding effect on the growth rate during the transitional dynamics phase would be:

$$[\partial(\Delta K_F/K_F)/\ \partial\varphi] + [\partial(\Delta K_F/K_F)/\ \partial\delta] + [\partial(\Delta K_F/K_F)/\ \partial RD_F] = \Psi \qquad (14)$$

with:

$\Psi > \partial(\Delta K_F/K_F)/\ \partial\varphi$

$\Psi > \partial(\Delta K_F/K_F)/\ \partial\delta$

$\Psi > \partial(\Delta K_F/K_F)/\ \partial RD_F$

Proposition 2: *The combination of imitation policy (openness and industrial structure) and innovation policy leads to a higher rate of growth along the transitional dynamics than either imitation or innovation policy alone.*

Table 4.1 - Summary of model outcomes:
Different policy strategies and growth trajectories

Policy strategy	**Openness ($\varphi\uparrow$)**	**Industrial structure ($\delta\uparrow$)**	**Innovation ($RD_F\uparrow$)**	**Equilibrium point in figure 2**	**Growth rate on the transition path**
No policy change along the transition path	No	No	No	A	Low
Openness policy	Yes	No	No	B	Medium
Industrial policy	No	Yes	No	B	Medium
Openness and industrial policy	Yes	Yes	No	B	Medium
Innovation policy	No	No	Yes	C_A	Medium
Innovation and openness policy	Yes	No	Yes	C_B	High
Innovation and industrial policy	No	Yes	Yes	C_B	High
Innovation, openness and industrial policy	Yes	Yes	Yes	C_B	High

4. DATA

Our empirical analysis focuses on 18 Latin American economies (listed in Appendix 1). We use time series data (annual observations) for each country for the whole period 1970 to 2010. As noted above, the use of time series data is a neglected aspect in the field of innovation and growth, and does therefore represent an important avenue for new research. However, the drawback of the time series approach is of course that time series data for a sufficiently long period of time are only available for some variables. Many other indicators of potential interest are only available for shorter periods of time (e.g. since the 1980s or 1990s), and cannot therefore be analyzed within a time series econometric setting. This is also the limitation and trade-off that we face in our study. The variables that we consider are available for the whole period 1970-2010, and this 40-year span is indeed the minimum period length that we can consider in order to have sufficient degrees of freedom and get sensible econometric results. By contrast, several other indicators that are often considered in cross-country studies of innovation and growth are only available for a shorter period of time, and this prevents us from using them in our time series study. The variables that we use are listed as follows.

- **GDP per capita**: GDP per capita, purchase power parity, derived from growth rates of overall consumption, government consumption and investment, at 2005 constant prices (source: Penn World Table 7.0; Heston et al., 2011)[2]. This is the dependent variable in our estimations. We use this variable as a measure of labor productivity, and use it to calculate the growth rate of Latin American countries over the period 1970-2010 (i.e. a proxy for the variable $\Delta K_F/K_F$ of the model in section 3).
- **Inward FDI**: Inward flow of foreign direct investments as a percentage of GDP (source: United Nations Conference on Trade and Development, 2012). We use this variable as a measure of the openness of the economy. This corresponds to the parameter φ of the theoretical model, which determines the potential

[2] Population data is from the World Bank Data Centre (World Bank, 2012a).

spillovers that a follower country can exploit if it has a sufficient level of absorptive capacity[3].

- **Industrial structure**: In order to consider the substantial diversity in industrial structure and specialization patterns across countries in Latin America, we use three different indicators:
    - *Services*: value added of the Service sector as percentage of GDP (World Bank, 2012b).
    - *Manufacturing*: value added of industrial sectors as percentage of GDP (World Bank, 2012c).
    - *Natural Resources*: rents coming from oil, natural gas, coal mineral and forest as percentage of GDP (World Bank, 2012d).

As previously explained in section 3, in our theoretical framework the industrial structure dimension represents the factor that shapes the absorptive capacity, or imitation capability, of a country (parameter δ, see equation 7 above). Our idea is that countries with a higher share of resources employed in technologically progressive industries – such as services, manufacturing and resource-based sectors – will in general have stronger absorptive capacity than economies in which labor resources are employed in traditional sectors (e.g. agriculture). Within the Latin American context, the ability of countries to upgrade their industrial structure and shift resources from traditional to progressive and more dynamic industries is a crucial factor to explain their imitation capabilities[4].

[3] In addition to this FDI indicator, we could have also used a variable measuring the openness of the economy through export and import activities (variables that are available in time series for the period 1970-2010). However, we have chosen to focus on FDI due to the great relevance of foreign MNEs' investments for most of the countries in the region, which is a well-documented fact in studies of the Latin American economy.

[4] In empirical studies of innovation and growth, a variable that is often considered as a proxy for absorptive capacity is human capital. Some of the standard indicators of human capital, such as literacy rates and enrolment ratios are available for most Latin American countries for the whole period under investigation, so we could in principle have used human capital, rather than industrial structure, as a measure of absorptive capacity. However, we have chosen to focus on the industrial structure dimension since this is a crucial aspect that is at the centre of policy debates in Latin America. During the period 1970-2010, Latin American countries have adopted radically different strategies regarding their specialization patterns and industrial policies. Hence, by focusing on this dimension, we intend to catch this important variety of development strategies in the region. By contrast, while human capital is in general an important aspect of absorptive capacity and economic development, its time series development is quite homogeneous among Latin American economies, and we therefore consider it as a less relevant dimension for the objectives of our time series study.

- **Innovation**: Number of patents registered at the USPTO per million people (U.S. Patent and Trademark Office, 2011). This is used as a measure of the variable IF of our model (see equation 5). It is important to acknowledge the possible limitations of patents as indicator of innovation, particularly in the context of developing economies. At the same time, however, this is indeed the best indicator that is available for a time series study like the one we are presenting in this paper. Other commonly used indicators of innovation, and particularly R&D investments, are available for a much shorter period of time for most Latin American countries, and we are therefore forced to disregard them due to the restrictions imposed by our time series analysis in terms of degrees of freedom and minimum number of observations that are needed to run the cointegration analysis (see next section). By using patents, our results on the innovation dimension of the model should therefore be interpreted with some caution, and compared with the results of other previous studies that, focusing on a shorter time period, were able to use a broader set of innovation indicators.

In addition to this basic set of variables, all estimations also include a control variable measuring the institutional quality of each country, defined as such: “Civil Liberties, people's basic freedoms without interference from the state” (source: Freedom House, 2012).

5. METHODS

The econometric analysis investigates the time series properties of the model presented in section 3, in order to estimate the effects of changes in imitation and innovation policies, on the one hand, and the growth rate of Latin American economies in the period 1970-2010, on the other. We make use of time series cointegration analysis, in the system approach developed by Johansen, and apply it to each of the 18 Latin American countries individually.

The time series cointegration approach analyses the relationships between non-stationary time series by looking both at their long-run equilibrium relationship as well as the process of short-run adjustment (Engle and Granger, 1987). More precisely, if two or more variables are integrated of the same order (e.g. they are both I(1) series), there might exist a linear combination of them whose residuals are stationary – in other words the two series are not stationary but one (or more) linear combination of them is[5]. If this is the case, the variables are said to be cointegrated. The Johansen cointegration method we use has one major characteristic that makes it suitable for analyzing the time series properties of the model described in section 3. Based on a Vector Error Correction (VEC) econometric specification, the approach makes it possible to distinguish between long-run and short-run structure, and hence to identify the long-run causal effect of each explanatory variable (policy parameter) on a country's growth rate along its development path. This is the crucial task that our analysis seeks to achieve.

The method proceeds in three steps. First, it investigates the presence of unit roots in the variables. This can be done through two different tests: the Augmented Dickey Fuller (ADF) test and the Phillips and Perron (PP) test . Secondly, it studies the existence of cointegration relationships among the variables of interest. For doing that, we specify a VEC model comprising K variables:

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-i} + \nu + \eta t + \varepsilon_t \qquad (15)$$

where Y_t is the vector that contains the K variables of the model, Π is the matrix that contains the Error Correction Term (ECT), Γ_i are the matrices related to the transitory effects (part of the short-term structure), p is the lag order, ν and ηt are the deterministic components, and ε_t are independently and identically distributed (i.i.d.) errors with mean zero and a finite variance σ^2. Engle and Granger (1987) show that if variables are cointegrated, the Π matrix in equation 15 should have a reduced rank r, such that $K > r > 0$. Johansen (1991; 1995) cointegration rank test seeks to determine those r cointegrating relationships by adopting Trace Test and Maximun Likelihood specifications. Under the null of finding an additional cointegrating relation, it uses a recursive test starting with r = 0 until the first rejection is encountered.

The third and crucial step is the estimation and identification of the model. The ECT term comprises all the information about the long run structure of the system. The Π matrix can be expressed as:

[5] It is also possible to find cointegration between I(1) and I(0) series. Some authors argue that the restriction of having only I(1) variables within the estimation is unnecessary: as long as there exists a stable combination of the variables, cointegration techniques can be used. On this point, see Juselius (2006) and Loayza and Ranciere (2005)

$$\Pi = \alpha\beta' \tag{16}$$

where β is a matrix with the cointegrating relations – representing the long-run equilibrium relationships – whereas α represents the set of long-run Granger causality effects, measuring how variables react to deviations from the long-run equilibrium path (Granger, 1969). Specifically, Johansen approach allows us to determine two distinct types of causality. On the one hand, we can analyze short-run causality by using the Γ_i matrices to investigate how variables react to short term external shocks (i.e. the effect of one variable change on another variable change). On the other hand, for our study it is more interesting to investigate long-run causality patterns, namely how variables react to deviations from the long-run equilibrium β. Hence, we will focus on the estimation results for the α matrix, which represents the way variables react when an exogenous shock (e.g. a policy change) tends to move the system out of its long-run equilibrium path.

To illustrate this further, consider the system of equations represented in (15) and focus on the equation that expresses the growth rate of a country (ΔK_t) as a function of the three main policy variables outlined in our theoretical model: openness (φ), absorptive capacity (δ) and innovation (IF). This can be expressed as:

$$\Delta K_t = \alpha_1(K_{t-1} - \theta_1\,\varphi_{t-1}) + \alpha_2(K_{t-1} - \theta_2\,\delta_{t-1}) + \alpha_3(K_{t-1} - \theta_3\, I_{t-1}) + \sum_j(X\Delta\varphi_{t-j}) + \sum_j(W\Delta\delta_{t-j}) + \sum_j(Z\Delta I_{t-j}) + \nu + \eta t + \varepsilon_t \tag{17}$$

where the vector [θ_1; θ_2; θ_3] represents the long-run cointegration (equilibrium) relationships, and the vector [α_1; α_2; α_3] provides a measure of the extent to which the growth rate of the economy responds to a (level) change in openness, industrial structure or innovation activity (e.g. due to a policy change). As explained in section 3, our theoretical model postulates a positive relationship between each of these variables, on the one hand, and the rate of growth of a catching up country along its transitional dynamics process. By looking at the sign and significance of the three coefficients α_1, α_2, and α_3, we are therefore able to identify the specific policy strategy and growth trajectory followed by each Latin American economy over the period 1970-2010[6]. Specifically, a positive value for the estimated coefficient α1 (or α_2, or α_3) for country i would indicate that a 1% change in the openness of that country (or in its industrial structure, or innovation activity) has a permanent α1% influence on the rate of growth of its GDP per capita over this four-decade period of its transitional dynamics. By contrast, a negative value of the coefficient α1 (or α_2, or α_3) would imply that changes in the country's openness (industrial structure or innovation activity) have had an equilibrium correcting effect, but no permanent impact on the growth rate of the economy along its transition path.

There are two more methodological aspects that it is worth to point out. During the last forty years, Latin American economies have undergone important economic and political transformations, and many of them have sometimes experienced episodes of crises and stability. These structural breaks have important effects on the aggregate time series dynamics, and must therefore be considered in the econometric analysis. The inclusion of permanent time dummies, for long-lasting external shocks, and temporary time dummies, for shocks with a shorter effect, allows us to control for the presence of these exogenous events in the empirical exercise. Besides the time dummies, the deterministic component of the model could also incorporate time series data: we have added an indicator measuring the institutional quality of each country as exogenous control variable in the model[7]. Based on this econometric methodology, we have specified three models (one for each of the three indicators of Industrial Structure) for each Latin American country. In total, we have evaluated and compared 54 different models specifications and selected those that exhibit the clearest pattern.

[6] Significance of these coefficients can be assessed by applying a Wald Test with a Chi-Squared statistic distribution. Reliability of the models could be evaluated by observing stationary cointegrating relations, testing that the roots of the companion matrix is smaller than one and that errors are uncorrelated and normally distributed.

[7] The decision of inserting this institutional variable as an exogenous factor is based on a previous study (Castellacci and Natera, 2013), in which we noticed that institutional variables move at a different pace than techno-economic variables, so that in a time series context it is appropriate to assume that the former affect the latter but not vice versa.

6. RESULTS

As outlined in the previous section, our empirical methodology follows three steps: the first two are preliminary phases that are necessary in order to check that it is appropriate to use a cointegration approach for the time series data of Latin American economies, whereas the third step is the estimation of the long-run determinants of economic growth in the region, which is the core phase of our research.

First, it is necessary to verify the presence of unit roots in all of the empirical models. We applied ADF and PP tests (including constants and trends in the regressions) and found that I(1) processes are present in the time series of Latin American economies in the period 1970-2010. Tables 2 and 3 report the results of these unit root tests. Next we checked for cointegration by applying the Johansen rank test. We considered the existence of structural breaks in the data by adding year dummies (see Appendix 2 for the full list of time dummies we used). On average, we have identified five permanent shocks for each economy: this indicates the substantial instability that has characterized the region over this four-decade period (Bulmer-Thomas et al., 2006; Ocampo and Ros, 2011). Table 4 shows the results of rank tests. We find a value $r > 0$ in all of the models, so there is no evidence to reject cointegration[8]. These tests also allow us to choose the rank of each model, an important decision that determines the number of parameters that will describe our VEC models.

[8] Only the results for some selected models are reported in table 4. Note also that we have used different deterministic components for each model and each country, depending on the nature of the time series data for each national economy.

Table 4.2 - ADF Unit root tests

	Level Data				First Difference Data			
	GDP	Innovation	Industrial Structure	Inward FDI	GDP	Innovation	Industrial Structure	Inward FDI
Argentina	-0.59	-2.424	-3.824**	-4.397***	-3.382*	-4.575***	-2.059	-1.78
Bolivia	-1.672	-	-2.063	-2.273	-2.002	-2.345	-2.495	-3.46*
Brazil	-3.878**	-3.895**	-2.049	-1.934	-5.4***	-7.749***	-4.907***	-6.764***
Colombia	-3.166	-4.686***	-3.59**	-4.161**	-2.702	-	-6.392***	-6.943***
Costa Rica	-0.892	-5.552***	-3.839**	-2.933	-2.868	-9.346***	-5.921***	-5.484***
Cuba	-1.664	-3.911**	-2.218	-4.636***	-4.29***	-6.535***	-3.235*	-6.513***
Chile	-3.12	-4.697***	-4.148**	-4.225***	-5.874***	-7.722***	-5.186***	-6.847***
Dominican Republic	-1.449	-5.877***	-2.03	-3.755**	-3.622**	-7.085***	-5.092***	-4.027**
Ecuador	-2.894	-5.926***	-3.599**	-3.139	-4.979***	-7.769***	-5.425***	-8.198***
El Salvador	-2.198	-4.657***	-5.456***	-4.753***	-4.829***	-9.54***	-10.211***	-7.421***
Honduras	-2.647	-5.683***	-3.471*	-1.905	-4.964***	-9.759***	-5.159***	-4.936***
Guatemala	-2.279	-6.208***	-3.539**	-5.45***	-2.786	-6.33***	-6.307***	-6.96***
Mexico	-2.513	-2.101	-2.962	-2.909	-6.049***	-7.782***	-4.94***	-7.298***
Nicaragua	-1.605	-	-3.493*	-2.424	-2.994	-9.7***	-6.345***	-7.011***
Panama	-2.022	-6.115***	-2.791	-3.543**	-4.983***	-10.792***	-6.453***	-7.596***
Peru	-2.097	-6.241***	-2.412	-3.532**	-1.676	-	-5.725***	-7.346***
Trinidad and Tobago	-1.029	-2.993	-2.333	-2.711	-2.729	-3.915**	-9.182***	-6.882***
Venezuela	-0.213	-5.03***	-9.414***	-3.631**	-3.844**	-5.007***	-5.335***	-8.455***

ADF statistics are reported. Test includes constants and trends in the regression.
Significance levels for rejection of the null hypothesis of unit root presence at 1% ***, 5% **, 10% *.

Table 4.3 - PP Unit root tests

	Level Data				First Difference Data			
	GDP	**Innovation**	**Industrial Structure**	**Inward FDI**	**GDP**	**Innovation**	**Industrial Structure**	**Inward FDI**
Argentina	-0.754	-2.364	-3.745**	-4.411***	-1.951	-4.55***	-2.029	-1.851
Bolivia	-1.236	-	-2.31	-2.273	-2.186	-2.401	-2.633	-3.454*
Brazil	-3.679**	-3.861**	-2.051	-2.203	-5.372***	-7.885***	-4.812***	-12.063***
Colombia	-2.501	-4.617***	-1.861	-4.015**	-2.624	-	-6.409***	-6.903***
Costa Rica	-0.844	-5.565***	-3.604**	-2.881	-4.316***	-10.063***	-5.972***	-5.489***
Cuba	-1.643	-3.689**	-1.817	-7.918***	-4.303***	-16.836***	-6.442***	-9.94***
Chile	-2.289	-4.817***	-4.158**	-4.205**	-3.58**	-12.251***	-10.647***	-7.829***
Dominican Republic	-1.449	-5.902***	-3.477*	-3.727**	-3.676**	-17.428***	-5.031***	-18.072***
Ecuador	-2.863	-6.045***	-3.853**	-2.879	-4.991***	-22.533***	-5.497***	-15.391***
El Salvador	-1.421	-4.669***	-3.737**	-4.743***	-4.555***	-17.006***	-10.08***	-9.181***
Honduras	-2.698	-5.708***	-2.81	-2.884	-5.055***	-28.395***	-5.201***	-8.712***
Guatemala	-2.129	-6.272***	-3.518*	-5.428***	-2.773	-13.71***	-7.339***	-14.293***
Mexico	-2.513	-2.101	-2.962	-2.909	-6.048***	-13.672***	-5.695***	-7.796***
Nicaragua	-1.581	-	-2.239	-2.325	-2.447	-23.972***	-9.121***	-20.145***
Panama	-1.831	-6.167***	-1.746	-3.462*	-4.983***	-10.792***	-6.453***	-7.596***
Peru	-2.098	-5.571***	-2.411	-3.522*	-6.609***	-	-8.989***	-8.078***
Trinidad and Tobago	-0.469	-5.439***	-2.357	-2.771	-4.8***	-16.352***	-11.121***	-15.551***
Venezuela	-0.832	-5.07***	-7.431***	-2.624	-3.844**	-18.733***	-5.269***	-9.133***

PP statistics are reported. Test includes constants and trends in the regression.
Significance levels for rejection of the null hypothesis of unit root presence at 1% ***, 5% **, 10% *.

Table 4.4 - Cointegration Rank tests

Country	Cointegration Rank	Eigenvalue	Statistic	Critical Value
Argentina	4	0.646515	40.55666*	44.4972
Bolivia	2	0.744867	53.27286*	56.70519
Brazil	4	0.578314	33.67626*	37.16359
Colombia	5	0.635025	39.30917*	43.41977
Costa Rica	4	0.608973	102.4784**	107.3466
Cuba	4	0.556854	31.7404*	38.33101
Chile	3	0.629525	114.6433**	117.7082
Dominican Republic	5	0.491200	26.35228*	38.33101
Ecuador	3	0.705373	47.65971**	49.58633
El Salvador	3	0.661082	42.19788**	43.41977
Honduras	4	0.472108	56.22696*	63.8761
Guatemala	4	0.613895	37.11423**	38.33101
Mexico	4	0.659618	42.02976*	50.59985
Nicaragua	3	0.591020	34.86947**	37.16359
Panama	5	0.542737	87.24515*	107.3466
Peru	3	0.654095	106.9985**	107.3466
Trinidad and Tobago	3	0.546955	78.79105**	79.34145
Venezuela	3	0.587682	100.0661*	117.7082

Significance levels for rejection of the null hypothesis of finding another cointegrating relation at 1% ***, 5% **, 10% *.

The third and crucial step in the analysis is the estimation of the VEC model, which relates the dynamics of GDP per capita, on the one hand, and our explanatory variables measuring openness, industrial structure and innovation, on the other. In order to have comparable models across countries, we have imposed restrictions on the β vector, in which GDP per capita is the main reference (dependent variable) and the behavior of the other variables adapts accordingly[10]. Once the β vector has been identified, we are able to proceed with the analysis of the α matrix, that contains our parameters of interest measuring the effect of changes in absorptive capacity and innovation on the growth rate of GDP per capita (see equation 17 in the previous section).

Table 5 shows the results of the VEC estimations for some selected models, reporting the α_i coefficients for each country along with their significance levels (between brackets). As explained in the previous section, we focus our attention on estimated coefficients that turn out to be positive (see the coefficients reported in bold in table 5). Specifically, a positive value for the estimated coefficient α_1 (or α_2, or α_3) for country i would indicate that an increase in the openness of that country (or in its industrial structure, or innovation activity) has led to a permanent α_1% increase in the rate of growth of its GDP per capita over this four-decade period. On the other hand, a negative value of the estimated coefficient α_1 (or α_2, or α_3) would simply imply that changes in the country's openness (industrial structure or innovation activity) have not led to a higher growth rate of the economy along its transition path, and we will therefore disregard them in our discussion of the results. In short, table 5 reports time series evidence that it is useful to identify the specific policy strategy and growth trajectory followed by each Latin American economy over the period 1970-2010.

[10] The specification of a cointegration model is a highly iterative process. The identification of the long-run and short-run structure could imply changes in the whole model. Further, reliability tests could also imply that some of the models should be re-specified or even disregarded. In our analysis, in particular, we could not set stable models for Bolivia (Industrial Production and Natural Resources), Costa Rica (Natural Resources), Ecuador (Services and Natural Resources), Guatemala (Services and Natural Resources), Mexico (Services) and Peru (Natural Resources). Furthermore, we have had to exclude Paraguay and Uruguay from the country sample because of reliability issues in the estimation of these models

Table 4.5 - Long-run Causality: VEC estimation results (selected models)

	Specification	Industrial structure	Inward FDI	Innovation
Argentina	Natural resources	**0.121665***	-0.210448***	-0.094763
		[7.982994]	[17.79498]	[1.781303]
Bolivia	Services	0.021519	-0.016766***	-
		[0.224313]	[8.894036]	-
Brazil	Manufacturing	**0.538939**	**0.09898***	**0.015187***
		[5.532527]	[3.419471]	[3.224582]
Chile	Services	-3.889594***	-0.037285	**3.280536***
		[8.873596]	[1.034816]	[7.358538]
Colombia	Manufacturing	**0.235119***	-0.214947**	0.049839
		[15.9551]	[5.546374]	[1.06647]
Costa Rica	Services	**0.018769***	**0.727968***	**0.065426**
		[3.45078]	[17.04856]	[6.14068]
Cuba	Manufacturing	**0.9324**	-0.013005	0.035388
		[5.703126]	[0.006341]	[1.259175]
Dominican Republic	Services	0.955652	-1.237764	**4.103316***
		[1.039793]	[0.510991]	[11.46506]
Ecuador	Natural resources	-1.533394***	**0.975586***	0.113227
		[17.41643]	[9.052073]	[1.096077]
El Salvador	Services	**0.020798***	-0.263562***	-0.13116*
		[8.987157]	[6.907432]	[2.749086]
Guatemala	Natural resources	**0.255708***	-0.013453**	-0.795252***
		[24.21908]	[5.131703]	[39.01117]
Honduras	Natural resources	0.035163	-0.147183*	-0.041747*
		[0.243395]	[3.18726]	[3.505973]
Mexico	Natural resources	**1.417296***	-0.004168	**0.092259***
		[25.52489]	[0.010498]	[2.925049]
Nicaragua	Natural resources	-0.61709***	**1.291423***	-
		[10.01845]	[62.43663]	-
Panama	Natural resources	-0.414099**	-0.971683***	**0.077899**
		[4.423823]	[11.30999]	[6.253894]
Peru	Manufacturing	-0.349571	**0.722861**	-0.525339**
		[2.069322]	[5.595606]	[5.350308]
Trinidad and Tobago	Manufacturing	0.141095	0.0118	**0.054081***
		[2.126461]	[0.280168]	[16.68752]
Venezuela	Natural resources	**0.245535***	**0.296107***	-0.405049**
		[3.41117]	[6.755397]	[5.587171]

Positive and significant coefficients in bold. Significance levels at 1% ***, 5% **, 10% *. Chi- Squared statistic in brackets.

An overview of the results confirms our general hypothesis that the three major dimensions investigated in this analysis have had different impacts on Latin American countries. Openness (FDI) has increased substantially throughout the whole region, but according to our time series evidence inwards FDI have led to a permanent increase in the GDP per capita growth rate only in five of the countries in the sample (Brazil, Costa Rica, Ecuador, Nicaragua, Peru).

Changes in the industrial structure have had a positive impact on economic growth in eight Latin American economies, with the strongest estimated impacts in Mexico and Cuba. This general result does however contain three distinct patterns. Some of these countries have benefitted from a process of structural change towards the manufacturing sectors (e.g. Brazil, Colombia); others have increased their production shares in natural resource-based activities (Argentina, Guatemala, Mexico); and only one economy, El Salvador, has sustained its growth rate by shifting labor resources to the service sectors (e.g. financial services).

Thirdly, the innovation variable does also turn out to be important in the VEC results. For seven out of 18 Latin American countries, changes in innovation performance (measured by patents) have had a positive effect on the rate of growth of GDP per capita. The strongest estimated impact is for the time series of Chile and the Dominican Republic. This is an interesting finding: despite the fact that industrial and technology policies have been quite low on the policy agenda of most Latin American countries during the period 1970-2010, the relatively low investments in innovative activities have had positive economic effects in the region. This confirms the important role of technological capability building for catching up economies, and suggests that public policy efforts to increase the innovation performance of business firms do matter for economic development, and should be strengthened substantially in the future.

Besides looking at the effects of these three dimensions separately, it is also important to consider their combination, i.e. the specific policy strategy or mix that each Latin American country has adopted, and how this has shaped its growth performance. Table 6 presents a summary of the VEC estimation results (taking into account all possible model specifications that we have run). Based on the VEC results that we have obtained from this exercise, it is evident that Latin American countries have followed different paths. Notice that table 6 can be directly compared to table 1 (section 3), which outlined the different policy strategies and growth trajectories that could be expected on the basis of our theoretical model.

For Bolivia we find that none of the three explanatory factors pointed out in the model has had a positive effect (i.e. a long-term impact) on the growth rate of the economy. Peru, Ecuador and Nicaragua show a positive effect from FDI activities. For other countries, structural changes and industrial transformations have been the main driving forces of economic development, specifically in services (El Salvador), manufacturing (Colombia) and natural resources (Argentina, Mexico, Guatemala and Honduras). The Venezuelan growth trajectory is based on a combination of inwards FDI and resource-based activities. All of the countries pointed out here, despite their different policy strategies, have on the whole had a stagnant dynamics in the period, with an average annual growth rate of GDP per capita lower than 2%.

In contrast, there are other countries that have had an above average performance within the region (growth rate above 2%). The specific characteristic of these economies, and the factor arguably explaining their dynamic trajectory, is innovation. Specifically, for Chile and Panama, we have found that innovation is one of the main factors that have led to a permanent increase in the growth rate of GDP per capita[11]. Results for Dominican Republic, Cuba and Trinidad and Tobago, the Caribbean economies in our sample, show a trajectory based on a combination of innovation and industrial transformation. Interestingly, no Latin American country shows evidence of combining inward FDI and innovation. This has been an important development path for some catching up countries (e.g. in East Asia), but it does not turn out to be relevant to explain the Latin American case. Finally, there are two countries that exhibit the best policy strategy, since they combine together all three growth factors (inward FDI, industrial transformation and innovation): Brazil and Costa Rica are, according to our VEC estimation results, these two leading economies.

On the whole, this clustering exercise should be taken with caution. Due to some differences in the results across model specifications, it is not easy to find common patterns among these economies, which indeed feature different structural

[11] This result calls for further research to analyze in further details the role of innovation for the development of Chile and Panama. These two countries have been successful in attracting FDI and been opened to other international activities. This might have had a second level effect on the innovation performance of these national economies.

characteristics. However, the purpose here is not to point out a thorough taxonomy of Latin American economies based on their long-run growth patterns. Rather, our exercise provides evidence that corroborates the theoretical framework and main propositions that we previously pointed out in section 3, and shows the large variety of development paths even in a relatively homogenous region such as Latin America.

The general result highlighted by our empirical analysis is twofold. First, as argued by Proposition 1, the Latin American case clearly illustrates that developing countries follow different growth trajectories depending on the combination of policies they adopt to catch up (openness, industrial transformation and/or innovation policy). Secondly, there is a clear correspondence between policy strategies and growth performance. As postulated by Proposition 2, the combination of imitation policy (openness and industrial transformation) and innovation policy (as in groups 5 to 8) leads to a higher rate of growth along the transitional dynamics than imitation policy alone (as in groups 1 to 4).

Table 4.6 - Summary of VEC estimation results

Group	**Development path**	**Countries**	**Growth rate (average annual)**	
1	No effect of policy changes	Bolivia	< 2%	
2	FDI-driven	Peru, Ecuador, Nicaragua	< 2%	
3A	Industrial transformation: Services	El Salvador	< 2%	**Below average performers**
3B	Industrial transformation: Manufacturing	Colombia	< 2%	
3C	Industrial transformation: Natural resources	Argentina, Mexico, Guatemala, Honduras	< 2%	
4	FDI and industrial transformation	Venezuela	< 2%	

Table 4.6 - Summary of VEC estimation results (cont.)

Group	Development path	Countries	Growth rate (average annual)	
5	Innovation-driven	Chile, Panama	> 2%	**Above average performers**
6	Innovation- and FDI-driven	-	> 2%	
7	Innovation and industrial transformation	Dominican Republic, Cuba, Trinidad & Tobago	> 2%	
8	Innovation, FDI and industrial transformation	Brazil, Costa Rica	> 2%	

7. CONCLUSIONS

The paper has carried out an analysis of long-run development paths in Latin America in the period 1970-2010. We have shown that economies in the region have responded differently to the opportunities and challenges presented by the globalization era and the related new market-led economic model. Specifically, we have focused on three main dimensions – openness, industrial structure and innovation – and analyzed how changes in these factors, and the specific combination of them adopted by each country, have affected the growth of income per capita of Latin American economies.

The first part of the paper has presented a simple theoretical model of growth and catching up, based upon, and extending further, Verpagen’s (1991) model. Our theoretical analysis has focused on the properties of the transitional dynamics of the model, in order to illustrate the extent to which policy changes that affect a country’s imitation capability and its innovation ability may lead to a permanent increase in the growth rate of the catching up economy over its transitional dynamics path. The second part of the paper has investigated the empirical evidence of this model by carrying out a time series analysis of 18 Latin American countries. We have made use of Johansen cointegration approach, which makes it possible to disentangle short-run and long-run causality effects, and it is then well-suited to estimate the effects of policy changes in terms of openness, industrial structure and innovation on the rate of income per capita growth.

This analysis leads to two main results. First, we have shown that Latin American countries have followed different growth trajectories depending on the combination of policies they have adopted to catch up (openness, industrial transformation and/or innovation policy). Secondly, we have found a clear correspondence between policy strategies, on the one hand, and growth performance, on the other. Countries that have managed to combine imitation policy and innovation policy have experienced a higher rate of growth in the period 1970-2010 than those economies that have only made efforts to improve their imitation capability.

These results have two major implications. The first relates to the literature on innovation and economic growth. Schumpeterian research has extensively investigated the role of innovation and international knowledge diffusion for the process of economic growth and development. The literature has so far greatly emphasized the cross-country comparative dimension of this process, e.g. by carrying out cross-country econometric studies of empirical data, or by studying the steady state properties of growth models. Our paper has instead focused on the time series dimension, which has so far been substantially neglected in this field. We argue that this is a major avenue for future research on innovation and growth. On the one hand, theoretical analyses should focus much more on the transitional dynamics properties of growth models rather than their steady state outcomes: the steady state is a fiction while transitional dynamics is all that matters, since it describes the path effectively followed by countries during their development process. On the other hand, time series econometrics is useful to shed further light on the different policy strategies followed by developing economies, and how these affect their growth trajectories. It is an important methodological approach that can extend and complement standard methodologies based on cross-country and panel data analyses, and provide a more in-depth analysis of the heterogeneity issue.

The second implication refers to economic policy. The time span considered in this paper, 1970-2010, marks a sharp rupture with the previous era of State-led industrialization, and the introduction of a new economic model according to which free market mechanisms represent the major force driving economic development. However, Latin American economies have responded differently to the opportunities and challenges of globalization, adopting different policy strategies and following distinct growth trajectories. Some of the countries in the region have more actively embraced the new market-oriented model, whereas others opted for a more cautious mixed model, which built on the path of the import-substitution approach. One of the findings of our paper is that those countries that have been able to shift to the new market-led model while at the same also maintaining an active role for the State in industrial and innovation policies (e.g. Brazil and Costa Rica) have experienced a more rapid process of industrialization and currently face better prospects for further economic growth in the future. The take home message of the Schumpeterian development literature is that it is crucial to combine imitation and innovation policies in order to catch up with the frontier, and that public policies that support capability building and the exploitation of technological opportunities play a key role for developing economies.

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APPENDIX

APPENDIX 1: LIST OF COUNTRIES

Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Peru, Trinidad and Tobago and Venezuela.

APPENDIX 2: TIME DUMMIES

Table 4A2.1 - Time dummies included in the selected models

Country	Permanent dummies	Temporary dummies
Argentina	1980, 1985, 1990, 1999, 2002, 2005	-
Bolivia	1974, 1977, 1986, 1994, 1999, 2002, 2005	-
Brazil	1981, 1985, 1990, 1994, 1999	2003
Colombia	1974, 1977, 1980, 1985, 1990, 1994, 1999	1997
Costa Rica	1975, 1980, 1991, 1996, 2000, 2008	-
Cuba	1980, 1985, 1990, 1994, 2000	1996, 1999
Chile	1975, 1981, 1988, 1992, 1999	-
Dominican Republic	1975, 1980, 1987, 1991, 1999, 2003	-
Ecuador	1976, 1980, 1987, 1990, 1999, 2008	1971, 1974, 2000
El Salvador	1974, 1978, 1983, 1991, 2008	1995, 1998, 2007
Honduras	1974, 1979, 1990, 1999	1973, 2000, 2006
Guatemala	1980, 1985, 1988, 2000, 2008	1972, 1976, 1998, 2001
Mexico	1973, 1981, 1988, 1994, 2000, 2003, 2008	-
Nicaragua	1977, 1980, 1987, 1993, 2001	-
Panama	1976, 1982, 1986, 1991, 1996, 2002, 2006	1989
Peru	1974, 1979, 1985, 1992, 2001	1988, 1996, 2009
Trinidad and Tobago	1980, 1989, 1999, 2008	1975, 1997
Venezuela	1977, 1983, 1992, 1998, 2003	1974, 1989, 1990

CHAPTER 5

THE DYNAMICS OF NATIONAL INNOVATION SYSTEMS: A PANEL COINTEGRATION ANALYSIS OF THE COEVOLUTION BETWEEN INNOVATIVE CAPABILITY AND ABSORPTIVE CAPACITY‡

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Abstract

This paper investigates the idea that the dynamics of national innovation systems is driven by the coevolution of two main dimensions: innovative capability and absorptive capacity. The empirical analysis employs a broad set of indicators measuring national innovative capabilities and absorptive capacity for a panel of 87 countries in the period 1980-2007, and makes use of panel cointegration analysis to investigate long-run relationships and coevolution patterns among these variables. The results indicate that the dynamics of national systems of innovation is driven by the coevolution of three innovative capability variables (innovative input, scientific output and technological output), on the one hand, and three absorptive capacity factors (infrastructures, international trade and human capital), on the other. This general result does however differ and take specific patterns at different levels of development.

Keywords: national systems of innovation; innovative capability; absorptive capacity; economic growth and development; coevolution; panel cointegration analysis.

JEL codes: O1, O3, O4

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1. INTRODUCTION

The study of national innovation systems (NIS) has attracted considerable attention in the last two decades (Lundvall, 2007). While a substantial amount of research has been devoted to the investigation of cross-country differences in technological capabilities and the related institutional and policy framework, much less attention has so far been given to the analysis of the *dynamics* of national systems over time.

This is unfortunate, since evolution and change represent indeed key aspects of Schumpeterian research, which did in fact constitute some of the crucial motivations for the original development of the NIS approach. The lack of focus on dynamic aspects is partly explained by the non-availability of time series data for a sufficiently long period of time, and partly by the analytical and methodological difficulties that are faced when it comes to model and empirically analyse the dynamics of complex evolving systems (Foster, 1991).

The Schumpeterian literature on innovation and economic growth does however provide important insights and key building blocks for developing an analytically stronger framework to study NIS dynamics. First, idea-based new growth models point out the important role of national innovation capability for the growth of the economic system (Romer, 1990; Furman, Porter and Stern, 2002). Secondly, technology-gap models highlight the important role played by countries' absorptive capacity for imitation-based catching up, and show the large set of factors that contribute to define a country's absorptive capacity (Abramovitz, 1986; Verspagen, 1991; Godinho et al., 2006; Fagerberg and Srholec, 2008; Lee and Kim, 2009).

Most of the empirical literature on innovation and growth, though, has so far neglected the study of two important issues. The first is that, while a substantial amount of research has been devoted to the analysis of the impacts of innovation on economic growth, the investigation of the determinants and drivers of national innovative activities, has so far received only limited attention (Castellacci, 2011; Filippetti and Peyrache, 2011). Secondly, the applied literature on innovation and growth has typically focused on the cross-country comparative aspect ("why growth rates differ across countries") and often neglected the time series properties of the process of technological change and economic development. In short, the existing literature provides only limited insights on the drivers of national systems of innovation and the mechanisms that may explain their evolution and growth over time.

Motivated by this important gap, this paper adopts a time series perspective and shifts the focus to the analysis of the drivers of national innovation systems over time. In a nutshell, the paper puts forward the idea that innovative capability and absorptive capacity are linked by a set of two-way dynamic relationships, and that their process of coevolution represents a key mechanism driving the growth of national systems in the long-run.

Our empirical analysis makes use of a broad set of indicators measuring national innovative capabilities and absorptive capacity for a panel of 87 countries in the period 1980-2007. The empirical methodology that we adopt is rooted in the panel cointegration approach, which represents a recent extension of the time series cointegration analysis of non-stationary variables to the panel data context (Breitung and Pesaran, 2008). The cointegration methodology has an inherent ability to uncover dynamic relationships among variables that coevolve over time, and we therefore argue that it constitutes a natural platform for investigating the long-run dynamics of national systems of innovation.

The empirical results indicate that innovative capability and absorptive capacity variables are indeed linked by a set of long-term structural relationships over the period 1980-2007. Specifically, the dynamics of national systems of innovation is driven by the coevolution of two sets of factors: innovative input, scientific output and technological output, on the one hand, and infrastructures, international trade and human capital, on the other. Further, both of these dimensions coevolve with the growth of income per capita.

The paper is organized as follows. Section 2 provides a brief review of the literature, section 3 presents the theoretical framework and hypotheses, section 4 points out the data and indicators, section 5 introduces the econometric method, sections 6 and 7 discuss the empirical results, and section 8 highlights some of the main findings and possible future extensions of the work.

2. LITERATURE REVIEW

National innovation systems (NIS) are key drivers of economic growth and competitiveness. The study of NIS focuses on the main components of the system, such as private firms and public organizations, and investigates their mutual interactions as well as their relationships with the social and institutional framework in which the system is embedded (Lundvall, 2007).

The study of the *dynamics* and *evolution* of national systems provided one of the original motivations for the development of this approach. However, the focus on long-run dynamics and historical transformations was mainly developed in a branch of qualitative and historical case studies research (Nelson, 1993; Edquist and Hommen, 2008; Lundvall et al., 2009). By contrast, quantitative and modelling oriented contributions in this field have not yet provided a consistent and fully-fledged analysis of the complex set of factors that drive the dynamics of national systems in the long-run. This is partly due to the lack of a strong analytical framework able to describe the dynamics of NIS as complex evolving systems, and, correspondingly, it is also related to the lack of quantitative empirical tools (data, indicators and methods) that would make it possible to carry out an empirical investigation of such a theory of complex innovation system dynamics.

Important branches of the literature on innovation and economic growth do however provide key theoretical insights and empirical results on some of the main factors that are relevant to describe the long-run evolution of a national innovation system and its relationships to economic performance.

The first is new growth theory, and in particular Romer's (1990) idea-based growth model. This seminal work points out that the growth of a country's knowledge stock, its innovation dynamics, depends on a few key factors such as the size of its research sector as well as the productivity of the latter, which defines the extent to which innovation input and investments are turned into innovation output and economic performance. The concept of *innovative capability*, despite its highly stylized character, defines a first key dimension to study the evolution of NIS. Furman, Porter and Stern

(2002) define it as “the ability of a country to produce and commercialize a flow of innovative technology over the long term” (2002: 899).[1]

Romer’s (1990) model has been highly influential and has inspired the development of an entire class of idea-based new growth models. Nevertheless, empirical analyses of this type of model have mostly focused on the main prediction of its reduced form on the relationship between the size of the research sector and the country’s economic performance, and have, by contrast, typically neglected the investigation of its structural form, and specifically of the determinants of a country’s innovation dynamics and its transformations in the long-run (Castellacci, 2007).

Secondly, a large modelling and empirical literature has focused on the process of international knowledge diffusion and investigated the set of factors that affect the extent to which a national system is able to grow and catch up with the technological frontier by means of international learning and imitation activities. This approach was originally inspired by the work of economic historians such as Landes, Gerschenkron and Abramovitz, which, by focusing on historical case studies of the technological catch up process, pointed out that international knowledge diffusion is a complex and demanding process, and investigated the set of factors that are necessary for imitation-based technological development. This set of factors, in a nutshell, defines the *absorptive capacity* of a country.

According to Abramovitz (1986; 1994), absorptive capacity may refer to both techno-economic characteristics (*technological congruence*) such as “the resource availabilities, factor supplies, technological capabilities, market scales and consumer demands”, as well as socio-institutional conditions (*social capability*) like “countries’ level of education and technical competence, the commercial, industrial and financial institutions that bear on their abilities to finance and operate modern, large-scale business, and the political and social characteristics that influence the risks, the incentives and the personal rewards of economic activity” (Abramovitz, 1994: 24).

Inspired by these original insights, theoretical models in the technology-gap (or distance-to-frontier) tradition have developed a more stylized notion of absorptive capacity, and often focused on human capital as the single most important factor

[1] Furman, Porter and Stern (2002), more precisely, used the expression “national innovative capacity”, instead of the term *innovative capability* that is adopted throughout this paper.

shaping a country's capability to imitate and absorb foreign advanced technologies (Nelson and Phelps, 1966; Verspagen, 1991; Benhabib and Spiegel, 1994; Papageorgiou, 2002; Stokke, 2004).

On the other hand, empirical works in this tradition have typically followed a growth-regression econometric approach, and shown the large variety of factors, of both a techno-economic and socio-institutional nature, that affect convergence and divergence patterns in broad cross-country samples (e.g. Fagerberg and Verspagen, 2002; Fagerberg et al., 2007; Fagerberg and Srholec, 2008; Castellacci, 2008; Lee and Kim, 2009).[2] Most of this empirical research, however, has so far focused on the cross-country comparative aspect ("why growth rates differ") and mostly neglected the time series dimension and the analysis of the dynamics of the technological catch up and economic growth process over time.

A more explicit investigation of the dynamic dimension is provided by a recent class of theoretical models in the distance-to-frontier tradition, which point out that the existence of threshold externalities may explain the cumulative nature of the process of technological accumulation and economic growth in the long-run. Specifically, threshold externalities models are based on the idea that the interactions between countries' R&D and innovation activities, on the one hand, and human capital and imitation activities, on the other, may generate different country clubs, and explain the transition of each national system from one stage of development to a more advanced one (Azariadis and Drazen, 1990; Howitt, 2000; Galor and Weil, 2000; Galor, 2005; Howitt and Mayer-Foulkes, 2005; Acemoglu et al., 2006; Iacopetta, 2010). In particular, these models argue that the key to explain countries' shift from an *imitation* to an *innovation* stage is the return to investment in human capital: this tends to grow during the development process, thus making it progressively more profitable for individuals to invest in education and, hence, sustaining further technological progress in the future. Despite its highly stylized character, this idea provides an important step forward in the theory of innovation and growth, since it implicitly points out the two-way interactive relationship that links the dynamics of innovation and absorptive capacity in the long-run.

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[2] See overview of this empirical literature in Fagerberg (1994) and Gong and Keller (2004).

This brief review of the literature leads to point out four major challenges ahead for research in this field. These four aspects represent the main motivations for the analysis carried out in the present paper.

1. *A time series perspective*. Most empirical research on national innovation systems and economic growth has so far adopted an explicitly comparative perspective – focusing on cross-country differences in technological capabilities – and largely neglected the time series dimension. The investigation of the dynamics and time series properties of the long-run evolution of national innovation systems is a key challenge ahead in the field, which should complement and inform cross-country comparative research.

2. *The dynamics and determinants of innovative capability*. An exceptional amount of research has been devoted to the study of the determinants of GDP and income per capita, and in particular to the role of innovation for the growth and development process. By contrast, only a limited number of studies have empirically investigated the dynamics of innovative capability over time and the main factors that may explain its long-run evolution (Furman, Porter and Stern, 2002; Varsakelis, 2006; Filippetti and Peyrache, 2011). This is a crucial task for future research in this field.

3. *The dynamics and multifaceted nature of absorptive capacity*. Although the concept of absorptive capacity was initially meant to define a broad and multidimensional set of capabilities, modelling and empirical exercises have often provided a rather stylized and simplified operationalization of it. As recently argued by Archibugi and Coco (2004), Godinho et al. (2006) and Fagerberg and Srholec (2008), it is indeed important to adopt a multifaceted description and measurement of the various factors that contribute to shape the absorptive capacity of nations. Further, it is crucial to investigate the dynamics and long-run evolution of absorptive capacity, rather than simply regarding it as a set of exogenous control factors in cross-country growth regression exercises.

4. *The coevolution between innovative capability and absorptive capacity*. In the cross-country applied growth literature, innovation and imitation have typically been regarded as two distinct (albeit related) drivers of growth and catching up. More precisely, while it is widely acknowledged that R&D and innovation investments may

also increase the imitation ability of nations, the opposite causation mechanism – linking countries' absorptive capacity to their innovation capability – has not been investigated to the same extent. This paper argues that, adopting a time series perspective, it is important to investigate the existence of a two-way relationship (coevolution) that links together the dynamics of these dimensions in the long run.

3. MODEL AND HYPOTHESES

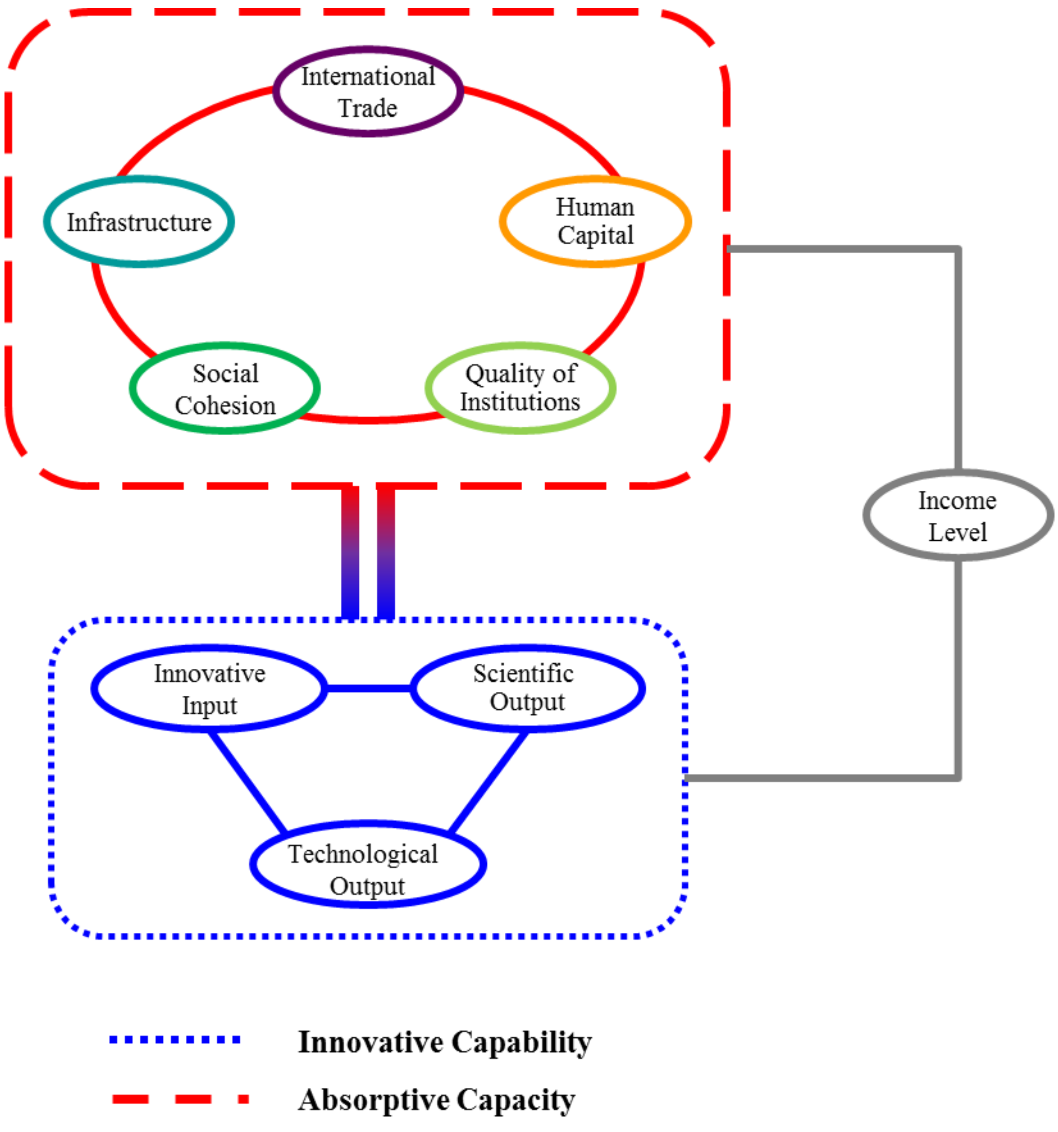
This section provides the theoretical framework for our empirical analysis of the coevolution between countries' innovative capability and absorptive capacity. The model focuses on the time series dimension of the process of technological change, i.e. its objective is to provide a foundation for the empirical analysis of the *dynamics* of the national innovation system for a given country, rather than comparing the characteristics of different national systems in a static sense.

First, since many different factors contribute to define the innovative capability and absorptive capacity of nations, it is important to highlight the key set of variables on which our model will focus. Figure 1 shows our theoretical framework. The diagram provides a stylized representation of the main dimensions that define the dynamics of a national innovation system.

I. Innovative capability:

- *Innovative input*. This represents the total efforts and investments carried out by each country for R&D and innovative activities (i.e. its innovation intensity).
- *Scientific output*. It denotes the result of research and innovation activities carried out by the public S&T system (e.g. scientific and technical publications).
- *Technological output*. This is the total output of technological and innovative activities carried out by private firms (e.g. patents, new products).

Figure 5.1 - Theoretical framework: The coevolution of innovative capability and absorptive capacity



II. Absorptive capacity:

- *International trade*. This represents the openness of the national system. The more open the system, the more capable to imitate foreign advanced knowledge (Gong and Keller, 2004).
- *Human capital*. This is the key absorptive capacity variable typically emphasized by technology-gap models (see references in section 2).

- *Infrastructures*. A greater level and quality of infrastructures (e.g. network, transportation, distribution) increases the country's capability to absorb, adopt and implement foreign advanced technologies (Esfahani and Ramirez, 2003; Freeman, 2004; Castellacci, 2011).
- *Quality of institutions and governance system*. A better and more efficient governance system tends to increase the country's commitment to technological upgrading as well as its imitation capability (Varsakelis, 2006; Fagerberg and Srholec, 2008).
- *Social cohesion and economic inequality*. A national system with a greater level of social cohesion and within-country income equality is in general characterized by a higher degree of trust and knowledge sharing, hence supporting the pace of diffusion and adoption of advanced knowledge within the country (Arocena and Sutz, 2003; Weinhold and Nair-Reichert, 2009).

III. Income level:

- *GDP per capita*. It defines the overall level of economic and social development of a country. Although our model focuses on the interactions between innovative capability and absorptive capacity, it is however important to include countries' income level in our theoretical framework. It is in fact reasonable to assume that both the innovative capability and the absorptive capacity dimensions are linked directly to the growth of GDP per capita. On the one hand, technological dynamics fosters income per capita growth, as well documented in the literature. On the other hand, GDP per capita growth may further sustain the process of capability building and technological accumulation. We therefore include countries' GDP per capita as an important control variable in our model.

In econometric terms, we represent the dynamics of the national system as a *vector autoregression model (VAR)*. Define **Y** as the vector that represents the National Innovations System components, namely the innovative capability variables listed above [Y_1; Y_2; Y_3], the absorptive capacity variables [Y_4; Y_5; Y_6; Y_7; Y_8] plus the GDP per capita (Y_9), and **ε** a vector of nonautocorrelated disturbances. Then, the VAR model of order *p* is defined as:

$$\mathbf{Y}_t = \boldsymbol{\mu} + \boldsymbol{\Omega}_1 \mathbf{Y}_{t-1} + \ldots. + \boldsymbol{\Omega}_p \mathbf{Y}_{t-p} + \boldsymbol{\varepsilon}_t \qquad (1)$$

This is a system of *m* equations, each of which models a given time series variable Y_{mt} as a function of the lagged values of all the variables in the vector **Y**and the disturbance term. In other words, the m[th] equation of the VAR system is given by:

$$Y_{mt} = \mu_m + \sum_j (\boldsymbol{\Omega}_j)_{m1} Y_{1,t-j} + \sum_j (\boldsymbol{\Omega}_j)_{m2} Y_{2,t-j} + \ldots. + \sum_j (\boldsymbol{\Omega}_j)_{mM} Y_{M,t-j} + \varepsilon_{mt} \qquad (2)$$

Given this VAR representation, we may then point out the three general propositions that will be investigated in our empirical analysis.

Proposition 1. The internal dynamics of innovative capability.

The dynamics of the innovative capability is driven by the coevolution of the three factors that define it, namely innovative input, scientific output and technological output.

By coevolution we mean that we expect to find a set of two-way relationships linking together the first three variables in the vector **Y** of our VAR (p) model. Specifically, and in line with the innovation literature, we argue that: (a) the innovative input and intensity is expected to affect the technological and scientific output (*input-output mechanisms*); in turn, (b) the technological and scientific output will have feedback effects on the dynamics of innovative input (*cumulativeness of technological progress*). While these two relationships are well-known and widely acknowledged in the field, the novelty of this proposition is that we specifically postulate the existence of a two-way self-sustaining dynamic relationship (coevolution) that drives the growth of innovative capability over time.

Proposition 2. The internal dynamics of absorptive capacity.

The dynamics of the absorptive capacity is driven by the coevolution of the five dimensions that define it.

In the VAR representation, this proposition implies that we expect the following five components of the vector **Y** to be linked together by a set of two-way dynamic relationships. Many such relationships have previously been investigated in different branches of research and particularly in the applied growth and development literature, which has extensively documented the relationships between some of these variables (international trade, human capital, infrastructures, quality of institutions and governance system, social cohesion and economic inequality). Our specific point here is to emphasize the joint dynamics of these factors, i.e. to investigate the process of coevolution (two-way dynamic relationships) that drives the growth of absorptive capacity over time.

Proposition 3. The coevolution between innovative capability and absorptive capacity.

Innovative capability and absorptive capacity coevolve over time, i.e. these two dimensions are linked together by a set of two-way dynamic relationships.

This is the central proposition of our theoretical framework. In terms of our VAR (p) model, this means that we expect the three first variables in the vector **Y** (innovative capability) to be linked to the following five components of the vector **Y** (absorptive capacity) by a set of two-way dynamic relationships. The intuition is briefly pointed out as follows.

- On the one hand, innovation activity and results may sustain the growth of absorptive capacity over time. The reason is twofold. First, R&D investments and innovative efforts may increase the agent's (country's) capabilities to imitate foreign advanced technologies (*learning and capability effect*). Secondly, the achievement of technological performance and commercial success tends to increase the country's pool of financial resources, some of which will be reinvested to increase its level of infrastructure, human capital or its institutional quality – hence raising the country's absorptive capacity in the future (*success-breeds-success effect*).
- On the other hand, the growth of absorptive capacity may in turn boost innovation dynamics over time. The reason is twofold. First, an increase in absorptive capacity, and in particular human capital, infrastructures and openness, is likely to strengthen the productivity of the country's R&D sector (*productivity effect*). Secondly, the development of the country's institutional and governance quality, which is an inherent manifestation of the process of upgrading of absorptive capacity, may systematically increase the amount of

resources that the system will devote to R&D activities, e.g. because it enhances the country's policy commitment to an increased level of innovation intensity (*policy effect*).

4. DATA AND INDICATORS

Our empirical analysis makes use of the CANA database, a newly released cross-country panel dataset containing a large number of indicators for the period 1980-2007 (Castellacci and Natera, 2011). The novelty of the database is that it provides full information for the whole set of country-year observations, i.e. it contains no missing value. The dataset has been constructed by combining together indicators available from a number of existing cross-country data sources, and then applying the method of multiple imputation recently proposed by Honaker and King (2010). The CANA database, along with the sources and definitions of the indicators and a description of the construction methodology, can be downloaded at the web address: http://cana.grinei.es.

Specifically, this paper focuses on a sample of 87 countries (listed in Appendix 1) and a set of nine selected indicators, which are pointed out as follows.

I. Innovative capability:

- *Innovative input*. (1) Total R&D expenditures as a percentage of GDP; (2) Public R&D expenditures as a percentage of GDP.
- *Scientific output.* Number of scientific and technical journal articles per million people.
- *Technological output.* Number of patents registered at the US Patent and Trademark Office per million people.

II. Absorptive capacity:

- *International trade.* (1) Openness: (Export + Import) / GDP; (2) Export of high-tech products as a percentage of GDP.

- *Human capital.* (1) Tertiary education: tertiary enrolment ratio; (2) Secondary education: secondary enrolment ratio.

- *Infrastructures.* (1) Electricity: number of kilowatt of electricity consumed per hour per capita; (2) Telephony: number of fixed and mobile phone subscribers per 1000 inhabitants.

- *Quality of institutions and governance system*. Corruption Perception Index (Transparency International), ranging from 0 (High Corruption) to 10 (Low Corruption).

- *Social cohesion and economic inequality*. Gini Index (within-country income inequalities).

III. Income level:

- *GDP per capita.* purchasing power parity.[3]

5. ECONOMETRIC METHOD

Panel cointegration analysis is a recent field in econometrics that extends time series cointegration analysis to a panel data setting. The approach has recently found an increasing number of applications in different fields of economics, although it has not been widely used within the field of innovation and growth. The cointegration methodology has an inherent ability to uncover dynamic relationships among variables that coevolve over time, and we therefore argue that it constitutes a natural platform for investigating the long-run dynamics of national systems of innovation.[4]

In a time series context, the key insight of the cointegration approach is to analyse the relationships between non-stationary time series by looking both at their long-run

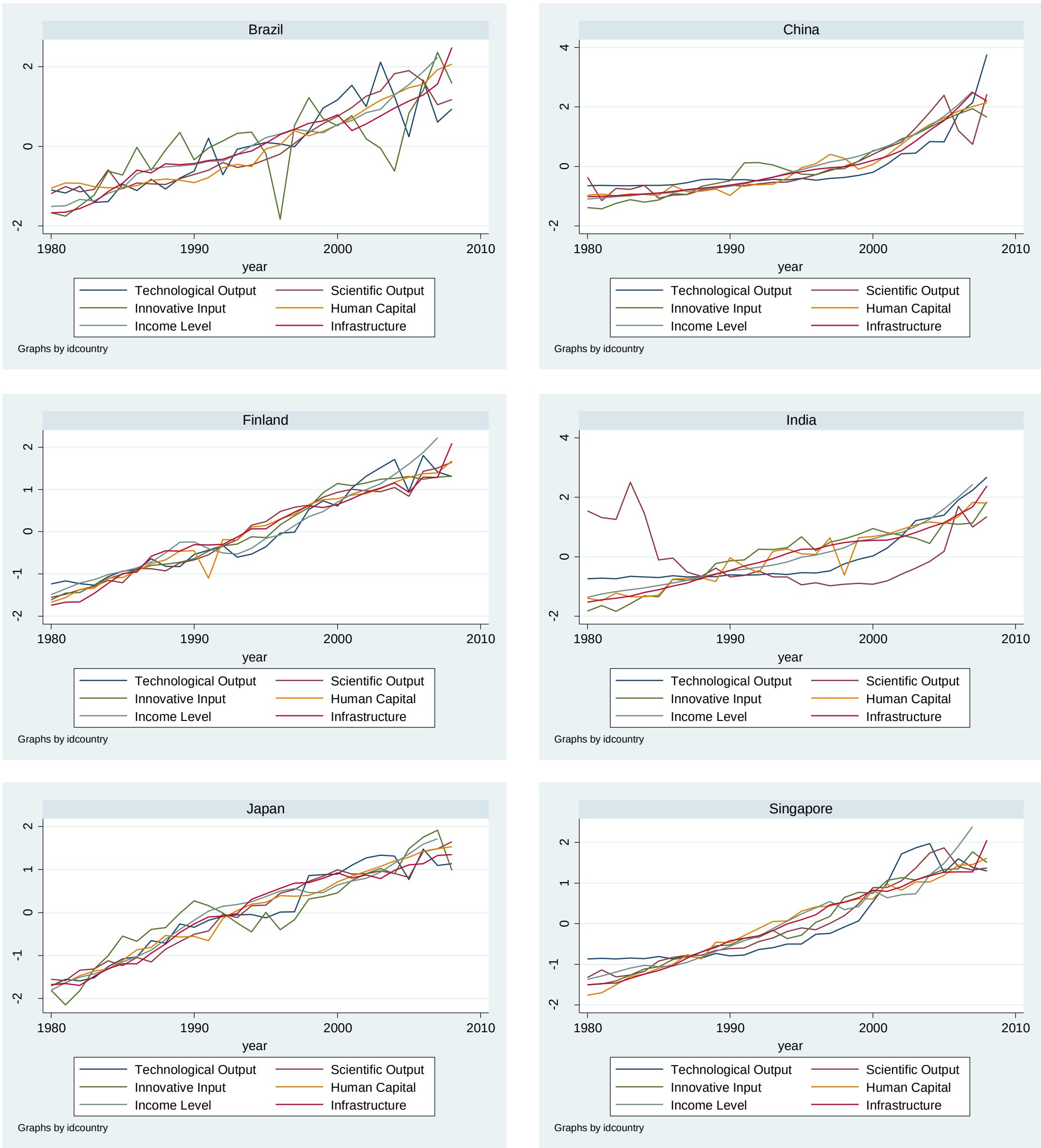
[3] As explained in section 7, in some additional model specifications we have introduced as main control factor a variable measuring the health conditions of the population instead of GDP per capita. The health variable we have used is the life expectancy of the population (measured in number of years; see table 5).

[4] An important antecedent of our approach is the work of Foster (1991), which already two decades ago discussed the suitability of time series cointegration analysis and error correction models for evolutionary analyses of technological change and economic growth. Recent applications of the panel cointegration approach have been presented, among others, in the field of energy economics (Costantini and Martini, 2010) and trade and FDI (Krammer, 2010).

equilibrium relationship as well as the process of short-run adjustment (Engle and Granger, 1987). More precisely, if two or more variables are integrated of the same order (e.g. they are both I(1) series), there might exist a linear combination of them whose residuals are stationary – in other words the two series are not stationary but one (or more) linear combination of them is. If this is the case, the variables are said to be *cointegrated*. To illustrate, figure 2 plots the time path of some of the indicators of innovative capability and absorptive capacity described in the previous section for a few selected countries over the period 1980-2007.[5] It is clear from the figure that most of these variables have a common time trend, and it is therefore reasonable to investigate the hypothesis that they coevolve over time linked by some structural long-term relationship (as argued in the three propositions presented in section 3).

[5] Notice that for the construction of this figure the indicators have been standardized, so that variables measured on a different scale can be reported in the same graph.

Figure 5.2 - Time series of the main variables (standardized) for six selected countries



The extension of this time series approach to a panel data context is relatively recent (see overview in Breitung and Pesaran, 2008). The use of panel datasets, by increasing substantially the number of observations in the sample, makes it possible to strengthen the power of cointegration tests. Specifically, the empirical methodology adopted in this paper consists of the following *four steps*. First, since cointegration analysis is useful to study the relationships between time series variables that have the same order of integration, we start by carrying out a battery of *panel unit root tests* (Levin, Lin and Chu; Breitung; Im, Pesaran and Shin; augmented Dickey-Fuller; Phillips-Perron), in order to verify if our variables are stationary after removing the time trend by first-differencing (i.e. they are I(1) series).

Secondly, we investigate the existence of a long-run equilibrium relationship between our variables of interest by means of the *Pedroni cointegration test*, which adopts ADF and PP-like specifications and extends them to a panel dataset by looking at both the within- and between-dimension of the panel. We repeat both the first and the second step for 10 different lags (from 1 to 10), as a robust and sensitivity analysis to the lag specification that it is used for each test . If the Pedroni test results are significant, this means that there exists at least one linear combination of our non-stationary variables that has stationary residuals, or in simpler terms that there exists a long-run equilibrium relationship among the variables. The nature, strength and direction of this long-run relationship are then investigated in the third and fourth steps, which represent the crucial phase of our empirical analysis.

The third step is the estimation of a *panel vector error correction model* (VECM). This model is useful because it estimates both the long-run equilibrium relationship among the variables as well as the short-run adjustment process by which they respond to external shocks that deviate from their long-run equilibrium path.

In order to explain the main idea and intuition of this model, let us first derive it in a time series bivariate context, and then extend it to a panel multivariate setting. Take first a simplified version of our VAR (p) model specified in equation 1 (section 3), i.e. only considering a vector Z_t composed by two variables, Z_{1t} and Z_{2t} and two lags (this may also be seen as an autoregressive distributed lag model, ARDL (2, 2)). By rearranging some of the terms, the ARDL (2, 2) model can be written in the error-correction form:

$$\Delta Z_t = \alpha\beta\, Z_{t-1} + \Gamma \Delta Z_{t-1} + \boldsymbol{\mu}_o + \varepsilon_t \qquad (4)$$

In this specification, the parameter β measures the long-term equilibrium relationship between the variables, whereas the term αβ is the so-called equilibrium error of the model, i.e. the extent to which the variables respond in the short-run to a deviation from their long-run path (the vector of parameters α thus measures the speed of adjustment that the system follows in the short term). Put it simply, in the context of our study, the parameter β measures the long-term relationship between innovative capability and absorptive capacity, while α gives an indication of how rapidly (or slowly) each variable goes back to its long-run structural path in the presence of an external shock (e.g. a policy change). Γ collects the transitory effects between variables, which are crucial to determine the minimum interaction level required to verify systemic relationships.

Let us now extend this ECM formulation to the more general case that is considered in this paper, i.e. where we have a vector **Y** that combines the innovation capability variables withof the absorptive capacity variables, *p* lags, and *n* countries. The panel version of our VAR (p) model in equation 1 (section 3) is:

$$\mathbf{Y}_{i,t} = \boldsymbol{\mu}_i + \boldsymbol{\Phi}_1 \mathbf{Y}_{i,t-1} + \ldots.. + \boldsymbol{\Phi}_p \mathbf{Y}_{i,t-p} + \boldsymbol{\varepsilon}_{it} \quad (5)$$

The system can be rewritten in its panel VECM specification as:

$$\Delta\mathbf{Y}_{i,t} = \boldsymbol{\mu}_i + \boldsymbol{\Pi}\, \mathbf{Y}_{i,t-1} + \sum_j \boldsymbol{\Gamma}_j\, \Delta\mathbf{Y}_{i,t-i} + \boldsymbol{\varepsilon}_{it} \quad (6)$$

The system of equation represented by (6) is the one that we will estimate in the following section. As explained above, the parameters in $\boldsymbol{\Gamma}_j$ measure the transitory effects, whereas the set of parameters **Π** measure the short-run adjustment of each variable to its long-run equilibrium.

Finally, the fourth and final step of our methodology is to investigate the *direction of causality*, i.e. to analyse whether the long-term relationship identified by the VECM model between each pair of variables Y_{it} and Y_{jt} is a uni-directional type of causality ($Y_{it} \rightarrow Y_{jt}$, or $Y_{it} \leftarrow Y_{jt}$) or rather bi-directional ($Y_{it} \leftrightarrow Y_{jt}$). This is done by making use of *Granger causality analysis*, i.e. by carrying out, for each pair of variables included in the VECM model, a panel Granger block exogeneity test. Since the results of Granger causality analysis are typically quite sensitive to the lag specification that is adopted, for each pair of variables we carry out block exogeneity tests for 10 different lags (from 1 to 10), and, as explained in the next section, we only consider reliable those results for which we obtain significant evidence of a causal relationship for at least five of the 10 lag specifications. Also, we decided to apply this test to the elements in the Γ matrix since this is the critical condition to verify (Granger) causality in the system.

To summarize, this four-step methodology provides an attempt to operationalize the concept of *coevolution* within a panel cointegration context. In our empirical analysis, the coevolution between two variables Y_t and X_t is meant to be characterized by two aspects: (1) there exists a long-run relationship that ties together the dynamics of these variables (*cointegration*); (2) there exist two-way causal relationships between them (*Granger bidirectional causality*).

6. EMPIRICAL RESULTS

Table 1 presents the results of a set of panel unit root tests (Levn, Lin & Chu; Breitung; Im, Pesaran & Shin; ADF; PP). Each test is repeated for all the nine variables included in the model and for ten different lags. Table 1 reports the results for the 5-lag specification, whereas the Online Appendix (available at: http://dynamicsnis.grinei.es) reports the results for all other lag specifications, plus a large battery of additional results (see section 7). The panel unit root test results clearly indicate that all variables in our panel of countries are I(1) series (trend stationary), thus confirming that it is appropriate to investigate the existence of cointegration relationships among them.

Next, the second step of our analysis is to carry out a set of Pedroni cointegration tests, which analyse the cointegration hypothesis for these nine variables in our panel of countries Table 2 presents the results, which provide strong evidence suggesting the existence of one (or more) long-run relationships (cointegration) linking together our set of innovative capability and absorptive capacity variables.

As explained in the previous section, the crucial steps of our empirical methodology are the third and the fourth, where we estimate this long-term relationship and then analyse the direction of causality linking each pair of variables. The third step is the estimation of the vector correction model (VECM) specified in equation (6) (see derivation and intuition of this model in the previous section). The results of VECM estimations are presented in table 3. Notice that table 3 reports the results for a model with a 5-lag structure, although we have in addition run the same exercise for ten different lag specifications (from 1 to 10) in order to check for the robustness of the results[6]. The extended version of this table, reporting results for all the lag specifications, is available in the Online Appendix.

The results in table 3 refer to our basic model specification, which includes the following seven variables (indicators used specified between parentheses): (1) technological ouput (patents); (2) scientific output (articles); (3) innovative input (total R&D as a share of GDP); (4) human capital (tertiary education); (5) infrastructures (electricity); (6) International trade (openness); (7) income level (GDP per capita). We label this basic model specification "model 1", to distinguish it from the other six model specifications that will be discussed in section 7.

[6] Since the Pedroni's test for Panel Cointegration verifies that there exists at least one cointegration equation, we decided to set rank to 1 so we do not impose any other assumption. This criterion is also convenient for comparative purposes (between different lags and different model specifications). Nevertheless, we believe that further investigation on the number of cointegration relationships should be carried out, since this could affect the subsequent results from the VECM estimations and Granger Causality tests.

Table 5.2 - Panel unit root tests (5-lag specification)

Tests	Technological Output	Scientific Output	Innovative Input	Human Capital	Infrastructure	International Trade	Social Cohesion	Quality of Institutions	Income Level
LLC	-28.7022 ***	-38.9816 ***	-29.0885 ***	-39.3175 ***	-11.0755 ***	-33.238 ***	-41.3525 ***	-28.0696 ***	-15.3902 ***
Breit	-9.33763 ***	-15.5619 ***	-8.41635 ***	-20.6934 ***	8.84453	-17.8781 ***	-24.1482 ***	-9.59712 ***	-4.01633 ***
IPS	-41.2368 ***	-44.4981 ***	-40.0511 ***	-45.6103 ***	-23.39 ***	-34.1429 ***	-49.0434 ***	-36.7005 ***	-14.0725 ***
ADF	1757.5 ***	1789.77 ***	1773.1 ***	1830.74 ***	929.127 ***	1242.39 ***	2065.67 ***	1364.07 ***	567.38 ***
PP	11298.8 ***	6371.34 ***	6026.4 ***	6094.23 ***	1402.72 ***	2257.17 ***	10527 ***	3259.69 ***	565.105 ***

LLC: Levin, Lin & Chu t; Breit: Breitung t-stat.; IPS: Im, Pesaran & Shin W-stat.. Significance levels: *** 1%; ** 5%; * 10%.

Table 5.2 - Pedroni cointegration test

	Max lags	Panel[1]	Group[2]
	10	-11.06791 ***	-20.61702 ***
	9	-12.21187 ***	-20.03907 ***
	8	-11.52201 ***	-21.37576 ***
	7	-11.62827 ***	-20.28275 ***
	6	-12.47312 ***	-21.68366 ***
ADF tests	5	-10.98558 ***	-21.0046 ***
	4	-11.08149 ***	-21.32561 ***
	3	-9.506939 ***	-21.28846 ***
	2	-12.83119 ***	-22.65517 ***
	1	-13.04044 ***	-22.74456 ***
PP tests	10 to 1	-12.72758 ***	-40.89562 ***

[1] Alternative hypothesis: common AR coefs. (within-dimension)

[2] Alternative hypothesis: individual AR coefs. (between-dimension)
Significance levels: *** 1%; ** 5%; * 10%.

Table 5.3 -Results of the estimation of the panel vector error correction model

(VECM, 5-lag specification)

	Long Run Cointegration Equation	**Short Run Adjustment Coefficients**	**R^2**
Technological output	1	-0.002601 (0.001) [-3.05628]***	0.20306
Scientific output	386541.1 (119074.000) [3.24624]***	-1.21E-08 (0.000) [-4.06239]***	0.22112
Innovative input	-65.9453 (34.354) [-1.91957]*	0.0000472 (0.000) [3.38174]***	0.09114
Human capital	-4.76499 (1.117) [-4.26781]***	-0.000558 (0.000) [-1.34256]	0.09089
Infrastructures	-0.013706 (0.005) [-2.50704]**	-0.079792 (0.039) [-2.06034]**	0.18925
International Trade	-129.5993 (36.459) [-3.55468]***	-0.0000508 (0.000) [-3.73755]***	0.07938
Income Level	-0.031801 (0.005) [-6.95572]***	-0.701127 (0.075) [-9.3097]***	0.55615

Exogenous variables: social cohesion; quality of institutions

Lags included: 5. Observations: 1914

T-statistics in brackets: *** 1% sig. level; ** 5% sig. level; * 10% sig. level.

Before discussing the results, it is important to notice that in all the model specifications presented in this and the next section two of the absorptive capacity variables – social cohesion and quality of institutions – have been included as *exogenous* variables in the model (and hence not reported in the table). The reason for this is that, in a preliminary estimation of the complete form of the model and in a set of Granger causality tests, we noticed that these two factors, while having an impact on the other variables in our model, are not Granger-caused by any of the other factors, and it is therefore reasonable to regard them as exogenous factors in our final VECM specification. It is important to emphasize that the exogeneity of these two variables should not be interpreted as an indication that social and institutional factors are not important in our model, since they do indeed have an effect on the dynamics of the system. Rather, this means that our time series approach is not able to confirm any significant relationship explaining the drivers shaping these two factors over time, hence suggesting that their dynamics cannot simply be explained by the coevolution of innovation and absorptive capacity factors but it does probably entail the complex interplay of other dimensions (social, political, cultural) that are not accounted for in our model.

Turning to the VECM results in table 3, the most important are those presented in the first column under the heading “long run cointegration equation”. These are the set of estimated parameters that identify a structural long-term relationship among our variables of interest, that is, in econometric terms, a linear combination of these variables that produce stationary residuals. The cointegration relationship reported in this column can be written as:

Technological output +386541,1 (scientific output) - 65,94 (innovative input) - 4,76 (human capital) - 0,01 (infrastructures) - 129,6 (international trade) - 0,03 (GDP per capita) = 0

These results indicate the existence of a long-run equilibrium relationship according to which the dynamics of technological ouput (patents) is positively and significantly related to the growth of innovative input (R&D), the evolution of the three endogenous absorptive capacity variables included in this model (human capital, infrastructures, and international trade), as well as the dynamics of GDP per capita.

It is interesting to observe, though, that the estimated long-run relationship between scientific and technological output turns out to have a negative coefficient, which contrasts with the typical expectation of a positive and self-reinforcing dynamics linking together scientific and technological activities (Dosi et al., 2006). One possible explanation for this peculiar finding is that the science-technology relationship may be characterized by different dynamics for countries at different levels of development, i.e. scientific production may be rapidly increased by means of public investments during the catching up phase of economic development, whereas technological output produced by private enterprises may become a more crucial driver of innovation systems as economies shift towards a more advanced development stage. In fact, the estimation results for different groups of countries – to be presented in further details in section 7.2 – indicate that the dynamic relationship between scientific and technological output turns out to be positive for the group of Latin American countries and the one of Eurasian (Former Soviet) economies. Hence, it is important to take this specific result on the science-technology relationship with caution, since it seems to be valid for some country groups but not for others.

The next column in table 3 reports the short-run adjustment coefficients, which confirm that most of the variables, when subject to external shocks (e.g. a policy change), tend to gradually readjust and go back to the long-term path identified by the cointegration equation. The only exception seems to be the innovative input variable, which shows a slight tendency to deviate permanently from its long-run path when subject to external shocks.

The fourth and final step of our analysis is to investigate the *direction of causality*, i.e. to analyse, for each pair of variables included in the VECM model, whether they are related through a uni-directional type of causality ($\Delta Y_{it} \rightarrow \Delta Y_{jt}$, or $\Delta Y_{it} \leftarrow \Delta Y_{jt}$) or rather by a bi-directional relationships ($\Delta Y_{it} \leftrightarrow \Delta Y_{jt}$). In the latter case, we conclude that there is a coevolution of the two variables over time.

Table 4 presents the results of Granger block exogeneity tests based on the VECM model results discussed above here. The Granger tests have been repeated for ten different lags in order to control for variability of the results: only when at least five of the different lag specifications turn out to have significant results, we conclude that there is robust evidence of Granger causality (see last column on the right-hand side of the table). The table is divided in four parts: the first three refer to the three propositions pointed out by our theoretical framework, whereas the fourth part refers to the interactions between our control variable, GDP per capita, and the innovative capability and absorptive capacity dimensions.

Further, to provide a more intuitive and more accessible presentation of these patterns, figure 3 shows a diagram that summarizes the main results of this causality analysis. The diagram has the same structure as our theoretical model (see figure 1, section 3), and it adds a set of arrows to show the causal relationship linking together each pair of variables (in this diagram, an arrow pointing in two (one) directions indicates evidence of a robust two-way (one-way) Granger causality relationship).

Proposition 1. The internal dynamics of innovative capability.

The first part of table 4 reports Granger block exogeneity tests referring only to the three innovative capability variables. These results support the hypothesis that the link between input and output of the innovative process is a two-way relationship. On the one hand, the growth of R&D and innovative investments drives the dynamics of both scientific and technological output (*input-output mechanisms*). On the other hand, in turn, the growth of technological output sustains further R&D and innovative investments over time (*cumulativeness of technological progress*). It is this two-way self-sustaining relationship that explains the dynamics of innovation at the macro level. In short, these Granger test results provide empirical support for the first proposition formulated in section 3, and show that the internal dynamics of innovative capability is driven by the coevolution of the three main factors that define it: innovative input, scientific output and technological output.

Proposition 2. The internal dynamics of absorptive capacity.

The second panel of the table focuses on the three absorptive capacity variables (i.e. those included as endogenous factors in the final specification of our VECM model): infrastructures, human capital and international trade. The Granger causality test results are in most cases significant and provide general support for the hypothesis that the dynamics of the absorptive capacity is driven by the coevolution of the dimensions that define it. More precisely, we find support for the hypothesis of bi-directional causality for the variables measuring infrastructures and international trade, as shown in the bottom part of this table, i.e. these two factors coevolve together and support each other's dynamics over time. Interestingly, we do not find an analogous result for the human capital (tertiary education) variable. This, in fact, does not affect directly the growth of infrastructures and international trade, but it influences them indirectly by sustaining income per capita growth (which in turn feeds back on the other two absorptive capacity variables).

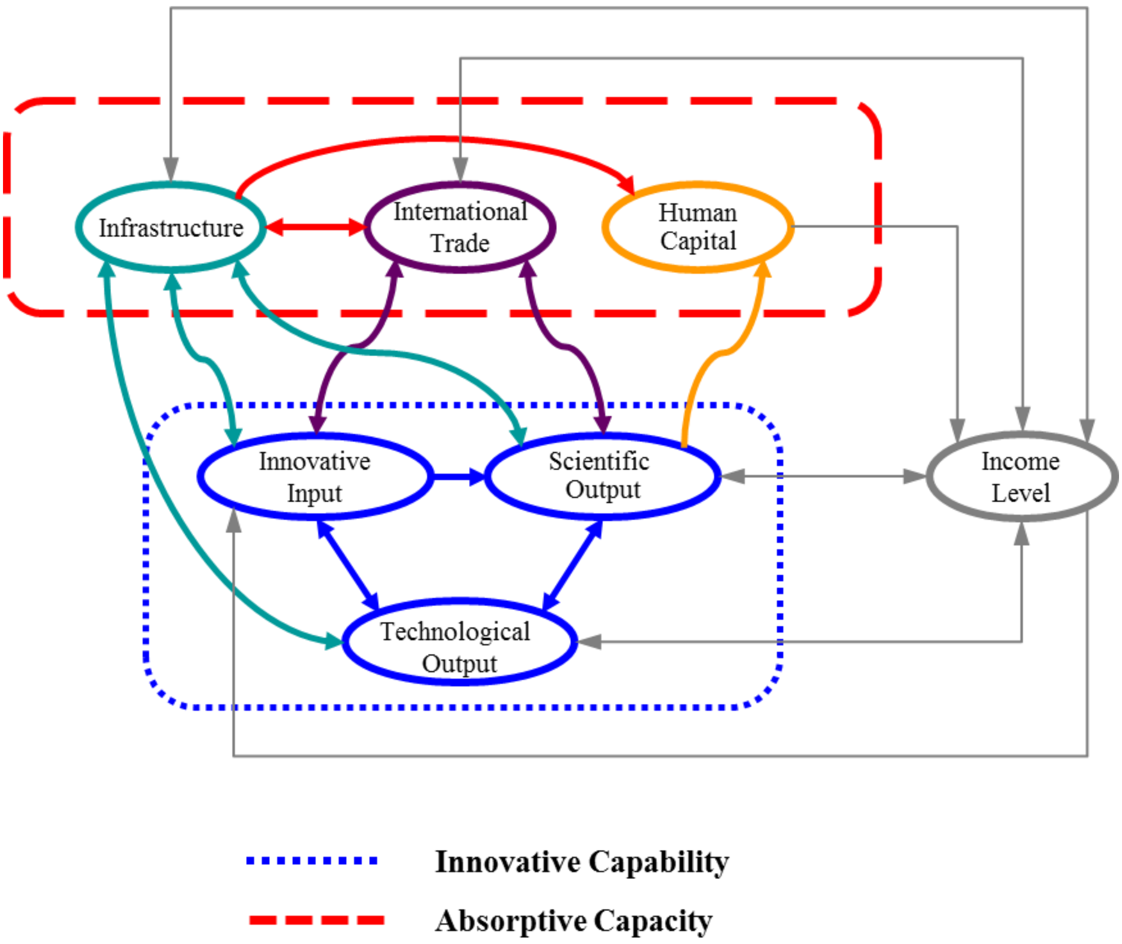
Proposition 3. The coevolution between innovative capability and absorptive capacity.

The third part of table 3 shifts the focus to the analysis of the mutual relationships between the innovative capability and the absorptive capacity variables. On the whole, the general result emerging from this table provides support for our third proposition, and indicates that innovative capability and absorptive capacity are linked together by a set of two-way dynamic relationships, i.e. they coevolve over time.

A more specific overview of the results points out the following patterns. (1) Technological output is linked by a two-way dynamic relationship to infrastructures, but it is not directly related to human capital and international trade. (2) Scientific output coevolves with infrastructures and international trade, and has a one-way causal effect on human capital dynamics. (3) Innovative input coevolves with infrastructures and international trade, but it has no direct relationship to the human capital variable. (4) Similarly to what noticed in relation to proposition 2 above, the human capital (tertiary education) variable does not have any significant *direct* effect on the three innovative capability variables, but it rather plays an *indirect* role through its impacts on GDP per capita dynamics (which in turn feeds back and sustains the dynamics of all three innovative capability variables). The direct link between human capital and income per capita growth is in line with the findings of Lee and Kim (2009).

Figure 5.3 - Summary of Granger test results: Causal relationships and the coevolution of innovative capability and absorptive capacity.

Basic model specification (model 1)



Last, the fourth panel of table 4 reports the results of Granger tests of the relationships between GDP per capita (our main control variable), on the one hand, and the innovative capability and absorptive capacity dimensions, on the other. These results highlight the important role of GDP per capita as an enabling factor in the dynamics of national innovation systems. Income per capita is in fact linked by two-way dynamic relationships to both innovative capability (technological and scientific output) and absorptive capacity (infrastructures and international trade). In other words, income per capita is fostered by technological dynamics (as well documented in the literature), but at the same time its growth enables the further development of absorptive capacity and innovative capabilities over time.

In a nutshell, a grand summary of our empirical results indicates that, over time, innovative capability and absorptive capacity factors are linked by a set of long-term structural relationships. Specifically, in our panel of countries for the period 1980-2007, the dynamics of national systems of innovation is driven by the coevolution of the three innovative capability variables, on the one hand, and the absorptive capacity variables measuring infrastructures and international trade, on the other. Human capital, the factor typically emphasized by most previous technology-gap and imitation-based growth models, coevolves with the rest of the system, but it turns out to have an indirect effect on the dynamics of the NIS by sustaining the growth of GDP per capita and the country’s absorptive capacity.

Table 5.4 - The direction of causality: Results of Granger block exogeneity tests (based on the panel VECM multivariate model).

Basic model specification (model 1)

I. The internal dynamics of Innovative Capability

Causal relationships	Lags										Granger Causality
	1	2	3	4	5	6	7	8	9	10	
Innovative Input → Technological Output	21.32004 ***	21.73125 ***	22.39227 ***	36.12588 ***	37.01912 ***	42.67967 ***	34.48828 ***	19.75859 **	23.74301 ***	28.16435 ***	Yes
Technological Output → Innovative Input	11.87908 ***	16.25183 ***	13.1056 ***	17.41765 ***	15.47013 ***	16.44623 **	23.6052 ***	33.8762 ***	38.81754 ***	38.73672 ***	Yes
Innovative Input → Scientific Output	0.036102	1.870124	2.940938	11.91267 **	9.281638 *	18.26053 ***	26.10059 ***	20.19472 ***	15.38625 *	14.68185	Yes
Scientific Output → Innovative Input	0.002631	1.066683	1.465886	3.735813	7.63818	7.23319	12.12452 *	14.57777 *	14.84209 *	13.01383	No
Scientific Output → Technological Output	0.203064	0.083062	32.55151 ***	45.22873 ***	33.77283 ***	33.54489 ***	12.23937 *	15.94935 **	15.30795 *	28.15139 ***	Yes
Technological Output → Scientific Output	15.53658 ***	15.95845 ***	17.49611 ***	113.3195 ***	105.9351 ***	78.0666 ***	97.8214 ***	81.94637 ***	83.12255 ***	88.63197 ***	Yes

II. The internal dynamics of Absorptive Capacity

Causal relationships	Lags										Granger Causality
	1	2	3	4	5	6	7	8	9	10	
Infrastructures → Human Capital	0.071123	16.69059 ***	11.91476 ***	12.25926 **	18.53966 ***	18.38033 ***	18.61766 ***	21.30625 ***	22.83197 ***	24.86613 ***	Yes
Human Capital → Infrastructures	0.489929	0.55542	1.70809	4.621779	4.476804	7.040358	15.49445 **	16.25869 **	16.48624 *	17.20511 *	No
International Trade → Human Capital	0.979598	1.088267	1.357368	4.87415	4.974863	4.655067	9.309686	8.146294	6.569753	5.834467	No
Human Capital → International Trade	1.139726	0.522869	0.641172	1.221106	5.969001	6.533309	8.430544	9.923185	12.32296	11.94279	No
International Trade → Infrastructures	3.164558 *	6.559222 **	7.853657 **	8.434165 *	9.544925 *	10.58685	10.01712	12.65833	13.1928	10.53763	Yes
Infrastructures → International Trade	0.872482	20.8078 ***	23.40596 ***	28.41551 ***	30.3896 ***	30.51383 ***	38.36711 ***	43.12035 ***	45.83851 ***	49.54764 ***	Yes

Table 5.4 - The direction of causality: Results of Granger block exogeneity tests (based on the panel VECM multivariate model).

Basic model specification (model 1, cont.)

III. The coevolution between Innovative Capability and Absorptive Capacity

Causal relationships	Lags										Granger Causality
	1	2	3	4	5	6	7	8	9	10	
Human Capital → Technological Output	1.572668	3.076869	4.726231	4.442304	5.729322	8.255578	15.90776 **	9.519367	10.19224	11.55729	No
Technological Output → Human Capital	0.116183	0.0868	6.676459 *	5.934444	6.151916	8.323827	7.516473	9.191246	11.14129	11.905	No
Infrastructures → Technological Output	16.20851 ***	8.596289 **	6.534365 *	5.844345	8.777307	7.310487	13.65961 *	19.24805 **	34.44249 ***	39.67968 ***	Yes
Technological Output → Infrastructures	0.132594	2.3588	3.502463	17.66325 ***	45.89948 ***	59.13195 ***	45.58645 ***	44.28836 ***	30.76277 ***	31.45328 ***	Yes
International Trade → Technological Output	0.039558	0.39889	0.319335	0.389719	2.451047	2.443907	4.900947	3.370879	1.954779	2.896627	No
Technological Output → International Trade	0.551105	2.645379	2.127481	2.621795	3.322556	3.769297	5.612922	11.99803	17.22806 **	18.33334 **	No
Human Capital → Scientific Output	2.541942	6.387079 **	7.881292 **	2.786648	6.077008	5.834888	6.55155	12.52758	12.87578	16.22468 *	No
Scientific Output → Human Capital	0.486708	3.178559	11.16304 **	15.63799 ***	12.15303 **	10.22731	9.941398	12.12528	15.10167 *	24.0325 ***	Yes
Infrastructures → Scientific Output	0.04624	3.445991	19.17683 ***	13.07436 **	16.37265 ***	10.90182 *	14.90601 **	31.92184 ***	35.0183 ***	35.6778 ***	Yes
Scientific Output → Infrastructures	9.295721 ***	10.46055 ***	15.36708 ***	11.95016 **	38.71275 ***	69.56984 ***	65.7457 ***	41.6428 ***	44.48924 ***	51.46617 ***	Yes
International Trade → Scientific Output	1.940913	12.10582 ***	7.055472 *	8.774521 *	6.935538	11.56188 *	13.03969 *	10.82183	12.73458	14.7039	Yes
Scientific Output → International Trade	8.8065 ***	10.18745 ***	9.969457 **	12.07784 **	10.44513 *	10.30247	20.22921 ***	16.52089 **	15.26703 *	19.24827 **	Yes
Human Capital → Innovative Input	0.049204	0.759877	1.622344	1.608096	5.023983	5.605948	5.348152	4.696185	7.294121	9.290443	No
Innovative Input → Human Capital	0.022714	0.936654	5.855463	5.644463	5.04275	6.879506	6.942036	5.793254	7.89203	8.533766	No
Infrastructures → Innovative Input	20.55227 ***	26.67827 ***	24.41194 ***	21.38503 ***	20.91794 ***	21.42687 ***	20.49803 ***	16.59417 **	24.72358 ***	29.46254 ***	Yes
Innovative Input → Infrastructures	13.27583 ***	9.641964 ***	7.788195 *	11.70094 **	14.34713 **	18.80563 ***	17.53996 **	20.1881 ***	27.00832 ***	26.32439 ***	Yes
International Trade → Innovative Input	5.074378 **	8.950417 **	9.273583 **	14.50388 ***	13.55485 **	15.49662 **	14.99663 **	11.16334	11.99277	12.55653	Yes
Innovative Input → International Trade	0.212552	5.940029 *	7.628062 *	8.538952 *	7.590382	8.862783	13.82523 *	15.33035 *	12.54729	13.91522	Yes

IV. The coevolution between Innovative Capability, Absorptive Capacity and Income Level

Causal relationships	Lags										Granger Causality
	1	2	3	4	5	6	7	8	9	10	
Income Level → Technological Output	4.414636 **	0.978824	5.077208	9.728226 **	38.28156 ***	43.02793 ***	41.53666 ***	50.05825 ***	62.9281 ***	64.31709 ***	Yes
Technological Output → Income Level	1.90049	1.606446	3.10514	6.002983	8.66107	10.95496 *	22.4891 ***	28.79514 ***	34.47383 ***	46.85428 ***	Yes
Income Level → Scientific Output	15.90829 ***	43.43056 ***	48.01339 ***	46.12999 ***	59.03562 ***	58.63725 ***	49.59162 ***	64.6799 ***	66.69526 ***	62.4862 ***	Yes
Scientific Output → Income Level	2.150289	4.219628	7.658135 *	9.199486 *	6.651817	9.508092	22.12943 ***	17.29285 **	24.7555 ***	22.94525 **	Yes
Income Level → Innovative Input	11.09302 ***	10.64323 ***	10.04898 **	12.95816 **	12.80222 **	14.4918 **	18.03748 **	8.728336	8.900332	7.422394	Yes
Innovative Input → Income Level	1.440607	1.78745	3.964316	11.62674 **	11.07349 **	8.875249	10.67465	16.4007 **	13.15223	11.1774	No
Income Level → Human Capital	2.063986	6.061931 **	4.638791	5.600141	5.821298	6.544538	5.12065	11.68177	10.60825	11.60882	No
Human Capital → Income Level	3.55786 *	4.877883 *	11.23341 **	11.38932 **	8.882979	12.51592 *	15.98829 **	19.37588 **	23.41289 ***	23.05119 **	Yes
Income Level → Infrastructures	25.65041 ***	34.25309 ***	28.57497 ***	31.39228 ***	35.38122 ***	47.09036 ***	48.16645 ***	45.07046 ***	41.79587 ***	60.98583 ***	Yes
Infrastructures → Income Level	0.586904	1.135882	1.3285	17.45814 ***	23.15759 ***	27.06655 ***	32.012 ***	42.1077 ***	55.55036 ***	49.22835 ***	Yes
Income Level → International Trade	5.250288 **	27.40494 ***	23.22531 ***	25.78274 ***	26.91603 ***	22.18023 ***	32.72833 ***	33.48354 ***	38.85942 ***	48.48927 ***	Yes
International Trade → Income Level	4.767861 **	4.611315 *	5.343564	10.59495 **	11.70891 **	14.7163 **	22.36506 ***	12.26364	12.77808	18.92982 **	Yes

7. Sensitivity analysis

This section presents the results of additional estimations that we have carried out to assess the robustness of the empirical patterns outlined in the previous section. We have carried out two types of sensitivity analysis. The first studies the results for different model specifications (section 7.1), and the second investigates whether the results are stable for different groups of countries (section 7.2). The Online Appendix (available at: http://dynamicsnis.grinei.es) reports detailed results for all of these additional exercises. Here, due to space limitations, we summarize the results of this sensitivity analysis in tables 5 and 6.

7.1 Different model specifications

Table 5 reports a summary of the results for six different model specifications (models 2 to 7). Each of these specifications introduces a new indicator to provide an alternative measure of some of the key factors in the model. The table points out whether these different specifications lead to different results *vis-à-vis* model 1 (the baseline specification presented in section 6), i.e. whether the three propositions are confirmed, and whether there is any salient change in the set of causal relationships. Table 5 does on the whole indicate that the results for these six different model specifications do not change substantially the baseline results discussed in section 6.

Model 2 makes use of an indicator of public (instead of total) R&D. This variable turns out to be causally linked to scientific output, but it does not affect directly technological output, thus implicitly showing the crucial role of private R&D for the dynamics of technological output (patents). Model 3 measures human capital by means of a secondary education indicator (instead of tertiary education as in model 1). A notable change in this specification is that this variable turns out to have a two-way causal link with technological dynamics. In other words, differently from model 1, model 3 points out a process of dynamic interaction between human capital and technological progress, which corroborates further our proposition 3. This empirical finding is also in line with recent distance-to-frontier threshold models in which human capital is the key factor enabling imitation-based catching up through its interactions with technological dynamics (e.g. Howitt and Mayer-Foulkes, 2005; Iacopetta, 2010).

Model 4 makes use of telephony, instead of electricity, as a proxy for technological infrastructures. The new indicator does not lead to any change in the model results *vis-à-vis* the baseline specification. Model 5 measures the openness of the system to international trade by means of an indicator of high-tech exports (as a share of GDP). This variable is intended to provide a more specific assessment of the relationships between technological activities and the export performance of countries (rather than the more general indicator of openness adopted in model 1). The results for model 5 indicate in fact the existence of a virtuous circle according to which innovative input and technological output sustain the dynamics of high-tech exports, and the latter does in turn support further technological dynamics by means of learning-by-exporting mechanisms.

Finally, the last two model specifications reported in table 5 provide an assessment of whether the results are stable to the exclusion of the GDP per capita variable (model 6), or the inclusion of a different control variable measuring health (life expectancy), used as an alternative proxy of countries' overall development level. The results for both of these specifications are closely in line with those for model 1, and the only notable change is that we find a direct effect of human capital on technological output (whereas in model 1 this effect was indirect and mediated by GDP per capita growth).

7.2 Different country groups

The second sensitivity analysis we have carried out investigates the extent to which cross-country heterogeneity affects the results presented in section 6. It is in fact reasonable to think that countries with different income and development levels may be characterized by a distinct set of relationships between innovative capability and absorptive capacity. In econometric terms, cross-country heterogeneity may turn out to affect the results of dynamic panel model estimations, and even more so in the presence of cointegrated variables (Pesaran and Smith, 1995).

There is however no easy solution to this methodological issue. Estimating the model for each country separately would avoid the heterogeneity problem, but this approach is not feasible in our exercise because the relatively short length of the time series does not allow a reliable estimation of our model for each individual country in the sample. A more appropriate and convenient solution is instead to divide the sample into different groups, and estimate the panel cointegration model separately for each of these country groups. This strategy alleviates the heterogeneity issue while at the same time retaining the advantages of panel estimations.

After experimenting with different cluster configurations, we have decided to focus our results on a five-group structure. The main criteria used for the grouping is to divide countries on the basis of their economic and development level (as typically done in the growth and convergence clubs literature, see e.g. Castellacci, 2008), as well as on the basis of the geographical area to which each country belongs, since geographical proximity ensures a good degree of homogeneity in terms of institutional, social and cultural conditions. Based on these criteria, our five country groups are defined as follows (see the composition of each cluster in Appendix 1): (1) OECD economies; (2) East Asia; (3) Latin America; (4) Eurasia (former Soviet countries); (5) Less developed economies (Africa and South Asia). We have found that this five-group structure provides better and more accurate estimation results than the corresponding two-, three- and four-group classifications.

Table 6 provides a summary of the results of estimations of the model for each of these five country groups, and the Online Appendix reports detailed results for each of these additional exercises. The main finding from this sensitivity analysis is that the three propositions outlined in our theoretical framework are on the whole confirmed in the first four country groups (advanced and middle-income economies), but not supported in the fifth cluster (less developed economies).

More specifically, the results for middle-income countries (East Asia, Latin America and Eurasia) point out three interesting differences *vis-à-vis* the working of the model for the OECD group: (1) Innovative input is not directly linked to technological output, indicating the lack of a systematic relationship between R&D investments and patenting activities in middle-income economies; (2) The important role played by the interactions between technological output and international trade dynamics; (3) The human capital variables (tertiary and secondary education) have no direct effect on innovation and GDP per capita dynamics in East Asia and Eurasia, but turn out to have an effect in the Latin American group.

By contrast, the results for the group of less developed economies (Africa and South Asia) indicate that many of the causal relationships that characterize our model for the more advanced clusters are not significant in this group. In other words, the national innovation system of less developed economies is not characterized by a dense network of causal relationships as in the rest of the sample, but it seems on the whole weakly integrated and it lacks the set of feedback effects that is capable of generating cumulative dynamics of growth and catching up.

Table 5.5 - Sensitivity analysis I: Different model specifications

Model specification	New indicator used	Proposition 1: The internal dynamics of innovative capability	Proposition 2: The internal dynamics of absorptive capacity	Proposition 3: The coevolution between innovative capability and absorptive capacity	Reference to the Online Appendix[1]
2	**Innovative Input:** Public R&D expenditures, percentage of GDP	**Confirmed.** Public R&D not linked directly to technological output	**Confirmed.** No major change *vis-vis* model 1	**Confirmed.** No major change *vis-vis* model 1	Pages 8 - 10
3	**Human Capital:** Secondary education, enrolment ratio	**Confirmed.** No major change *vis-vis* model 1	**Confirmed.** Secondary education not linked directly to infrastructures and trade	**Confirmed.** Secondary education has a two-way link with technological output	Pages 11 - 13
4	**Infrastructure:** Telephony: Mobile and fixed-line subscribers per 1000 people	**Confirmed.** No major change *vis-vis* model 1	**Confirmed.** No major change *vis-vis* model 1	**Confirmed.** No major change *vis-vis* model 1	Pages 14 - 16
5	**International Trade:** High-tech exports, share of GDP	**Confirmed.** No major change *vis-vis* model 1	**Confirmed.** No major change *vis-vis* model 1	**Confirmed.** A virtuous circle between innovative input, technological output and high-tech exports	Pages 17 – 19
6	**Income Level:** Control variable GDP per capita not included in this model	**Confirmed.** No major change *vis-vis* model 1	**Confirmed.** No major change *vis-vis* model 1	**Confirmed.** Human capital has a direct effect on technological output	Pages 20 – 22
7	**Health:** Life Expectancy. Included as control variable instead of income level	**Confirmed.** No major change *vis-vis* model 1	**Confirmed.** No major change *vis-vis* model 1	**Confirmed.** Human capital has a direct effect on technological output	Pages 23 – 25

[1] The Online Appendix is available at the web address: http://dynamicsnis.grinei.es.

Table 6.5 - Sensitivity analysis II: Different country groups

Model specification	Country group	Proposition 1: The internal dynamics of innovative capability	Proposition 2: The internal dynamics of absorptive capacity	Proposition 3: The coevolution between innovative capability and absorptive capacity	Reference to the Online Appendix[1]
1.1	**OECD**	**Confirmed.** No major change *vis-vis* the results for the whole sample	**Confirmed.** No major change *vis-vis* the results for the whole sample	**Confirmed.** No major change *vis-vis* the results for the whole sample	Pages 26 - 28
1.2	**East Asia**	**Confirmed.** Innovative input not linked directly to scientific and technological output	**Confirmed.** No major change *vis-vis* the results for the whole sample	**Confirmed.** Technological output affects international trade dynamics. Human capital has no direct effect on innovation and income per capita	Pages 29 - 31
1.3 & 3.3	**Latin America**	**Confirmed.** Innovative input not linked to technological output. The latter does not have a feedback effect on scientific output	**Confirmed.** No major change when secondary education is used to measure human capital (model 3.3)	**Confirmed.** A virtuous circle between secondary education, scientific and technological output (model 3.3)	Pages 32 – 37
1.4	**Eurasia**	**Confirmed.** Innovative input does not affect technological output. Scientific output emerges as the central innovation factor	**Confirmed.** No major change *vis-vis* the results for the whole sample	**Confirmed.** Technological output affects international trade dynamics. Human capital has no direct effect on innovation and income per capita	Pages 38 – 40
1.5	**Africa & South Asia**	**Not confirmed.** No feedback effects between innovative input and scientific and technological output	**Not confirmed.** No feedback effects between the three absorptive capacity dimensions	**Partly confirmed.** A two-way interaction between scientific output and infrastructure building. But no other feedback effects emerge	Pages 41 - 43

[1] The Online Appendix is available at the web address: http://dynamicsnis.grinei.es.

8. CONCLUSIONS

The paper has argued that, in order to advance our analytical understandings and empirical measurement of how national systems of innovation evolve over time, a time series approach should complement the cross-country comparative perspective that has so far dominated most of the literature in the field of innovation and growth. In particular, by shifting the focus to the time series properties of the process of technological accumulation and economic development, the paper has put forward the idea that the dynamics of national systems is driven by the coevolution of two main dimensions: innovative capability and absorptive capacity. On the one hand, the dynamics of the former sustains the growth of the latter, because innovative efforts and investments tend to increase countries' imitation capabilities as well as the pool of resources that can be reinvested in technological activities in the future. On the other hand, the evolution of a country's absorptive capacity may in turn sustain the dynamics of innovation by enhancing the productivity of the R&D sector and the country's policy commitment to technological activities.

In order to explore this new direction of research, we have made use of a set of indicators measuring national innovative capabilities and absorptive capacity for a panel of 87 countries in the period 1980-2007. Our empirical methodology is rooted in the panel cointegration approach, which represents a recent extension of the time series cointegration analysis of non-stationary variables to the panel data context. Our empirical operationalization of the concept of coevolution is twofold: first, we investigate the existence of a long-run structural relationship (cointegration) among our set of innovative capability and absorptive capacity variables; secondly, for each pair of variables, we analyse the direction of causality by means of Granger block exogeneity tests. For those variables for which we find robust evidence of a two-way dynamic relationship, we conclude that a process of coevolution among these factors is at stake.

The empirical results indicate that innovative capability and absorptive capacity variables are indeed linked by a set of long-term structural relationships over the period 1980-2007. Specifically, the dynamics of national systems of innovation is driven by the coevolution of two sets of factors: the innovative capability factors (innovative input, scientific output and technological output), on the one hand, and the absorptive capacity variables measuring infrastructures and international trade, on the other. This joint dynamics is further enabled and sustained by the growth of GDP per capita. Human capital, the absorptive capacity factor typically emphasized by technology-gap and imitation-based growth models, does also coevolve with the rest of the system. However, the specific role of this variable depends on the indicator that it is used to measure it. When secondary education is used, human capital has a two-way link to innovation dynamics. However, when a tertiary education indicator is used, human capital does not turn out to have a direct effect on the dynamics of innovation activities, but rather an indirect effect by sustaining the growth of GDP per capita (which in turn feeds back and sustains the innovation dynamics over time).

On the whole, these results have important implications for theory-building and policy-making. NIS are dynamic systems whose evolution is driven by a complex set of two-way self-reinforcing relationships. Any given change in one of the factors composing the NIS has a set of direct effects on several other variables of the system, as well as a set of indirect effects that are mediated through other factors in the model. Policy-makers should to the extent possible take this web of feedback effects into account, and theory-builders should provide the building blocks for a better understanding of the dynamics of complex evolving systems.

We conclude by pointing out two main limitations and possible future extensions of our approach. First, an important element is missing in our operationalization of the concept of coevolution, namely structural change. When new technological paradigms emerge, the radically new nature and pervasiveness of emerging GPTs introduces disruptive change and transformations in the dynamics of innovative capability and absorptive capacity. This type of structural breaks has potentially important effects on the working of a cointegration and error correction time series model like the one presented in this paper (Foster and Wild, 1999). This problem is arguably of little relevance in the context of a relatively short time span like the one considered in this work, since the investigation period used here by and large represents a relatively stable long-run growth phase related to the emergence and diffusion of the ICT technological paradigm. However, when confronted with a longer time frame, the set of dynamic relationships among innovation and absorptive capacity variables would certainly be affected by technological shocks and episodes of structural and disruptive change, and this should be taken into account in future research by means of an appropriate time series analysis of structural breaks and the response of the variables to external shocks.

Secondly, the focus of our paper has been on the working of the model for the whole sample of countries, without an explicit investigation of how different country clubs may differ with respect to the set of identified relationships (Lee and Kim, 2009). The sensitivity analysis presented in section 7.2 has provided a first step in this direction, and shown that our model works much better for advanced and middle-income countries than for the group of less developed economies (e.g. Africa and South Asia). Nevertheless, these findings call for future research to provide a more thorough understanding of the extent to which the key drivers of NIS dynamics differ for countries characterized by different levels of economic, social and institutional development. We intend to consider these challenging issues and possible refinements of our approach in future research.

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APPENDIX 1: COUNTRY SAMPLE AND COMPOSITION OF THE FIVE COUNTRY GROUPS

OECD: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States.

East Asia: Cambodia, China, Indonesia, Malaysia, Mongolia, Philippines, Singapore, Thailand, Vietnam.

Latin America: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay.

Eurasia: Armenia, Azerbaijan, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia, Tajikistan, Ukraine.

Africa and South Asia: Algeria, Botswana, Burkina Faso, Ethiopia, India, Jordan, Lesotho, Madagascar, Mauritius, Morocco, Mozambique, Pakistan, Senegal, South Africa, Sri Lanka, Tunisia, Uganda, Zambia.

CHAPTER 6

CONCLUSIONS, LIMITATIONS AND FUTURE EXTENSIONS

The main topic of this dissertation is the dynamic relationship between innovation, economic growth and development. It is an effort to contribute to the literature by presenting four papers: two of them have a conceptual and methodological orientation, while the others analyze, from an empirical perspective, the structure that unravels over ***time***. This chapter aims at discussing the main conclusions, restrictions and further developments that the compendium of these four papers offer.

CONCLUSIONS

There still is an ongoing debate about the characterization of innovation systems as a theory, a concept or a framework to understand development and growth from an economic perspective. This issue comes from the need of having solid foundations to study evolutionary processes: Innovation Systems are often criticized for their theoretical underpinnings and lax structure (Niosi et al., 1993). Nevertheless, such criticism does not take into account that evolutionary theorizing should be based on open structures, in which complexity and the information coming from non-static environments must be constantly incorporated in the analysis (Nelson and Winter, 2002, 1977). Bearing this in mind, the survey of the most influential development theories and their interactions with innovation systems, presented in Chapter 2, proposes to switch the focus of the debate on the theoretical bases of innovation systems. The offered alternative suggests taking complementarities between the innovation system approach and the selected development theories under consideration to increase the explanatory power on the development process.

Development theories could represent an interesting perspective to observe and describe the systemic phenomena of innovation. Innovation systems' flexibility is useful to incorporate complexity in the theoretical analysis of economic development and could be a source of adaptation and evolution of the theories that it complements: it offers an open window to constantly revisit the theoretical foundations in which research and policy are being designed (Lundvall et al., 2009).

The empirical analyses here included have been conceived from this viewpoint. The models have been inspired in the distance-to-the-frontier tradition. Naturally, they have been augmented to include the socio-institutional dimensions, the technological capabilities, the internationalization activities and the productive structure as determinants of the development at the national level. Results confirm the validity of the scheme discussed in Chapter 1, as they offer evidence against reductionist approaches: since structures differ across countries, if the multifaceted characteristics of the economic development process are not included in the analysis, there is a high risk of leaving aside critical variables that are central for that particular economy (Foray, 2004).

Without investigating the structure of the system, it is not possible to discriminate *a priori* the relative importance of specific capabilities: a wide spectrum of possibilities to assess the multidimensional characteristic is required. The construction of the CANA dataset, presented in Chapter 3, is a first step to operationalize the analysis: 80 indicators are available to represent the interaction of eight different capabilities. It is still a simplification of the enormous complexity of economic processes, but this approach reduces the gap between theories and the related empirical exercises.

Nowadays, dynamic empirical analyses could get closer to the expectations of theoretical foundations of innovation and economic development. As a start, data is not as problematic as it was in the past. Multiple imputation methods allow the exploitation of available data at country level (Castellacci and Natera, 2011): it does not force the estimations to respond to a particular model; it considers the heterogeneity of the process and the interactions among variables when estimating data-points and; there are robust methods to assess the reliability of the estimations. The ideal situation, of course, would be to have access to fully observed data constructed under equal methodological strategies across countries (Smith, 2005). We acknowledge that there are some risks when we use country level data and that they increase in importance when we estimate the missing data. Multiple imputation is neither a perfect solution for all cases (Abayomi et al., 2008), nor a universal remedy, but it allows us to obtain important information: it gives the opportunity of investigating the revealed structure of innovation and development, an open door to applying truly dynamic econometric methodologies, such as cointegration.

The cointegration methodology is one of the more suitable econometric tools to conduct empirical analyses on development and innovation from a systemic perspective. First of all, it considers how variables co-evolve and react when a shift occurs: it determines the dynamics of non-linear effects among the different relationships. Moreover, cointegration has the advantage of disentangling the long-run structure from the short-run. Given the big challenge of investigating development processes, any opportunity for distinguishing between long lasting and transition effects is useful for interpreting results and deriving policy recommendations.

The application of this methodology has provided new insights on the relationships between innovation and development. We have offered a new vision of the structures that time reveals. In the two different exercises (panel and time series), linkages between different capabilities have been described as having unidirectional or mutual effects, creating a network of intertwined causation. This is a step forward in incorporating history in the econometrics of innovation: present, past and changes in the variables are all considered at once to extract the patterns of their interactions (Hoover et al., 2008).

Our empirical results, we believe, offer a rich source of information, especially for policy issues. Let us begin with the complexity of the economic development. The panel case (Castellacci and Natera, 2013a) showed that there is evidence of coevolution between innovative capabilities, absorptive capacity and economic growth. This highlights that reductionist approaches that do not consider the multidimensional nature of development are likely to fail to provide pertinent recommendations: one change in any part of the system will drive many changes in the other dimensions; consequently, expected results in any specific dimension will also depend on the effects it gets from the rest of the system (Arthur, 1999).

Being this the case, the take away message is clear: development strategies need massive coordination. Evidence suggests that it is just not enough to focus on a particular sector or a reduced part of the system when development is the final objective. Certainly, there are some dimensions that will have a higher impact on the system and, therefore, could be used to prioritize policy actions. Particularly, innovation has always appeared as one of the critical dimensions. Still, feedback loops will remain as crucial sources of causation: innovative activities are inserted in a complex structure of driving forces.

Both the time series and the panel case, respectively Chapters 4 and 5, have shown that complexity and economic development evolve together. Countries that have managed to increase the interactions between their capabilities are those that exhibit a higher development level. This implies that sustainable growth could only be achieved by building bridges between different sources of knowledge, i.e., by having strong connectivity among different agents.

Probably the main implication of the complexity evidenced in the empirical exercise is related to the institutional configuration required to foster innovation. Particularly in developing countries, ministerial bodies have been created to promote Science, Technology and Innovation activities. This decision is not harmful by itself but it carries the risk of allocating the whole responsibility of building innovative capabilities on a constrained organization: the multidimensional characteristic of innovation and development must find counterparts in countries' institutional structures. Of course, because of the high heterogeneity found, the institutional design should be country specific.

The time series exercise (Chapter 4) studies the Latin American case and it remarks why specificity is necessary (Castellacci and Natera, 2013b). Development paths are constructed by the mix of strategic decisions that each country has followed. The combination of innovation and imitation policies is the best practice that, based on the empirical results, could be recommended to policy makers. Indubitably, it is critical not to forget that development strategies heavily rely on historical conditions. Decisions taken over time make impossible to fully reapply proven successful strategies: those actions were time-specific and therefore cannot be replicated blindly. Based on the revealed capabilities and the interactions among them, societies should coordinate and agree on how to construct the competences they need.

The panel analysis, presented in Chapter 5, also confirms the importance of considering heterogeneity in the relationships between economic development and innovation. As pointed out in the paper, allocating countries in a five-group configuration – in which geographical, institutional and development level characteristics are considered – provided the most consistent results. The causal structure that links the selected capabilities changes with the development level (Castellacci and Natera, 2013a). It is not only a matter of finding a higher number of causal interactions in more developed countries: causality is configured differently for each country group, according to their own particular historical path.

LIMITATIONS

Some limitations have been faced during the development of this dissertation. For instance, capturing the complex dimensions that are implicit in the catching-up process is still a big challenge. Available indicators are not free of shortcomings. This, of course, is part of the nature of many economic analyses, but it is especially relevant when the objective is to investigate evolutionary processes (Kleinknecht et al., 2002). In Chapter 3, there is an effort to overcome this issue; nevertheless, the discussion is far from conclusive. From a methodological point of view, changes in the data collection process and external sources of variation (such as the implementation of new legal procedures, terms redefinition, changes in questionnaires, etc.) might affect the measurement of the indicator and the information that could be extracted from it (Hall et al., 2010): since time series data are used, it is necessary to keep in mind that changes from one year to the other might be caused by methodological updates and not necessarily by changes in the process that we would like to measure. To some extent, this problem is hard to address since methodological changes are not always reported in full detail: it is a risk that time series analysis will inexorably face.

There is still another issue that is more linked to the conceptual approach. The selection of indicators as a proxy for innovation or absorptive capacity processes is a challenging task. As a matter of fact, this is a relevant limitation of Chapter 4. For developing countries, using patents as an indicator of innovative activities is a matter of heated debates (Archibugi and Coco, 2004; Archibugi et al., 2009; Vaitsos, 1972): because of the low propensity to patenting activities, innovation results are underestimated by this proxy. Also, measuring absorptive capacity as a combination of indicators is not obstacle free: we need to consider its multifaceted nature and this is only possible when different dimensions are incorporated in the analysis. The main question is where to stop. Literature review was carefully executed and the CANA dataset was constructed with a wide vision in order to cope with the selection bias, and sensitivity analyses have shown the reliability of the results. Nevertheless, we acknowledge that different proxies might also be suitable for the analysis presented here and remain open for additional exercises.

Other limitations are related to the characterization of the time structure. First of all, the inclusion of structural breaks in panel analyses has not been completely developed (Banerjee, 2006; Banerjee et al., 2004): it is not possible to fully control for changes in variables behavior (step-like patterns, collapses or changes in the trend) when analyzing groups of countries jointly, as we did in Chapter 5. Second, even in the time series case (Chapter 4), in which structural breaks can be described, the structures revealed by this analysis could change over time: it is important to continuously revisit the model by adding new information that could improve and change the results. We are not facing static processes, we are living in an ever changing environment in which agents learn and transform themselves and their ways to interact. On this regard, at least for the time series case, there are available recursive tests in which the stability of the parameters can be assessed (Juselius, 2006). However, reliability of these tests is limited by the time spam currently available: future data collection will offer the opportunity of nurturing the database on this respect as well.

FUTURE EXTENSIONS

Including ***time*** in the analysis has been essential to deliver these policy recommendations. Other characteristics of the time structure could also be studied. So far, we have used time to evaluate the structures behind economic development and innovation. We could also use this information to analyze the responsiveness of the system; we could try to answer the following question: how long does it take to see the reaction of the system when one dimension changes? Do all of the dimensions react exactly at the same pace? This could have important implications for policy making. It might be the case that we evaluate policy effectiveness too soon (or too late) to capture its real impact. If we assess how fast the system reacts, we would be able to adjust evaluation timing accordingly, instead of using an *ad hoc* – and not evidence supported – criteria. Impulse Response Functions (IRF) could provide this information (Hamilton, 1994): they show how changes propagate in the system and how variables reach different levels at particular points of time.

Besides the cointegration analysis, there are other alternative dynamic econometric exercises. Foster and Wild (1999) present an interesting one: by a applying an augmented logistic diffusion model (ADLM), they propose a characterization of economic systems in which structural change could be evaluated as a result of self-organizing structures. The beauty of this novel approach is the possibility of endogenizing those critical points in which disruptive processes arise.

Other possibilities of extensions are related to economic complexity studies. Complexity could be assessed from many different perspectives. For instance, by looking at countries' product space, Hidalgo and Hausmann (Hidalgo and Hausmann, 2009; Hidalgo et al., 2007) rendered conclusions related to ours. They state that countries with a higher level of development have managed to increase the network of products they produce and export. They also propose that this complexity increase is supported by the required capabilities to enjoy a diversified and interconnected network of products. Building bridges between this type of complexity and the one we propose would be a useful project: it could help policymakers to understand which key actions are needed in order to develop those contiguous sectors that will sustain countries' economic growth. Hausmann and Hidalgo use a metaphor to explain how their economic complexity works: firms are represented by monkeys that jump from one tree (sector) to another, in search of more profitable activities; to put in simple words, combining their analysis with the capability approach would be a way of understanding what kind of diet the monkeys should follow.

A final set of future developments is devoted to the assessment of simulation models (both in terms of their design and reliability testing). The innovation system tradition would greatly benefit from simulation exercises: by analyzing different configurations of the relationships between agents or capabilities, it is possible to draw conclusions about the impacts that each part of the system could have on the rest of the components and their interactions. One of the main challenges when modeling complex systems is defining the causal structures that represent the interactions between different variables (Borshchev and Filippov, 2004; Wu et al., 2010). Econometric analyses presented in this thesis are a contribution to overcome or reduce these barriers: following the same scheme of Chapters 4 and 5, the main relationships could be taken from empirical evidence, giving a more solid foundation for the model setting (Karnopp et al., 1976). Simulation models could be an enormous source of information about the relationship between innovation and economic development: assessment of intermediate processes, description of the aggregation structure, evaluation of the different speeds within the system and the levels reached by selected variables, are open possibilities.

Hopefully, the limitations outlined will be solved in the future and some of the possible extensions of this research work will be undertaken. Complexity in the relationships between innovation, development and economic growth is still far to be fully understood. Nevertheless, evidence up to this point provides a clear message: strong interactions are a common characteristic of developed economies.

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FIGURES AND TABLES

LIST OF FIGURES

LIST OF TABLES

RESUMEN EXTENDIDO

1. INTRODUCCIÓN

Existe una dimensión crucial que revela cómo los países han utilizado el conocimiento en su camino hacia el crecimiento económico y el desarrollo: ***el tiempo***. El desarrollo sólo puede entenderse investigando la manera en la que el paso del tiempo ha dado forma al proceso evolutivo de las sociedades. Esta es la principal motivación de este trabajo doctoral, en las páginas siguientes se explicará el abordaje y las implicaciones de este análisis.

Este proyecto de investigación tiene sus raíces en la economía evolutiva y en la tradición de sistemas de innovación. En esta rama del análisis económico, los procesos de cambio graduales son de suma importancia: agentes heterogéneos interactúan y aprenden de sus interacciones; la información no siempre está disponible gratuitamente y, aun cuando lo está, su mera posesión no garantiza que los agentes serán capaces de beneficiarse de ella; se necesitan capacidades para explotar el conocimiento existente y crear uno nuevo. El proceso de aprendizaje depende de la trayectoria recorrida, la misma que determina la capacidad de los agentes (empresas, regiones y países) para adaptarse y progresar o para no mutar y estancarse. Este proceso es de mucha importancia, pues la innovación es el motor del crecimiento económico y el desarrollo (Nelson and Winter, 1982).

La literatura sobre innovación y desarrollo económico es amplia. En este proyecto doctoral, dos corrientes han tenido una fuerte influencia. En primer lugar, el marco de los sistemas de innovación (Freeman, 1995; Lundvall et al., 2002) ha sido el eje principal para abordar la relación entre innovación y desarrollo. Mediante la aplicación de un enfoque sistémico de innovación, se ha incluido gran parte de la complejidad que caracteriza el crecimiento económico y el desarrollo. La otra rama importante es enfoque de las capacidades, introducido por Abramovitz (1986) y Lall (1992). Ambas corrientes son los hitos que han guiado el análisis empírico donde se ha considerado las condiciones institucionales desde un enfoque multidimensional y se ha evaluado el proceso acumulativo de la construcción de capacidades desde una perspectiva temporal.

La innovación ha sido siempre planteada como un proceso no estacionario (Dosi, 1982; Metcalfe and Ramlogan, 2008; Perez, 1983; Schumpeter, 1934). Sin embargo, los estudios empíricos no han acompañado plenamente este argumento. Buena parte del trabajo aplicado presenta análisis comparativos de forma estática, lo cual puede ser miope a los patrones y cambios estructurales. El objetivo de este trabajo doctoral es contribuir a la literatura mediante el cierre de la brecha entre teoría y empirismo: utiliza métodos econométricos de series temporales y de panel para evaluar las dinámicas del proceso de innovación y sus vínculos con el crecimiento económico y el desarrollo. Naturalmente, también se ha puesto mucha atención en el estudio de cómo las economías difieren en sus sendas de desarrollo, en especial porque hay interés en hacer recomendaciones de políticas públicas. Las estructuras varían entre economías, los vínculos entre los agentes son específicos a los diferentes contextos y momentos históricos.

2. SISTEMAS DE INNOVACIÓN: UNA PERSPECTIVA HISTÓRICA

Entender la relación entre innovación, crecimiento económico y desarrollo ha sido un objetivo constante de la economía evolucionista. De hecho, las características esenciales de esta pregunta se remontan a la división del trabajo de Adam Smith en 1776 y a los sistemas nacionales de producción y de aprendizaje de Friedrich List en 1841 (Lundvall et al., 2002). De los diferentes enfoques que se pueden aplicar para resolver este problema, en esta tesis se ha seleccionado la visión sistémica como principio rector de la investigación, pues ésta ofrece la posibilidad de capturar las dimensiones de la complejidad del desarrollo económico.

El marco de los Sistemas de Innovación se propuso al final de la década de los ochentas. Las contribuciones de Freeman, Lundvall y Nelson son reconocidas como los tres principales pilares de esta tradición (Fagerberg and Sapprasert, 2011). Ellos han propuesto una nueva línea de investigación que ha tenido un gran auge en las últimas tres décadas (Uriona-Maldonado et al., 2012). El trabajo seminal de Christopher

Freeman (1987) analiza cómo las diferencias en el desempeño económico de Japón, Alemania, la URSS, Asia del Este y América Latina podrían explicarse desde el punto de vista histórico. El ejercicio comparativo ilustra las múltiples facetas del proceso de innovación: se muestra cómo la red de instituciones científicas, los sectores industriales, las políticas y las raíces culturales fueron determinantes del desarrollo económico. Lundvall propone que el fenómeno principal en esta red es el *aprendizaje*, un proceso evolutivo en el que cada agente cambia mediante la interacción con otros agentes y con el medio ambiente (Lundvall, 1996, 2004; Lundvall and Johnson, 1994). El enfoque institucional de Nelson (Dosi and Nelson, 1994; Nelson and Nelson, 2002; Nelson, 2008, 1986) completa las principales características del marco de sistemas de innovación. Para Nelson el contexto determina las vinculaciones, contiene las reglas del juego que se generan en un proceso no lineal: las interacciones continuas son la base de las rutinas que dan estructura a las relaciones entre los agentes; al mismo tiempo y como resultado de esa continuidad, las rutinas cambian para adaptarse a la evolución de ellos.

Diferentes enfoques de sistemas de innovación han sido desarrollados con el fin de encontrar el ángulo más *adecuado*: el enfoque sectorial (Geels, 2004; Malerba, 2002), el regional (Cooke, 2001; Cooke et al., 1997; Uyarra, 2010) y el internacional (Álvarez and Marín, 2010; Carlsson, 2006; Niosi and Bellon, 1994) se han agregado como alternativas a la habitual "visión nacional" como una forma de adaptar la unidad de análisis. Todas estas opciones han resultado muy útiles para ofrecer evidencia a la academia y a las políticas públicas. En esta tesis, se hace un esfuerzo para entender el desarrollo a distintas fases: una buena proporción de los países del mundo se incluye en el análisis empírico, lo cual nos da una razón para usar el nivel nacional como la unidad seleccionada (Lundvall, 1998).

Encontrar un método adecuado para aplicar el marco de sistemas de innovación es un reto que va más allá de la selección de la unidad de análisis. Esta línea de investigación se ha nutrido de la discusión política (Godin, 2009) y de una variedad de visiones académicas. De hecho, Niosi et al. (1993) y Sharif (2006) presentan una discusión de las principales preocupaciones alrededor de los sistemas de innovación: su definición y delimitación, los fundamentos teóricos, el grado adecuado de flexibilidad y la posibilidad de medición. Queda, sin embargo, algo que no ha sido cuestionado en sus diferentes enfoques: la perspectiva histórica. La dependencia de la historia y la no-reversibilidad se consideran fundamentales para explicar el proceso de desarrollo y, por ello, no se pueden dejar fuera del análisis (Cowan and Foray, 2002). Hasta ahora, los estudios de caso han sido seleccionados como la herramienta metodológica preferida para llevar a cabo esta tarea. Una cantidad muy valiosa de evidencia empírica se ha recogido desde la investigación cualitativa: la descripción de Freeman (1995, 1987) de los agentes, sus interacciones y la importancia del Estado en las actividades de innovación de los países, estableció una referencia importante para el campo; Nelson (1993) hizo análisis comparativos señalando las diferencias y la heterogeneidad del proceso; más recientemente Lundvall et al (2009) y Edquist y Holman (2008) han mostrado, respectivamente, los puntos de vista de los países desarrollados y en desarrollo en cuanto a sus políticas y marcos institucionales. Otra corriente de investigación interesante, más centrada en el caso sectorial, se ha desarrollado en torno a las “Modelos Compatibles con la Historia” (*History Friendly Models*, en inglés) (Malerba, 2002; Malerba et al., 1999): éstos se han centrado en el seguimiento de la evolución de nichos específicos de tecnologías, en la identificación de las transformaciones y cambios estructurales importantes que han tenido un impacto en el sistema productivo. En cualquier caso, todas estas alternativas no han incorporado (al menos en un nivel considerable) evidencia econométrica.

Los enfoques econométricos centrados en el estudio de la relación entre crecimiento e innovación han tratado de integrar la visión sistémica en los análisis comparativos entre países. Fagerberg (1994) presenta una revisión que incluye más de una veintena de trabajos empíricos que habían evaluado – para ese entonces – la relación entre crecimiento económico y tecnología. Las variables seleccionadas combinaban participación de sector público en la economía, crecimiento demográfico, apertura económica y medidas de productividad con típicos indicadores de actividades de innovación (como las variables de educación, los esfuerzos en I+D y las patentes). Otros desarrollos de estos enfoques han aumentado el número de los países analizados, alcanzando economías con niveles de desarrollo más bajos cuando los datos así lo permitían (Castellacci and Archibugi, 2008; Castellacci, 2008; Fagerberg and Verspagen, 2002; Fagerberg et al., 2007; Lee and Kim, 2009). Sin embargo, estos trabajos aún utilizan regresiones simples: se mantienen estáticos y, más importante aún, no reconocen explícitamente las relaciones bidireccionales entre innovación y desarrollo.

Los ejercicios empíricos más cercanos a los enfoques dinámicos se pueden encontrar en modelos schumpeterianos de equilibrios múltiples, en los que se combina la tradición de "distancia a la frontera" en la brecha tecnológica con diferentes regímenes de convergencia dentro de grupos de países (Castellacci, 2010). Estos modelos proponen una caracterización no lineal de la relación entre innovación, capacidad de absorción y desempeño económico, en la que un umbral mínimo de la capacidad para incorporar el conocimiento es un factor crítico para alcanzar a los líderes o quedarse atrás: las transiciones no suceden en un contexto fijo, sino en un entorno evolutivo donde las brechas tecnológicas están cambiando constantemente. Además, debido a los diversos puntos de partida, el crecimiento económico de los países no se produce de forma homogénea (Acemoglu et al., 2006; Azariadis and Drazen, 1990; Galor and Weil, 2000; Howitt, 2000). Las economías caracterizadas por diferentes condiciones iniciales (por ejemplo, diferentes niveles de ingreso per cápita) tienden a tener trayectorias divergentes de crecimiento a través del tiempo (Durlauf and Johnson, 1995): algunos países logran cerrar la brecha mientras que otros quedan atrás. Los clubes de convergencia emergen como un resultado de este proceso.

Los estudios empíricos recientes extienden la literatura de estos clubs de convergencia y sostienen que la innovación y la difusión de tecnología son los principales factores que explican por qué existen varios regímenes de crecimiento (o diferentes etapas de desarrollo). Esta nueva literatura, que versa sobre los "clubes de tecnología", investiga cómo la relación tecnología-crecimiento difiere entre grupos de países y cuáles son los factores más críticos que determinan la migración de un club a otro (Castellacci and Archibugi, 2008; Castellacci, 2008; Filippetti and Peyrache, 2011). Tres grupos (clubes) se distinguen en función de su capacidad para usar, adaptar y generar tecnología (Galor, 2005; Howitt and Mayer-Foulkes, 2005; Verspagen, 1991): el grupo más avanzado (alta capacidad), el grupo que está cerrando la brecha (*catching-up* en inglés, demostrando aumento de la capacidad), y el grupo más rezagado (baja capacidad).

En los estudios comparativos entre países, los modelos de equilibrios múltiples también son útiles debido a la consideración de la heterogeneidad. En el centro de los principios de economía evolutiva se encuentra la consideración de las especificidades de los agentes, determinadas por su naturaleza, por su proceso particular de aprendizaje y por las interacciones con el medio ambiente (Dosi and Nelson, 1994). De hecho, la perspectiva histórica señala que la heterogeneidad es uno de los aspectos más importantes: el proceso de evolución de los países sólo se puede entender en función a su propio pasado. En este trabajo doctoral, incluso cuando se han aplicado análisis de panel y con el fin de tomar en cuenta esta heterogeneidad, en los estudios empíricos se definió varios grupos de países de acuerdo con su origen geográfico e institucional.

Acercar a los ejercicios empíricos con la teoría requiere operacionalizar los sistemas de innovación: un enfoque de capacidades ha sido seleccionado para evaluar la relación dinámica entre innovación y desarrollo. Sobre la base de Abramovitz (1986), Kim (1980) y Lall (1992); Fagerberg y Shrolec (2008) identificaron un conjunto de capacidades relevantes que pueden ser representativas de los sistemas nacionales de innovación: ellos proponen un conjunto de indicadores y fuentes para medir capacidades a nivel nacional. Su propuesta fue utilizada como una referencia inicial en el análisis empírico que aquí se presenta: a través de una revisión de la literatura, se añadieron otros tipos de capacidades para lograr un abordaje multidimensional. Hay una búsqueda consciente de incorporar la complejidad y el tiempo en el análisis.

En general esta breve introducción a la literatura sobre innovación y los factores de desarrollo económico muestra que la mayoría de los estudios empíricos ha adoptado hasta ahora una perspectiva más bien estática, centrándose en la comparación entre países de los sistemas nacionales en un período determinado de tiempo, abandonando, casi en su totalidad, la dimensión de series temporales en los procesos de crecimiento y desarrollo económico. Este vacío importante en la literatura, entre los estudios empíricos de los modelos teóricos schumpeterianos y los sistemas de innovación, proporciona la motivación general de esta tesis doctoral.

3. OBJETIVOS Y PREGUNTAS DE INVESTIGACIÓN

El objetivo general de esta tesis doctoral es el estudio de las relaciones dinámicas y el proceso de co-evolución entre innovación, crecimiento económico y desarrollo en una amplia muestra de sistemas nacionales en las últimas tres décadas con un enfoque de una serie temporales (cointegración). Se busca contribuir a la literatura y a las recomendaciones de políticas públicas mediante la descripción, basada en la evidencia cuantitativa, de las estructuras que unen las dimensiones multifacéticas de los sistemas de innovación con los sistemas económicos en el tiempo. Lass pregunta de investigación general, que proporcionan una base y conectan entre sí a la mayoría de los capítulos de esta tesis se pueden formular de la siguiente manera:

¿Cómo evolucionan los sistemas nacionales de innovación a través del tiempo? ¿Cuáles son los principales factores de largo plazo? ¿Cómo se diferencia este proceso evolutivo para países con distintos niveles de desarrollo?

El proceso de desarrollo implica una enorme complejidad: al ver los datos de series temporales y sus propiedades dinámicas, se puede evaluar la forma en que se comportan las estructuras y sus cambios. Además, la heterogeneidad es omnipresente, por lo que el análisis de diferentes casos podría mostrar la evolución de las interacciones internas. Se propone no partir de supuestos fuertes y tratar de ver, desde la evidencia empírica, los tipos de relaciones que se están llevando a cabo y cómo éstas podrían afectar al desarrollo económico. La idea es incluir la información complementaria que sólo ***el tiempo*** puede ofrecer.

Para responder estas preguntas, se definieron tres objetivos específicos. Siguen una estructura secuencial: primero, hay un esfuerzo por comprender las bases teóricas del trabajo empírico; en segundo lugar hay un control de viabilidad en términos de disponibilidad de datos y, para terminar se persigue realizar análisis empíricos. Más en detalle, estos tres objetivos son:

- Analizar los enfoques teóricos que vinculan el proceso de innovación con crecimiento económico y desarrollo.
- Generar una base de datos para estudiar los sistemas de innovación y la evolución de los resultados económicos durante las últimas tres décadas.
- Investigar las estructuras que han vinculado, en el tiempo, los sistemas de innovación, el crecimiento económico y el desarrollo. Este análisis debe ser dinámico y depender, en gran medida, del uso de la dimensión del tiempo para incorporar la perspectiva histórica en el ejercicio econométrico.

Como Schumpeter (1934) propone, la historia, la teoría y la estadística siempre deben de ser parte de los análisis económicos. Organizar las ideas de investigación de esta manera, más allá del objetivo de incluir dinámicamente el tiempo en el ejercicio empírico, permite contribuir en dos cuestiones más específicas. La primera es el debate en curso sobre el nivel de la teorización de los sistemas de innovación: a la luz de las teorías de desarrollo disponibles y las deficiencias que pudieran tener, convendría explorar la posibilidad de encontrar complementariedades con los sistemas de innovación. El otro problema está relacionado con la medición de la innovación desde un punto de vista sistémico. Existen propuestas recientes que evalúan las capacidades a nivel nacional con el fin de cuantificar algunas de las características del proceso de innovación. La disponibilidad de datos sería la única limitante en este sentido, sin embargo, existe la posibilidad de utilizar los datos existentes y extraer el máximo provecho de ella para los análisis empíricos.

3.1 METODOLOGÍA ECONOMÉTRICA

Durante las últimas dos décadas, el número de análisis econométricos que investigan problemas evolutivos ha crecido. Una de las razones es la disponibilidad de datos: el paso del tiempo ha permitido la recolección de datos en las principales dimensiones (como el gasto en actividades de I+D, por ejemplo), abriendo la puerta a la econometría de series temporales y de panel. Además, los nuevos métodos se han desarrollado para incluir el efecto de los acontecimientos precedentes como determinantes de las estructuras y patrones que definen los sistemas económicos. Uno de esos métodos avanzados es el modelo de vectores autorregresivos, el cual permite la plena endogeneización y efectos cruzados de las variables del sistema, incorporando la información del pasado para explicar los estados actuales (Greene and Zhang, 1997). En particular, hay un método específico que ha tenido mucha influencia en esta tesis: la metodología de cointegración, principalmente desarrollada por Johansen (1995, 1991), es útil para separar las relaciones entre las variables que se mueven juntas en el tiempo, tal como un sistema. Si se confirma la cointegración – lo que significa que el vector contiene una raíz unitaria y que las variables incluidas se mueven juntos – es posible distinguir entre las relaciones de largo plazo, que se encuentran en el núcleo del sistema y la estructura de corto plazo, que representan cómo el sistema reacciona a los cambios (Hendry and Juselius, 2000; Juselius, 2006).

Al investigar la estructura de corto plazo, es posible señalar las relaciones de causalidad entre las variables, una característica de las dinámicas del sistema. La forma en la que las variables logran adaptarse a los cambios en la estructura de largo plazo y cómo transitoriamente se ajustan a las nuevas condiciones es una rica fuente de información (Juselius, 2006). Mediante la aplicación de la metodología de cointegración se puede aportar pruebas de los motores de los sistemas económicos, de las relaciones que la estructura temporal revela, de las interacciones globales de los agentes. Además, esta metodología no impone fuertes restricciones: está orientada a utilizar la información contenida en los datos para arrojar luz sobre las relaciones sistémicas. Es una alternativa a los métodos rígidos que prueban modelos en el que las teorías se confirman o rechazan; su objetivo es iluminar los hechos empíricos que pueden mejorar los esfuerzos de teorización (Colander et al., 2009; Frydman and Goldberg, 2008; Hoover et al., 2008).

Debido a estas ventajas, la metodología de cointegración se ha encontrado muy adecuada para los análisis empíricos a los sistemas de innovación y el desarrollo económico. Es una metodología versátil que coincide con gran parte de la flexibilidad que los sistemas de innovación exigen, que reconoce la historia como la principal fuente de información y que evalúa las relaciones como el resultado de los efectos mutuos entre diferentes dimensiones. En esta tesis, se presenta este enfoque econométrico como una forma de cerrar la brecha entre la teoría y empirismo: los análisis cualitativos son elementos básicos de la investigación económica y se propone que también son necesarios enfoques cuantitativos para tener una visión completa. De hecho, ambos ejercicios son fundamentales y deben ser aplicados en un contexto histórico.

Los análisis empíricos cuantitativos consisten en dos tipos de enfoques de cointegración. La cointegración de series temporales evalúa datos para un único país en un período determinado, es una metodología adecuada para considerar la heterogeneidad en su mayor expresión: la evaluación individual permite identificar eventos específicos en cada país, es la versión más cercana a la utilización de análisis empíricos en forma de estudios de caso (Hendry and Juselius, 2000). Además, este enfoque permite analizar la estructura de tiempo en un nivel más profundo: una vez que las relaciones entre las variables se han resuelto, es posible investigar la capacidad de respuesta del sistema (Juselius, 2006). El otro enfoque es cointegración en panel: combina la información de series de tiempo con la estructura de la sección transversal, a través de lo cual se potencia la estimación. Al ampliar el número de datos, se puede realizar un ejercicio mucho más complejo: una mayor cantidad de variables pueden ser incluidas gracias al incremento de grados de libertad disponibles (Breitung and Pesaran, 2006). En el caso de panel, la heterogeneidad, sin embargo, no puede caracterizarse a su nivel más alto (Pedroni, 2001; Persyn and Westerlund, 2008): la agrupación de países, según sus similitudes en términos institucionales y de proximidad geográfica, ha sido la estrategia para no dejar este factor de lado. En cualquier caso, es la combinación de ambos enfoques (el de panel y el de series temporales) lo que enriquece la solidez de las conclusiones de esta tesis doctoral.

4. UNA APROXIMACIÓN EMPÍRICA A LA INNOVACIÓN, EL CRECIMIENTO Y EL DESARROLLO

Cuatro documentos se incluyen en esta tesis. El primero contiene las consideraciones teóricas de las relaciones entre la innovación y el desarrollo económico. En el segundo documento abrió la puerta a la metodología econométrica: proporcionó datos completos de series temporales en los últimos tres decenios para más de 130 países. Finalmente, los últimos trabajos son dos contribuciones empíricas para el análisis de la dinámica de la innovación y la interacción con el crecimiento económico y el desarrollo. En las siguientes líneas de cada uno de estos artículos científicos serán introducidos.

4.1. DESARROLLO: UN ENFOQUE SISTÉMICO

El primer documento se llama "*How innovation systems and development theories complement each other*"[1] ("Cómo los sistemas de innovación y las teorías de desarrollo se complementan entre sí"), escrito con Mario Pansera (2013). Forma parte de esta recopilación con el fin de dar una definición de desarrollo y su interacción con los sistemas de innovación. El objetivo principal de este artículo es evaluar cómo el marco de los sistemas de innovación se podría aplicar a las caracterizaciones teóricas más influyentes del desarrollo, identificando las interacciones bidireccionales.

En este trabajo se propone una definición multidimensional del desarrollo: "no es sólo una cuestión de dotación de factores, sino que implica la interacción de las habilidades sociales y el uso productivo del conocimiento" (Natera y Pansera, 2013). Desarrollo, por tanto, difiere del crecimiento económico, ya que va más allá de la posesión de bienes o de la correcta asignación de los recursos. De hecho, ambos conceptos no son considerados antagónicos por naturaleza, pero se necesita un enfoque sistémico si el objetivo es analizar cómo el desarrollo puede tomar lugar. Teniendo en cuenta la

[1] Este documento se ha enviado a la revista científica *Prometheus: critical studies on Innovation* (http://www.tandfonline.com/loi/cpro20); está actualmente bajo proceso de revisión.

innovación como uno de los factores clave para impulsar el desarrollo, se propone que la visión de los sistemas de innovación es ideal para este tipo de estudios.

La caracterización de los sistemas de innovación incluye los agentes y sus interacciones, el proceso de aprendizaje que realizan y el entorno institucional en el que están inmersos. Los sistemas de innovación se presentan como un marco flexible que podría arrojar luz sobre el análisis de las relaciones complejas de desarrollo, que surge como una herramienta para la acción en lugar de una teoría rígida, son versátiles y se adecuan a diferentes enfoques teóricos.

Dado que los sistemas de innovación se originaron en países de la OCDE, es necesario hacer una evaluación de algunas consideraciones desde el Sur. Destacamos la importancia de adoptar un enfoque de creación de capacidad al usar los sistemas de innovación como instrumentos de desarrollo. También estamos de acuerdo con Arocena y Sutz (2000) cuando consideran que los Sistemas de Innovación son un concepto ex-post de los países en desarrollo, que se acompaña de una carga normativa y que se trata de un modelo relacional útil para la formulación de políticas. Hemos tomado estas ideas como aportes para revisar la literatura.

"*Desarrollo como libertad*", *la economía institucional, la teoría neoclásica del crecimiento, el enfoque de equilibrio múltiple, el estructuralismo latinoamericano* y *la teoría del sistema mundo* son las teorías de desarrollo analizadas en el documento, siempre desde una perspectiva sistémica: la innovación se coloca en el centro de ellas, en una búsqueda de relaciones simbióticas en las que se combinen la flexibilidad y la estructura. De hecho, a la luz del debate en curso sobre la formalización del enfoque de sistemas de innovación, sostenemos que su combinación con las teorías del desarrollo podría generar nuevos marcos de análisis para la comunidad de investigación: es una forma de aumentar el poder del análisis y dar constante actualización a los presupuestos teóricos.

En cuanto a los análisis empíricos desarrollados en esta tesis, el enfoque de equilibrios múltiples ha sido el que tiene la mayor influencia. Ha sido seleccionado por su idoneidad para hacer comparaciones internacionales: se tiene en cuenta la heterogeneidad entre países y considera el desarrollo como un proceso dinámico. En función a la definición de desarrollo presentada, se ha aplicado una visión sistémica complementaria al enfoque equilibrios múltiples: se ha aumentado la complejidad de las dimensiones consideradas, lo que permite una combinación de factores socio-económicos y tecnológicos multifacéticos.

4.2. DATOS PARA EL DESARROLLO

El análisis empírico necesario para evaluar el desarrollo exige datos. Además, si la idea es ser inclusivo y no sólo centrarse en los países más avanzados, un gran reto se presenta: la falta de datos puede impedir el uso de los análisis econométricos. Esta fue la motivación del segundo artículo de esta compilación: "*A new panel dataset for cross-country analyses of national systems, growth and development (CANA)*" ("Un nuevo panel de datos para el análisis de sistemas nacionales, crecimiento y desarrollo (CANA)"), escrito con Fulvio Castellacci (2011), es un esfuerzo para poner a disposición datos para estudios de desarrollo con series temporales.

Los investigadores interesados en los análisis empíricos del desarrollo a menudo han tenido que elegir entre estudiar un grupo seleccionado de países – normalmente los de la OCDE y los países de ingresos medios – y aplicar técnicas de series de tiempo, o bien, aumentar el número de países de la muestra y aplicar metodologías de regresión transversal (estáticas). Esta situación es desafortunada: la primera opción deja fuera a los países que necesitan más atención, aquellos en los que las actividades de investigación podrían tener un mayor impacto en términos de mejorar la calidad de vida; la segunda opción no investiga a fondo la dinámica y la evolución de los sistemas económicos. En particular, para los estudios de innovación, pensamos que no tener en cuenta plenamente el proceso evolutivo es una gran limitación. En este trabajo propone una salida a este problema.

Mediante la aplicación de un nuevo método de imputación múltiple (Honaker and King, 2010), se construyó un panel de países con datos completos. El método utiliza los datos existentes para estimar los puntos faltantes: combina la tendencia de cada país en el tiempo con las observaciones de corte transversal para producir, a través de un algoritmo de expectación-maximización, un conjunto completo de datos estimados que se asemeja a la distribución originalmente observada. El conjunto de datos, en su primera versión, contiene 41 indicadores para medir seis dimensiones fundamentales: innovación y capacidad tecnológica, sistema de educación y capital humano, infraestructuras, competitividad económica, factores político-institucionales, y capital social[2]. Consta de 134 países y 29 años, de 1980 a 2008.

La calidad de la estimación se puso a prueba mediante la comparación de la distribución de los datos observados y los datos completos. También se aplicó un análisis de correlación. Sólo aquellos indicadores que resultaron ser fiables se incluyeron en el conjunto de datos. Un anexo con los detalles del proceso de estimación y de transformación de datos está a disposición del público. Como parte de la contribución, se ha ofrecido a la comunidad científica los datos generados en http://cana.grinei.es.

El método aquí propuesto ofrece una serie de ventajas frente a otras posibilidades. En primer lugar, incluye una mayor participación de los países en desarrollo, una visión más representativa del mundo. En segundo lugar, usa la información ya disponible para producir estimaciones sin imponer ningún modelo a los datos. Por último, las técnicas de series temporales son ahora factibles y, por tanto, la dinámica de los sistemas nacionales de innovación y sus interacciones con el desarrollo económico pueden ser evaluadas cuantitativamente.

4.3. ESTRUCTURAS EN EL TIEMPO: CAUSALIDAD Y SENDEROS DE DESARROLLO

La evolución es un proceso que se desarrolla ***el tiempo***. Podría decirse que la única manera de analizar la estructura de revelado de un proceso evolutivo es mediante la incorporación de la dimensión ***tiempo*** en el análisis. El documento *"Innovation, Absorptive Capacity and Growth Heterogeneity: Development Paths in Latin America 1970–2010"*[3] ("Innovación, capacidad de absorción y heterogeneidad del crecimiento: vías de desarrollo de América Latina 1970-2010"), escrito con Fulvio Castellacci (2013a), lleva a cabo un análisis de series temporales para cada uno de los 18 países incluidos en la muestra.

Los países de América Latina fueron seleccionados debido a la relevancia de los cambios estructurales en las últimas cuatro décadas: la región está formada por países

[2] Una versión más reciente (construida en el 2012) incluye 80 indicadores. El conjunto de datos fue ampliado al añadir dos dimensiones más: *Estructura Productiva* e *Internacionalización*. El objetivo de esta adición ha sido aumentar la complejidad en el análisis.

[3] Este documento se ha enviado a la revista científica "Structural change and economic dynamics" http://www.journals.elsevier.com/structural-change-and-economic-dynamics/; está actualmente en proceso de revisión.

de ingresos medios en los que el proceso de crecimiento sostenido parece estar teniendo lugar en estos momentos. En base a impulso actual de estas economías, parece interesante evaluar qué tan bien preparados están sus estructuras económicas para pasar a un nivel de desarrollo más alto. La muestra está compuesta por 18 países, estudiados entre 1970 y 2010, periodo que representa la transición del proceso de industrialización por sustitución de importaciones hacia una economía más global y abierta. Muchos de los cambios estructurales se han producido en ese período, por lo que el estudio podría revelar los factores motrices subyacentes que han sostenido el proceso económico. Además, debido a la diferente combinación de políticas que cada país ha seguido, América Latina podría arrojar luz sobre las repercusiones de esta mezcla en el desarrollo.

Basado en Verspagen (1991), se presenta un modelo que tiene en cuenta el efecto de tres dimensiones en el crecimiento económico: uno está relacionado con las actividades de innovación y otros dos están vinculados a la imitación. La apertura y la estructura industrial son los factores que representan la capacidad de los países para aprender de los efectos secundarios generados en el exterior. Dos hipótesis acompañan a este modelo: en primer lugar, los países seguirán caminos diferentes según la combinación de políticas que hayan adoptado, en segundo lugar, los países que combinan las políticas de innovación de imitación y tienen una mayor tasa de crecimiento económico.

Los resultados provienen de un modelo de corrección de error del vector en series de tiempo. Se utilizó la metodología de cointegración de Johansen para analizar la causalidad de largo plazo que vinculan el crecimiento económico con diferentes estrategias de política. Los indicadores seleccionados son: patentes per cápita (la política de innovación), el flujo de IED (imitación - apertura) y tres representaciones diferentes de la estructura industrial: la industria, los servicios y los recursos naturales en porcentajes del PIB.

La selección de indicadores es un proceso difícil. El uso de patentes en el contexto de América Latina, por ejemplo, tiene importantes limitaciones pues subestima la actividad innovadora que se lleva a cabo en la región. También, para la estructura industrial y la apertura podríamos encontrar argumentos similares. Estos hechos abren la puerta para un posterior análisis y ubican, desde el principio, los resultados de este trabajo como un paso inicial para describir empíricamente camino de desarrollo de América Latina.

En el último artículo de esta tesis se ha llevado a cabo un ejercicio de panel para analizar las relaciones dinámicas entre la innovación y el desarrollo. Esta metodología permitió la aplicación de una caracterización más compleja del proceso y evaluar las diferencias entre regiones del mundo. El documento *"The dynamics of national innovation systems: a panel cointegration analysis of the coevolution between innovative capability and absorptive capacity"* ("Las dinámicas de los sistemas nacionales de innovación: un análisis de cointegración de panel de la co-evolución entre la capacidad innovadora y la capacidad de absorción"), escrito con Fulvio Castellacci (2013b), es una propuesta para investigar la evolución de 87 países , durante las últimas tres décadas[4].

En este trabajo se destaca la importancia de comprender cómo la innovación tiene lugar. Además de la inclusión del tiempo en el análisis, hay tres motivaciones más detrás de este ejercicio aplicado. En primer lugar, la investigación empírica se ha centrado principalmente en la relación entre crecimiento económico e innovación, mientras que los esfuerzos por comprender el propio proceso de innovación no han sido tan numerosos. Se podría estar corriendo el riesgo de saltar a las conclusiones sin haber entendido cómo funciona el motor del crecimiento sostenible. Recientemente, algunos trabajos empíricos han revivido el interés en éstos aspectos tecnológicos: se han centrado en las capacidades tecnológicas y de innovación de los países como una manera de explicar su desempeño económico (Castellacci, 2011; Filippetti and Peyrache, 2011). Este trabajo está orientado a contribuir en esta dirección.

En segundo lugar, la capacidad de absorción normalmente ocupa un papel secundario en análisis empíricos. Para los países en desarrollo, esto podría subestimar sus posibilidades de cerrar la brecha. Este resultado es bastante sorprendente, ya que la literatura ha destacado el papel de los derrames (*spillovers*, en inglés) y las actividades de imitación en el proceso de convergencia, sobre todo en el aprendizaje continuo de los países y la acumulación de capacidades (Aghion et al., 2001; Lee and Kim, 2009; Pérez and Soete, 1988; van Elkan, 1996; Verspagen, 1991). Teniendo en cuenta la complejidad de este concepto, es posible explicar buena parte de la dinámica del

[4] Con el objetivo de superar limitaciones econométricas (grados de libertad), un nuevo proceso de imputación fue aplicado, siguiendo la misma metodología descrita en Castellacci y Natera (2011). El periodo de tiempo fue ampliado de 1970 al 2010.

desarrollo: en lugar de considerarlo un factor de control en los ejercicios empíricos, se plantea endogeneizar este subsistema en el análisis.

Por último, estos dos subsistemas co-evolucionan para impulsar el desarrollo económico y se necesita más evidencia empírica para describir cómo se producen estas relaciones. No se evalúa la imitación y la innovación como actividades separadas, sino más bien se trata de procesos entrelazados. Se ha propuesto un modelo donde se representan tres subsistemas. En el primero se encuentran las capacidades innovadoras: los recursos para la innovación (el esfuerzo y la inversión en I+D y en las actividades relacionadas), la producción científica (resultados de las actividades de investigación e innovación del sistema público de Ciencia y Tecnología) y la producción tecnológica (la producción total de las actividades tecnológicas y de innovación llevado a cabo por empresas privadas). En el segundo subsistema está la capacidad de absorción, muy diversa en su composición, pues incluye: el comercio internacional (apertura del sistema nacional), capital humano (educación y habilidades de la población), infraestructuras (red de transporte, distribución, etc), la calidad de las instituciones y la gobernanza sistema (eficiencia del sistema de gobierno), la cohesión social y la desigualdad económica (efectos de la igualdad en la confianza y el intercambio de conocimientos entre las personas). Finalmente, en el tercer subsistema está el nivel de ingresos (PIB per cápita) como componente final del modelo: es un indicador del desempeño global de los países y – en el contexto de las interacciones sistémicas – de su nivel de desarrollo.

La configuración propuesta de los sistemas nacionales de innovación nos lleva a cuatro proposiciones (Castellacci and Natera, 2013):

- La dinámica de la capacidad de innovación es impulsada por la co-evolución de los tres factores que la definen: recursos para la innovación, producción científica y producción tecnológica.
- La dinámica de la capacidad de absorción es impulsada por la co-evolución de las cinco dimensiones que lo definen.
- La capacidad de innovación y la capacidad de absorción co-evolucionan con el tiempo, es decir, estas dos dimensiones están unidas entre sí por un sistema de dos vías relaciones dinámicas.

- La dinámica de la capacidad de innovación y la capacidad de absorción y la co-evolución entre ellos, difieren entre los grupos de países que se caracterizan por diferentes niveles de desarrollo.

El modelo de vector de corrección de error, en su versión de panel, fue el método econométrico seleccionado. Esto permitió examinar la estructura causal que vincula las variables dentro entre las capacidades de innovación, la capacidad de absorción y el nivel de ingresos. Se muestra la estructura en el tiempo: por un lado, se observan las relaciones de equilibrio a largo plazo en el que las variables se mueven juntas (como partes de un sistema), en el otro, se describe la estructura de la causalidad para revelar cómo las variables reaccionan cuando algo cambia en el sistema. Los resultados se organizan en función de estos dos tipos de tiempos de las estructuras y de los diferentes grupos de países: la heterogeneidad ha sido abordada a través de la creación de grupos de países en función a su origen geográfico e institucional.

5. UNA VISIÓN GENERAL DE LA TESIS DOCTORAL

La Tabla 1 presenta una breve descripción del contenido y estado actual de cada artículo que forma parte de la tesis doctoral.

Tabla 1. Una visión general de los artículos incluidos en la tesis doctoral

Título y co-autores	Publicación	Objetivo	Metodología
"How innovation systems and development theories complement each other" (con Mario Pansera)	*Prometheus: critical studies on Innovation* (en proceso de evaluación)	Investigar las interacciones entre los Sistemas de Innovación y teorías de desarrollo seleccionadas.	Revisión de la literatura relacionada con los Sistemas de Innovación con Desarrollo como la libertad, la economía institucional, la teoría neoclásica del crecimiento, el enfoque de equilibrio múltiple, el estructuralismo latinoamericano y la teoría del sistema mundial.
"A new panel dataset for cross-country analyses of national systems, growth and development (CANA)" (con Fulvio Castellacci)	*Innovation and Development,* 1(2), 205–226, 2011	Desarrollar de un conjunto de datos de panel (134 países y 29 años) adecuado para el análisis de series temporales de innovación, desarrollo y crecimiento económico.	Aplicación de un nuevo método de imputación múltiple que genera estimaciones de los datos faltantes mediante la extracción de la información existente de los datos observados.
"Innovation, Absorptive Capacity and Growth Heterogeneity: Development Paths in Latin America 1970–2010" (con Fulvio Castellacci)	*Structural Change and Economic Dynamics* (en proceso de evaluación)	Identificar de las fuerzas motrices del desarrollo de América Latina en las últimas cuatro décadas.	Análisis de series temporales de 18 países de América Latina mediante el uso de modelos de corrección de error del vector (el enfoque de Johansen) para identificar estimaciones causalidad a largo plazo entre crecimiento económico, innovación y capacidad de absorción.
"The dynamics of national innovation systems: a panel cointegration analysis of the coevolution between innovative capability and absorptive capacity" (con Fulvio Castellacci)	*Research Policy,* *42*(3), 579–594, 2013	Analizar la co-evolución de los subsistemas de la capacidad de innovación, la capacidad de absorción y crecimiento económico a lo largo de diferentes niveles de desarrollo.	Análisis de cointegración en panel de 87 países durante los últimos tres decenios. La heterogeneidad se evaluó mediante la definición de 5 grupos de países en función de su procedencia geográfica e institucional.

6. Conclusiones, limitaciones y posibles extensiones

El tema principal de esta tesis es la relación dinámica entre innovación, crecimiento económico y desarrollo. Es un esfuerzo por contribuir a la literatura mediante la presentación de cuatro documentos: dos de ellos tienen una orientación conceptual y metodológica, mientras que los otros analizan, desde una perspectiva empírica, la estructura que se desenvuelve el tiempo. Este capítulo tiene como objetivo discutir las principales conclusiones, limitaciones y desarrollos que el compendio de estos cuatro documentos puede ofrecer.

6.1. Conclusiones

En primer lugar, todavía hay un debate en curso acerca de la caracterización de los sistemas de innovación como una teoría, un concepto o un marco para entender el desarrollo y el crecimiento económico. Este problema surge de la necesidad de contar con bases sólidas para el estudio de los procesos evolutivos: los sistemas de innovación son frecuentemente criticados por sus fundamentos teóricos y estructura laxa (Niosi et al., 1993). Sin embargo, esta crítica no tiene en cuenta que la teorización evolutiva debe basarse en estructuras abiertas, en las que la complejidad y la información procedente de entornos que no sean estáticas deben ser incorporados permanentemente en el análisis (Nelson and Winter, 2002, 1977). Teniendo esto en mente, el estudio de las teorías de desarrollo más influyentes y su interacción con los sistemas de innovación, se sugiere cambiar el foco del debate sobre las bases teóricas de los sistemas de innovación. La alternativa ofrecida propone que considerar la complementariedad entre el enfoque de sistema de innovación y las teorías del desarrollo seleccionados aumenta el poder explicativo sobre el proceso de desarrollo.

Las teorías de desarrollo podrían ser un ángulo para observar y describir los fenómenos sistémicos de innovación. La flexibilidad de los sistemas de innovación es útil para incorporar la complejidad en el análisis teórico del desarrollo económico y podría ser una fuente de adaptación y evolución de las teorías que complementa: ofrece una ventana abierta para revisar constantemente los fundamentos teóricos en los que la investigación y la política se están diseñando (Lundvall et al., 2009).

Los análisis empíricos incluidos han sido concebidos a partir de esta visión. Los modelos se han inspirado en la tradición de "distancia a la frontera". Naturalmente, estos modelos se han aumentado para incluir las dimensiones socio-institucionales, las capacidades tecnológicas, actividades de internacionalización y la estructura productiva como factores determinantes del nivel de desarrollo. Los resultados de esta tesis confirman la validez de esta visión, pues van en contra de los enfoques reduccionistas: dado que las estructuras difieren entre los distintos países, si las características multifacéticas del proceso de desarrollo económico no están incluidos en el análisis, hay un alto riesgo de dejar a un lado variables críticas que son fundamentales para que la economía en particular (Foray, 2004).

Sin investigar la estructura del sistema, no es posible discriminar, *a priori*, la importancia relativa de las capacidades específicas: se requiere un amplio espectro de posibilidades para evaluar las características multidimensionales. La construcción del conjunto de datos CANA (Castellacci and Natera, 2011) es un primer paso para la operacionalización pues 80 indicadores están disponibles para representar la interacción de las ocho capacidades diferentes. Todavía es una simplificación de la enorme complejidad de los procesos económicos, pero este enfoque reduce la brecha entre la teoría y los ejercicios empíricos relacionados.

Hoy en día, los análisis empíricos dinámicos podrían acercarse a las expectativas de los fundamentos teóricos de la innovación y el desarrollo económico. Sólo para empezar, los datos no son tan problemáticos como lo eran en el pasado. Los métodos de imputación múltiple permiten la explotación de los datos disponibles a nivel de país (Castellacci and Natera, 2011): no obliga a las estimaciones a responder a un modelo en particular, sino que considera la heterogeneidad de los procesos y las interacciones entre las variables en la estimación de datos. Además, hay métodos robustos para evaluar la fiabilidad de las estimaciones. En la situación ideal, por supuesto, se utilizarían únicamente datos observados construidos de acuerdo con estrategias metodológicas iguales en todos los países (Smith, 2005). Es imposible no reconocer que existen algunos riesgos cuando usamos datos a nivel de país y que éstos se vuelven más importantes cuando estimamos datos faltantes. La imputación múltiple no es una solución perfecta para todos los casos (Abayomi et al., 2008), ni es un remedio universal, pero es un facilitador de información importante: brinda la oportunidad de investigar la estructura revelada entre innovación y desarrollo, una puerta abierta para aplicar metodologías econométricas verdaderamente dinámicas.

La metodología de cointegración es una de las herramientas econométricas más adecuadas para llevar a cabo análisis empíricos sobre desarrollo e innovación desde un enfoque sistémico. En primer lugar, considera cómo las variables se mueven juntas y reaccionan cuando se produce un cambio: determina la dinámica de los efectos no lineales entre las diferentes relaciones. Por otra parte, la metodología de cointegración tiene la ventaja de diferenciar la estructura de largo plazo de la de corto plazo. Dado el gran reto de los procesos de desarrollo de investigación, toda posibilidad de distinguir entre efectos a largo plazo y los transitorios, es útil para la interpretación de los resultados y su transformación en recomendaciones de política.

La aplicación de esta metodología ha proporcionado nuevos conocimientos sobre las relaciones entre innovación y desarrollo. Se ha ofrecido una nueva visión de las estructuras reveladas en el tiempo. En los dos ejercicios diferentes (panel y series temporales), los vínculos entre las distintas capacidades se han descrito en función a sus efectos unidireccionales o recíprocos, lo cual ha dado como resultado la creación de una red de causalidades. Este es un paso adelante en la incorporación de la historia en la econometría de la innovación: presente, pasado y cambios en las variables se consideran al mismo tiempo para extraer los patrones de sus interacciones (Hoover et al., 2008).

Los resultados empíricos han ofrecido una rica fuente de información, especialmente en materia de política. La primera de ellas está relacionada con la complejidad del desarrollo económico. En este sentido, hay dos ideas principales. El caso del panel (Castellacci and Natera, 2013b) mostró que hay pruebas de la co-evolución entre las capacidades innovadoras, la capacidad de absorción y el crecimiento económico. Esto pone de manifiesto que los enfoques reduccionistas que no tienen en cuenta la naturaleza multidimensional del desarrollo pueden fallar con recomendaciones pertinentes: un cambio en cualquier parte del sistema conducirá a muchos cambios en las otras dimensiones, y en consecuencia, los resultados esperados en alguna dimensión específica dependerá también sobre los efectos que recibe de todo el resto del sistema (Arthur, 1999).

Siendo este el caso, el mensaje principal es claro: las estrategias de desarrollo necesitan coordinación masiva. La evidencia señala que no es suficiente centrarse en un sector en particular o una parte reducida del sistema cuando el desarrollo es el objetivo. Ciertamente, hay algunas dimensiones que tendrán un mayor impacto en el sistema y, por lo tanto, pueden ser utilizadas para dar prioridad a las acciones de política, como es el caso de la innovación. Sin embargo, los lazos de retroalimentación se mantendrán como fuentes cruciales de la causalidad: las actividades innovadoras se insertan en una estructura compleja de fuerzas motrices.

Tanto las series temporales como el caso del panel han mostrado que la complejidad y el desarrollo económico se mueven juntos. Los países que han logrado aumentar la interacción entre sus capacidades son los que presentan un nivel de desarrollo más alto. Esto implica que el crecimiento sostenible sólo puede lograrse mediante la construcción de puentes entre las diferentes fuentes de conocimiento, al tener una fuerte conexión entre los diferentes agentes.

Quizás la principal implicación de la complejidad está relacionada con la configuración institucional para hacer frente a la promoción de la innovación. Especialmente en los países en desarrollo, se han creado organismos ministeriales para fomentar las actividades de ciencia, tecnología e innovación. Esta decisión no es perjudicial en sí misma, pero conlleva el riesgo de asignar toda la responsabilidad de la construcción de capacidades de innovación en una organización restringida: el carácter multidimensional de la innovación y el desarrollo deben encontrar contrapartes en las estructuras institucionales de los países. Por supuesto, debido a la alta heterogeneidad encontrada, el diseño institucional debe ser específico a cada país.

El ejercicio de series de tiempo (el caso de América Latina) es un buen ejemplo de por qué la especificidad es necesaria (Castellacci y Natera, 2013a). Las sendas de desarrollo se construyen mediante la combinación de las decisiones estratégicas que cada país ha seguido. La combinación de las políticas de innovación e imitación es la mejor práctica que, sobre la base de los resultados empíricos, podría recomendarse a los responsables políticos. Indudablemente, es importante no olvidar que las estrategias de desarrollo depende en gran medida de las condiciones históricas, las decisiones tomadas en el tiempo hacen imposible volver a aplicar plenamente las estrategias exitosas probadas: las acciones son específicas en el tiempo y, por lo tanto, no pueden ser replicadas a ciegas. En base a las capacidades reveladas y a las interacciones entre ellas, las sociedades deben coordinarse y acordar la forma en que construirán las competencias que necesitan.

El análisis de panel, presentado en el Capítulo 5, también confirma la importancia de considerar la heterogeneidad en las relaciones entre desarrollo económico e innovación. Como se señala en el documento, se configuraron cinco grupos de países, de acuerdo a sus características geográficas e institucionales, lo que proporcionó resultados más consistentes: la cantidad de relaciones causales aumenta con el nivel de desarrollo. Sin embargo, es importante destacar que no se trata sólo de una cuestión de encontrar un mayor número de interacciones causales en los países más desarrollados: la causalidad se configura de forma diferente para cada grupo de países, en función de su propia trayectoria particular.

6.2. LIMITACIONES

Algunas limitaciones se han enfrentado durante el desarrollo de esta tesis. Por ejemplo, la captura de las dimensiones complejas, implícitas en los procesos de cierre de brechas con los países líderes, es un gran desafío. Los indicadores disponibles no están libres de defectos. Esto, por supuesto, es parte de la naturaleza de muchos análisis económicos, pero es especial relevancia cuando el objetivo es investigar los procesos evolutivos (Kleinknecht et al., 2002). La construcción de la base de datos CANA (Castellacci and Natera, 2011) es un esfuerzo por superar este problema, sin embargo, la discusión está lejos de cerrarse. Desde un punto de vista metodológico, los cambios en el proceso de recolección de datos y otras fuentes exógenas de variación (por ejemplo, la implementación de nuevos procedimientos legales, redefinición de términos, los cambios en los cuestionarios, entre otros) pueden afectar la medición del indicador y la información que se pudiera extraer de él (Hall et al., 2010): el uso de series temporales implica tener en cuenta que los cambios de un año a otro podrían ser causados por cambios metodológicos y no necesariamente por los cambios en el proceso que se busca medir. En cierta medida, este problema es difícil de resolver ya que los cambios metodológicos no siempre se informan al máximo detalle.

Hay, sin embargo, otra cuestión que está más relacionada con el enfoque conceptual: la selección de indicadores como representación de procesos de innovación o capacidades de absorción es una tarea difícil. De hecho, esta es una limitación importante del ejercicio de series temporales aplicado a los países latinoamericanos. Para las economías en desarrollo, el uso de patentes como indicador de las actividades de innovación genera fuertes debates (Archibugi and Coco, 2004; Archibugi et al., 2009; Vaitsos, 1972): debido a la baja propensión a patentar, al escoger este indicador se subestiman los resultados de la innovación. Además, la medición de la capacidad de absorción como una combinación de indicadores no está libre de obstáculos: hay que tener en cuenta su carácter multifacético y esto sólo es posible cuando las diferentes dimensiones forman parte del análisis. El asunto está en saber cuándo detenerse: si bien una minuciosa revisión de la literatura permitió construir el conjunto de datos CANA con una visión amplia (a fin de hacer frente al sesgo de selección) y los análisis de sensibilidad han demostrado la fiabilidad de los resultados; es justo reconocer que distintas fuentes también podrían ser adecuadas para el análisis que aquí se presenta, por lo que se propone una postura abierta a aplicar otros análisis de sensibilidad.

Otras limitaciones están relacionadas con la caracterización de la estructura de tiempo. En primer lugar, la inclusión de cambios estructurales en los análisis del panel no ha sido completamente desarrollado (Banerjee, 2006; Banerjee et al., 2004): no es posible controlar totalmente los cambios en los patrones de comportamiento de las variables (escalones, colapsos o cambios en la tendencia) al analizar los grupos de países en forma conjunta. En segundo lugar, incluso en el caso de series temporales, en el que los cambios estructurales pueden ser descritos, las estructuras reveladas por este análisis podrían cambiar con el tiempo: es importante revisar continuamente el modelo mediante la adición de nueva información que podría mejorar y actualizar los resultados. No se trata de procesos estáticos, el entorno es siempre cambiante, los agentes aprenden y se transforman a sí mismos y a sus interacciones. En este sentido, al menos para el caso de series temporales, hay pruebas disponibles recursivas en la que la estabilidad de los parámetros se puede evaluar (Juselius, 2006): la fiabilidad de estas pruebas, sin embargo, se limita por el lapso de observación de las variables disponibles en la actualidad: la recopilación de datos futuros ofrecerá la oportunidad de alimentar las bases de datos y solucionar estos problemas también.

6.3. POSIBLES EXTENSIONES

Otras características de la estructura de tiempo también podrían ser estudiados. Hasta ahora, se ha utilizado el tiempo para evaluar las estructuras que sustentan el desarrollo económico y la innovación. También se podría utilizar esta información para analizar la capacidad de respuesta del sistema, para tratar de responder a la siguiente pregunta: ¿Cuánto tiempo se tarda en ver la reacción del sistema cuando hay un cambio en alguna dimensión? ¿Todas las dimensiones reaccionan exactamente al mismo ritmo? Esto podría tener implicaciones importantes para la formulación de políticas: si la evaluación llega demasiado pronto (o tarde) para capturar su impacto real, se tendrá una visión errada de la eficacia de esa acción. En cambio, si se evalúa la rapidez con la que reacciona el sistema, sería posible ajustar el tiempo de evaluación en consecuencia. Las funciones de impulso respuesta (*IRF*, por sus siglas en inglés) podrían proporcionar esta información (Hamilton, 1994): ellas muestran cómo los cambios se propagan en el sistema, cómo las variables alcanzan diferentes niveles de estabilidad en puntos particulares de tiempo.

Además del análisis de cointegración, otros ejercicios econométricos dinámicos podrían aplicarse. Foster y Wild (1999) presentan una alternativa interesante: la aplicación de un modelo de difusión logística aumentada (*ADLM*, en inglés), en el que se caracterice el cambio estructural de los sistemas económicos como un resultado de las estructuras de auto-organización. La utilidad de este nuevo enfoque es la posibilidad de endogeneizar los puntos críticos en los que se presentan los procesos disruptivos.

Otras posibilidades están vinculadas al análisis de la complejidad, desde diferentes perspectivas. Por ejemplo, utilizando el espacio del producto de los países, Hidalgo y Hausmann (Hidalgo and Hausmann, 2009; Hidalgo et al., 2007) plantearon previamente conclusiones similares a las de este trabajo doctoral. Los países que han logrado aumentar la red de productos que producen y exportan muestran un mayor nivel de desarrollo. Asimismo, ellos proponen que este aumento de la complejidad es compatible con las capacidades necesarias para disfrutar de una red diversificada e interconectada de productos. La construcción de puentes entre estos dos tipos de complejidad sería un proyecto útil: permitiría a los hacedores de políticas públicas comprender cuáles acciones claves se necesitan para diversificar la estructura sectorial de los países. Hausmann e Hidalgo usan una metáfora para explicar cómo funciona su complejidad económica: las empresas están representadas por monos que saltan de un árbol (sector) al otro, en busca de las actividades más rentables; para ponerlo en palabras simples, la combinación de su análisis con el enfoque de capacidades que aquí se ha elegido, se propone como una manera de entender qué tipo de dieta de estos monos deben seguir.

El uso de modelos de simulación extiende las posibilidades para entender las interacciones entre innovación y desarrollo económico. La tradición de los sistemas de innovación se beneficiaría enormemente de este enfoque: mediante el análisis de diferentes configuraciones de las relaciones entre los agentes o capacidades, es posible obtener conclusiones acerca de los impactos que cada parte del sistema puede tener en el resto de los componentes y sus interacciones. Siendo que uno de los principales retos a la hora de modelar sistemas complejos es la definición de las estructuras causales entre las variables (Borshchev and Filippov, 2004; Wu et al., 2010); el análisis econométrico presentado en esta tesis es una contribución para superar o reducir estas barreras: siguiendo metodologías similares a la de cointegración, las principales relaciones causales se podrían tomar de la evidencia empírica, dando una base más sólida para el ajuste del modelo (Karnopp et al., 1976). Los modelos de simulación pueden ser una enorme fuente de información sobre la relación entre la innovación y el desarrollo económico: se podría evaluar los procesos intermedios, las diferentes velocidades dentro del sistema y los niveles alcanzados por las variables seleccionadas.

El avance de las ciencias sociales quizás permitirá que las limitaciones descritas sean resueltas en el futuro y que algunas de las posibles extensiones de este trabajo de investigación se lleven a cabo. La complejidad de las relaciones entre innovación, desarrollo y crecimiento económico está todavía lejos de ser plenamente comprendida. La evidencia hasta ahora ofrece, sin embargo, un mensaje claro: las interacciones fuertes son una característica común de las economías desarrolladas.

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EXTENDED ABSTRACT

1. INTRODUCTION

There exists a crucial dimension that reveals how countries have used knowledge in their path to economic growth and development: ***time***. Development could only be understood by considering the effect of ***time*** on societies' evolutionary process. This is the main motivation of this doctoral research. In the following pages we will elaborate on how this could be done and the implications of this analysis.

This research project is grounded in the evolutionary economics and innovation systems tradition. In this branch of economic analysis, gradual processes of change are of upmost importance. Heterogeneous agents interact and learn from their interactions. Information is not always freely available and, even when it is, its mere possession does not guarantee that agents will be able to take full advantage of it. Capabilities are needed to exploit the existing knowledge and to create new one. This path dependent process is specific, it determines *how* nations, regions, firms, individuals will react to change, their real possibilities to adapt and evolve or to lock-in and stagnate. This is not a minor issue since innovation is considered the engine of economic growth and development (Nelson and Winter, 1982).

The literature on innovation and economic development is extensive. In the case of this doctoral project, two streams have had a major influence. First, the innovation systems framework (Freeman, 1995; Lundvall et al., 2002) has served as the main approach to study the relationship between innovation and development. By applying a systemic perspective to innovation, we have been able to include much of the complexity that characterizes economic growth and development. The other noteworthy branch has been the capability approach, mainly introduced by Abramowitz (1986) and Lall (1992). Both branches are the milestones that have guided our empirical analyses, in which a multidimensional approach is applied, institutional conditions are considered and the cumulative process of capability building is evaluated over time.

Innovation has been always characterized as a non-stationary process (Dosi, 1982; Metcalfe and Ramlogan, 2008; Perez, 1983; Schumpeter, 1934). However, empirical studies have not fully accompanied such argument. Much of the applied work presents static comparative analyses that might be myopic to patterns and structural changes. We aim at contributing to the literature by closing this gap between theory and empirics. We use time series and panel econometric methods to assess the *dynamics* of innovation and its linkages to economic growth and development. Naturally, we have also put substantial attention on studying how economies differ in their development paths. We consider that, especially for policy action, considering heterogeneity is a must: economic structures vary from one economy to another. The complexity that comes from interactions between agents and their environment should not be neglected in economic assessments.

This introductory chapter contains three additional parts. Section 2 is a review of the literature that has guided the elaboration of this dissertation. The research question and its related objectives, as well as the econometric methodology applied, are also included in this section. Section 3 introduces each of the four papers that compose this doctoral dissertation. The final section offers a summary of the content of this body of research, introducing the main implications of our results, methodological discussions, avenues for future research and limitations to our approach.

2. INNOVATION SYSTEMS: A HISTORICAL PERSPECTIVE

Assessing the relationship between innovation, economic growth and development has been a constant objective of evolutionary economics' research. In fact, some crucial characteristics of this question – such as those related with learning processes and the integration of innovation in productive systems – date back to Adam Smith's labor division discussions in 1776 and Friedrich List's national systems of production and learning in 1841 (Lundvall et al., 2002). Out of the different approaches that could be applied to solve this issue, we have selected the systemic vision as the guiding principle of our research. The possibility of capturing many dimensions of economic development's complexity is behind this decision.

The Innovation Systems framework has been proposed in the end of the 1980s. Freeman, Lundvall and Nelson's contributions can be identified as the three main pillars of this tradition (Fagerberg and Sapprasert, 2011). They have proposed a new research path that has seen a major explosion in the last three decades (Uriona-Maldonado et al., 2012). Christopher Freeman's (1987) seminal work analyzed how the differences in economic performance of Japan, Germany, the URSS, East Asia and Latin America could be explained from a historical point of view. The comparative exercise illustrated the multifaceted nature of the innovation process: the network of scientific institutions, industrial sectors, policies and cultural roots were exposed as the determinants of economic development. Lundvall has put forward that the main phenomenon embedded in this network is *learning*, an evolutionary process in which each agent changes by interacting with other agents and with the environment (Lundvall, 1996, 2004; Lundvall and Johnson, 1994). Nelson's institutional approach (Nelson and Nelson, 2002; Nelson, 2008, 1994, 1986) completes the main characteristics of the Innovation Systems framework: the context determines how agents link up; it contains the *rules of the game* that are generated in a non-linear process. Continuous interactions are the base of established routines that frame relationships and, as a result of this continuity, routines change to adapt to agents' evolution.

Different approaches to Innovation Systems have been developed in order to find the more suitable angle: sectorial (Geels, 2004; Malerba, 2002), regional (Cooke, 2001; Cooke et al., 1997; Uyarra, 2010) and international (Álvarez and Marín, 2010; Carlsson, 2006; Niosi and Bellon, 1994) levels have been added as alternatives to the traditional 'national view'. This multiplicity of viewpoints has been a way of adapting the unit of analysis to investigate how innovation intervenes in the development process. In this dissertation, we have made an effort to understand how development takes place at many different stages: a substantial sample of countries is included in the empirical analysis, giving us a reason to use the national level as the selected unit (Lundvall, 1998).

Nonetheless, finding an adequate approach to apply the innovation system framework is a challenge that goes beyond selecting the unit of analysis. The expansion of this tradition has been nurtured by policy discussion (Godin, 2009) and a variety of visions. Niosi et al. (1993) and Sharif (2006) present discussions regarding the main concerns in this field: its definition and delimitation, the theoretical foundations, the *adequate* degree of flexibility and the possibility of measurement. There remains, nevertheless, one thing that has not been challenged across the different approaches to innovation systems: if historical perspectives are fundamental to explain development, then path dependence and non-reversibility cannot be left out of the analysis (Cowan and Foray, 2002). Case studies have been selected as the preferred methodological tool to accomplish this duty. A great amount of empirical evidence has been collected from qualitative and historical research: Freeman's (1991, 1987) description of agents interactions and the importance of the state in countries' innovation activities set an important reference for the field; Nelson's (1993) comparative analyses pointed out the differences and heterogeneity of the process; more recently Lundvall et al (2009) and Edquist and Hommen (2008) have shown, respectively, insights from developing and developed countries in terms of their policies and institutional settings. Another interesting stream of research, more centered on the sectorial case, has developed around the *history friendly models* (Malerba, 2002; Malerba et al., 1999): they have focused on tracking the evolution over time of specific niches of technologies, identifying the course of key structural changes that have had an impact on the productive systems. In any case, all of these alternatives have not incorporated (at least at a desirable level) econometric evidence.

Econometric approaches to growth and innovation have been trying to integrate the systemic vision in cross-country comparative analyses. Fagerberg (1994) presented a review including more than twenty empirical papers that had assessed –back then– the relationship between economic growth and technology; selected variables combine the share of public sector in the economy, population growth, economic openness, with productivity measures (GDP per capita), and typical innovation activities indicators (like education variables, R&D efforts and patents). Further developments of these approaches have increased the number of the countries analyzed, reaching lower development levels when data was available (Castellacci and Archibugi, 2008; Castellacci, 2008; Fagerberg and Verspagen, 2002; Fagerberg et al., 2007; Lee and Kim, 2009). However, they all still follow a cross section regression approach: they remain static and, most importantly, they do not explicitly acknowledge the two-way relationships between innovation and development.

Empirical exercises closer to the dynamic approaches could be found in Schumpeterian multiple equilibria models, which combine distance-to-the-frontier tradition or technology gap models with different convergence regimes within groups of countries (Castellacci, 2010). In short, they consist in a non-linear characterization of the relationship between innovation, absorptive capacity and economic performance; in which a minimum threshold of countries' ability to incorporate knowledge is a critical factor for catching-up or falling behind: transitions do not happen in a fixed context, but in an evolving environment where technology gaps are constantly changing. Additionally, because of countries' diverse starting points, economic growth does not take place homogenously (Acemoglu et al., 2006; Azariadis and Drazen, 1990; Galor and Weil, 2000; Howitt, 2000). If nonlinear systemic relationships matter, then economies characterized by different initial conditions (e.g. different levels of income per capita) will tend to have diverging growth performances over time (Durlauf and Johnson, 1995): again, some countries will catch-up while others will fall behind and *convergence clubs* will arise as a normal outcome of this process.

Recent empirical studies extend this *convergence clubs* literature and argue that innovation and technology diffusion are the main factors explaining why multiple growth regimes (or different stages of development) exist. This new literature on *technology clubs* investigates how the technology-growth relationship differs across country groups. They also point out the most critical factors of catching up and growth for countries at different stages of technological development (Castellacci and Archibugi, 2008; Castellacci, 2008; Filippetti and Peyrache, 2011). Three groups (clubs) are distinguished according to their capacity to use, adapt and generate technology (Galor, 2005; Howitt and Mayer-Foulkes, 2005; Verspagen, 1991): the most advanced group (high capacity), the catching-up group (developing and increasing capacity) and, the laggard group (low capacity).

For cross-country comparative studies, the multiple equilibria models are also useful because of their consideration of *heterogeneity*. At the very heart of the evolutionary economic principles lies the consideration of agents' specificities, determined by their nature, particular learning process and interactions with the socioeconomic environment (Dosi and Nelson, 1994). As a matter of fact, the historical perspective highlights heterogeneity as the most important aspect: countries' evolution process could only be understood in the view of their own past. Even when panel analyses have been applied, in order to take heterogeneity into account, country groups were defined according to their institutional and geographical backgrounds.

Closing the gap with empirical exercises requires an operationalization of the innovation systems framework: a capability approach has been selected to evaluate the dynamic linkage between innovation and development. Based on Abramovitz (1986), Kim (1980) and Lall (1992); Fagerberg and Shrolec (2008) identified a set of relevant capabilities that could be representative of national innovation systems: this useful contribution proposes a set of indicators and sources to measure capabilities at country level. Their proposal was used as an initial reference in the empirical analysis here presented: by surveying the literature, other types of capabilities were also added.

On the whole, this brief introduction to the literature on innovation and economic development indicated that most of the empirical literature in the field has adopted a rather static perspective so far. It has focused on cross-country comparisons of national systems in a given period of time and has neglected almost entirely the time series dimension of the growth and development process. This important gap in the literature, between Schumpeterian theoretical models and innovation systems empirical studies, provides the general motivation for this doctoral thesis.

3. OBJECTIVES AND RESEARCH QUESTIONS

The general objective of this doctoral work is to study the dynamic relationships and process of coevolution between innovation, economic growth and development in a broad sample of national systems in the last three decades by using a time series (cointegration) approach. We aim at contributing to the literature and policy by generating quantitative based evidence of the structures that link the multifaceted dimensions of innovation systems to economic systems over time. The general research questions that provides a foundation and links together most of the chapters in this thesis can be formulated as follows:

How do national innovation systems evolve over time? What are their main long-run drivers? How does this evolutionary process differ for countries at different levels of development?

Development processes involve a great deal of complexity. The way structures behave and change can be assessed by looking at time series data and their dynamic properties. Furthermore, heterogeneity is everywhere and the analyses of different cases could show the evolution of the interactions. We propose not to put too strong assumptions and try to see, from the empirical evidence, what types of relationships are taking place and how they could affect economic development. We put forward the idea of including the complementary information that only ***time*** can offer as part of the discussion

In order to answer this question, three specific objectives were defined. They follow a sequential structure: first, there is an effort to understand the theoretical bases of the empirical work; second there is a feasibility check in terms of data availability and; finally, the empirical analyses – ultimate purpose of this dissertation – are targeted. These three objectives are:

4. To analyze the theoretical approaches that link the innovation process with economic growth and development processes.
5. To generate a database to study the innovation systems and the evolution of the economic performance over the last three decades.
6. To investigate the structures that have linked innovation systems, economic growth and development over time. This analysis should be dynamic and rely on the use of the time dimension to incorporate the historical perspective in the econometric exercise.

As Schumpeter (1994) proposed, history, theory and statistics should always be combined in the economic analyses. Organizing the research ideas in this fashion, beyond the main objective of dynamically including time in the empirical exercise, allows us to contribute in two more specific issues. The first one is the on-going debate on the level of theorization of innovation systems. In light of the available development theories and the shortcomings that they might have, we would like to explore the possibility of finding another alternative to look at this issue: focusing on the interactions between them. The other issue is related to innovation measuring from a systemic point of view. Recent proposals have arisen as feasible ways of assessing capabilities at the country level in order to quantify some features of the innovation process. Data availability would be the only constraint in this sense. The possibility of using the existent data and extracting the most out of it is an open question for empirical analyses.

3.1. Econometric methodology

During the last two decades, the number of econometric analyses investigating evolutionary matters has grown. One reason is data availability: the passage of time has allowed for data collection on key dimensions (like the expenditure on R&D activities, for instance), opening the door for time series and panel econometrics. Also, new methods have been developed to include the effect of precedent events as determinants of the structures and patterns that define economic systems. One of those advanced methods is the vector autoregressive model: it allows for full endogenization and cross effects of the variables in the system, incorporating information from the past to explain current states (Greene and Zhang, 1997). In fact, there is a specific case of this method that has had a major influence in this dissertation: the cointegration methodology, mainly developed by Johansen (1995, 1991), is useful to disentangle the relationships among variables that co-evolve, growing over time as a *system*. If cointegration is confirmed – which means that the vector contains a unit root and that included variables move together – it is possible to distinguish different relationships. On the one hand, the long-run relations, that are at the core of the system, and on the other hand, the short-run structure, that represents how the system reacts to changes (Hendry and Juselius, 2000; Juselius, 2006).

Out of the short-run structure, causality among the variables could be analyzed: this represents the dynamics of the system. The way the variables adapt to the changes in the long-run structure and how they transitorily adjust to the new conditions is a rich source of information (Juselius, 2006). By applying the cointegration methodology we can provide evidence of the driving forces of the economic systems, of the relationships that the time structure reveals, of agents' aggregate interactions. Furthermore, this methodology does not impose strong restrictions: it is oriented to use the information contained in the data to shed light on the systemic relationships. It is an alternative to the rigid model testing approaches in which theories are confirmed or rejected, and it aims at illuminating empirical facts that could help to improve theorizing efforts (Colander et al., 2009; Frydman and Goldberg, 2008; Hoover et al., 2008).

Because of these benefits, the cointegration methodology has been found very suitable for empirical analyses of the innovation systems and economic development. It offers the flexibility that the innovation systems need, it recognizes history as the main source of information and it evaluates the relationships as the result of mutual effects among different dimensions. In this dissertation, this econometric approach is presented as a way of closing the gap between theory and empirics: we regard qualitative analyses as building blocks of the economic research and believe that quantitative approaches are also needed to have a full vision of the related phenomena. In fact, both exercises are fundamental and should be applied in a historical context.

The applied empirical analyses consist of two types of cointegration approaches. Time series cointegration, in which a single country data is evaluated over a given period, is suitable for considering the highest level of heterogeneity in the data: the individual evaluation makes it possible to identify specific events in each country; it is the closest version to using empirical analyses in a case study fashion (Hendry and Juselius, 2000). Also, this approach allows us to analyze the time structure in a deeper level: once the relationships between the variables have been settled, it is possible to investigate the responsiveness of the system (Juselius, 2006).

The other approach is panel cointegration: it combines the information from time series with the cross-section structure of the data, increasing the power of the estimation. By expanding the size of the data, a much more complex exercise could be set: a larger number of variables can be included thanks to the increase of available degrees of freedoms (Breitung and Pesaran, 2006). Heterogeneity, nevertheless, could not be characterized at its highest level (Pedroni, 2001; Persyn and Westerlund, 2008): cluster exercises help to address this issue, by grouping countries according to their similarities in terms of institutional backgrounds and proximity. In any case, it is the mix of both approaches (the panel and the time series case) what enriches the robustness of the conclusions of this PhD dissertation.

4. AN EMPIRICAL APPROACH TO INNOVATION, GROWTH AND DEVELOPMENT

This dissertation is composed by a compendium of four interrelated papers. The first one contains theoretical considerations of the relationships between innovation and economic development. The second paper opened the door to the econometric methodology: it provided full time series data over the last three decades for 134 countries. Finally, the last papers represent two empirical contributions to the analysis of innovation dynamics and the interaction with economic growth and development. In the following lines each of these papers will be summarized.

4.1. DEVELOPMENT: A SYSTEMIC APPROACH

The first paper is called "*How innovation systems and development theories complement each other*"; it is coauthored with Mario Pansera (2013)[5]. Its scientific role in this compendium is to give a definition of *development* and its interaction with Innovation System (IS) approaches, as considered in this thesis. The main objective of this article is to assess how the Innovation System framework could be applied to the most influential theoretical characterizations of development, identifying bidirectional interactions.

This paper proposes a multidimensional definition of *development*: "*it is not only a matter of factor endowments; it implies the interaction of social abilities and productive use of knowledge*" (Natera and Pansera, 2013). Development, then, differs from economic growth since it goes beyond the possession of goods or the correct allocation of resources. In fact, both concepts are not considered antagonistic in nature, but a systemic approach is needed if the objective is to analyze how development takes place. Considering innovation as one of the key factors to foster development, we propose that the IS vision is ideal for this kind of studies.

The characterization of innovation systems includes the agents and their interactions, the learning process that they undertake and the institutional setting in which they are embedded. IS approach is presented as a flexible framework that could shed light on the analysis of development's complex relationships. IS emerges as a tool for action rather than a theory that stands alone; it is versatile and therefore suitable to many different theoretical approaches.

Given that the IS framework was born in OECD countries, an appraisal of some considerations from *the South* is part of this paper. We highlight the importance of taking a capability building approach when using IS as a development tool. We also agree with Arocena and Sutz (2000) when they consider that Innovation Systems are an ex-post concept for developing countries, that it carries a normative weigh and that it is

[5] This paper has been submitted to the scientific journal *Prometheus: critical studies on Innovation* (http://www.tandfonline.com/loi/cpro20); it is currently going through the review process.

a relational model useful for policy making. We have taken these insights as inputs when surveying the literature.

Development as freedom, the Institutional economics, the Neo-Classic theory of growth, the Multiple Equilibrium approach, the Latin American Structuralism and the World System theory are the development theories discussed in the paper, always from a systemic perspective: innovation was centered at the very heart of them, finding a symbiotic relationship in which flexibility and structure are combined. In fact, in light of the on-going debate about the formalization of the Innovation System approach, we argue that its combination with development theories could generate new frameworks of analysis for the scientific community: it is a way to increase the analytical power and constantly update our theoretical assumptions.

In terms of the empirical analyses developed in this dissertation, the Multiple equilibria approach has been the one with the greatest influence. It has been selected because of its suitability to make international comparisons: it takes into account heterogeneity between countries and considers development as a dynamic process. Based on our definition of *development*, we applied a complementary systemic vision to the Multiple equilibria approach: we have augmented the complexity of the dimensions taken into account, allowing for a combination of multifaceted socio-economic and technological factors.

4.2. DATA FOR DEVELOPMENT

The empirical analysis needed to assess development calls for data. Furthermore, if the idea is to be inclusive and not to only focus on the more developed countries, a big challenge arises: missing data harms and sometimes restricts econometric analyses. This was the motivation of the second paper of this compilation: "*A new panel dataset for cross-country analyses of national systems, growth and development (CANA)*", co-authored with Fulvio Castellacci (2011), which represents an effort to make data available for time series development studies.

Researchers interested in empirical analyses of development often have had to face the compromise of choosing a selected group of countries – normally OECD and middle income countries – and apply time series techniques or, alternatively, increasing the number of countries in the sample and apply cross-sectional (static) econometrics. We found this very unfortunate: the first option leaves out those countries that experience lower aggregate levels of living standards, in which research activities could have a bigger impact in terms of improving quality of life. The other option does not fully investigate the dynamics and evolution of the economic systems, since they fall short of including evolution over time in the analysis. Particularly for innovation studies, we think that not fully considering the evolutionary process is a big limitation. This paper proposes a way out of this problem.

By applying a novel Multiple Imputation method (Honaker and King, 2010), we constructed a cross-country panel of complete data. The selected method makes use of the existing data to estimate the missing points: it combines the individual time trend with the cross-section observations to produce, through an expectation-maximization algorithm, a complete set of data points that resembles the distribution of the original observed data. The dataset, in its first version, contains 41 indicators to approximate six key country-specific dimensions: innovation and technological capabilities, education system and human capital, infrastructures, economic competitiveness, political-institutional factors, and social capital[6]. It comprises 134 countries and 29 years, from 1980 to 2008.

The quality of the estimation was tested by comparing the distribution of the observed data and the complete data. A correlation analysis was also applied. Only those indicators that were found to be reliable were included in the dataset. An appendix with the details of the estimation process and the data transformation is presented. As part of the contribution that we wanted to offer to the scientific community, we have made the data entirely available at http://cana.grinei.es.

The method here proposed offers several advantages when compared with other possibilities. First, it includes a bigger share of developing countries, a more representative vision of the world. Second, it makes use of the already available information to produce estimations without imposing any model on the data. Finally, time series techniques are now feasible and the dynamics of the national innovation systems and their interactions with economic development could be assessed.

[6] A more recent version (constructed in 2012) includes up to 80 indicators. We increased the dataset by adding more indicators to the dimensions already defined and by including two new dimensions: *Productive Structure* and *Internationalization*. The objective behind these additions has been to consider the greater level of the complexity involved in the development process.

4.3. TIME STRUCTURES: CAUSALITY AND DEVELOPMENT PATHS

Evolution unfolds over time. Arguably the only way to analyze the revealed structure of an evolutionary process is by incorporating the time dimension in the analysis. The paper, "*Innovation, Absorptive Capacity and Growth Heterogeneity: Development Paths in Latin America 1970–2010*"[7], written with Fulvio Castellacci (2013a), carries out a time series analysis for each of the countries included in the sample.

Latin American countries were selected because of the relevance of their structural changes during the last four decades: the region is basically constituted by middle income countries in which the catching-up process is taking place. Based on the current economic boost of these economies, we find interesting to evaluate how prepared their economic structures are to move to higher development levels. The sample is composed by 18 countries. Years between 1970 and 2010[8] represent the transition from the Import Substitution Industrialization process towards a more global and open economy. Many structural changes have occurred in that period and, therefore could reveal the underlying driving factors that have sustained economic growth.

Based on Verspagen (1991), we present a model that considers the effect of the three dimensions on economic growth: one is related to the innovative activities and the other two are linked to imitation. Openness and industrial structure are the factors that represent countries' abilities to learn from spillovers generated abroad. Two hypotheses accompany this model: first, countries will follow different paths according to the mix of policies that they have adopted to catch up; second, those countries that combine imitation and innovation policies have a higher rate of economic growth.

Results come from a Vector Error Correction model in time series: we used Johansen's system cointegration methodology to analyze the long-run causality that links economic growth with different policy strategies. The indicators selected are: patents per capita (innovation policy), FDI inward flow (imitation – openness) and three different proxies for industrial structure: industry, services and natural resources as percentages of GDP.

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[7] This paper have been submitted to the scientific journal "Structural change and economic dynamics" http://www.journals.elsevier.com/structural-change-and-economic-dynamics/ ant it is currently under the revision process.

[8] In order to overcome econometric limitations (degrees of freedom on the estimation), a new imputation process was applied following the same methodology described in Castellacci and Natera (2011). The time spam was expanded to include years from 1970 to 2010.

Indicator selection was a tough process. Using patents in the Latin American context has important limitations, since it does not fairly assess the innovative activity that takes place in the region. Also, for openness and industrial structure we might find similar arguments. These facts open the door for further analysis and place, from the beginning, the outcomes of this exercise as an initial step to empirically describe the Latin American development path.

In the last paper of this dissertation we have carried out a panel exercise to analyse the dynamic relationships between innovation and development. This methodology allowed us to introduce a more complex characterization of the process and to evaluate the differences between the most relevant regions of the world. The paper "*The dynamics of national innovation systems: a panel cointegration analysis of the coevolution between innovative capability and absorptive capacity*", written with Fulvio Castellacci (2013b), is a proposal to investigate the evolution of 87 countries, during the last three decades.

In this paper we highlight the importance of understanding how innovation takes place. Besides the inclusion of time in the analysis, there are three other motivations behind this applied exercise. First, empirical research has mainly focused on the relationship between economic growth and innovation, while efforts to understand the innovation process itself have not been so numerous. We might be running the risk of jumping to the conclusions while still needing to look at the engine of sustainable growth. Recently, some empirical work has revived the interest on the technological aspects: they have centred on countries' technological and innovative capabilities as ways of explaining their economic performance (Castellacci, 2011; Filippetti and Peyrache, 2011). This paper is oriented to contribute in a similar manner.

Second, absorptive capacity normally occupies a secondary role in empirical analyses. For developing countries this could underestimate their possibilities of catching up. This finding is quite surprising since literature has emphasised the role of *spillovers* and imitation activities in the catching-up process, especially in countries' continuous learning process and capabilities accumulation (Aghion et al., 2001; Lee and Lim, 2001; Pérez and Soete, 1988; van Elkan, 1996; Verspagen, 1991). We think that by considering the complexity involved in this concept, much of the dynamics of development could be explained. Instead of considering a control factor in the empirical exercises, we will make this subsystem endogenous in our analysis.

Lastly, these two subsystems co-evolve to drive economic development: more empirical evidence is needed to describe how these relationships occur. We do not assess imitation and innovation as separate activities, but rather we believe that they are intertwined processes that could not be understood separately. We proposed a model composed by three subsystems. *Innovative capabilities* are represented by three factors: innovative input (effort and investment in R&D and related activities); scientific output (results of research and innovation activities from the public S&T system) and; technological output (total output of technological and innovative activities carried out by private firms). *Absorptive capacity* is quite diverse in its composition, it includes: international trade (openness of the national system), human capital (education and skills in the population), infrastructures (network, transportation, distribution, etc.), quality of institutions and governance system (efficiency of the governance system) and, social cohesion and economic inequality (effects of equality in trust and knowledge sharing among individuals). *Income level* (GDP per capita) is the final component of the model: it is a proxy of countries' overall performance and – in the context of systemic interactions – of their development stage.

The proposed configuration of national innovation systems leads us to four propositions (Castellacci and Natera, 2013b):

- The dynamics of the innovative capability is driven by the coevolution of the three factors that define it: innovative input, scientific output and technological output.
- The dynamics of the absorptive capacity is driven by the coevolution of the five dimensions that define it.
- Innovative capability and absorptive capacity co-evolve over time, i.e. these two dimensions are linked together by a set of two-way dynamic relationships.
- The dynamics of innovative capability and absorptive capacity, and the coevolution between them, differ across country groups characterized by different levels of development.

The Vector Error Correction model, in its panel version, is the selected econometric method. It allowed us to examine the causal structure that links together the variables within and between innovative capabilities, absorptive capacity and income level. It shows the structure over time: on one hand, it looks at the long-run equilibrium relationships in which variables move together (as parts of a system); on the other, it describes the causal structure to reveal how variables react when something changes in the system. Our results are organized in terms of these two types of time-structures and of different country groups: heterogeneity has been addressed by clustering countries according to their geographical and institutional background.

5. Summary of this PhD Dissertation

Before proceeding to the papers, it is convenient to take a look at Table 1.1, which offers a brief description of the content and current status of each article. Apart from those included in the table, a closing chapter, called "Conclusions, limitations and possible extensions", will expose the main outcomes from this PhD dissertation.

Table 1.1 - An overview of the articles included in the PhD dissertation

Title and co-authors	Publication	Purpose	Methodology
Chapter 2 "How innovation systems and development theories complement each other" (with Mario Pansera)	*Prometheus: critical studies on Innovation* (under review process)	Investigating the interactions between the Innovation Systems approach and development theories	Review of the literature that relates Innovation Systems with Development as freedom, the Institutional economics, the Neo-Classic theory of growth, the Multiple Equilibrium approach, the Latin American Structuralism and the World System theory
Chapter 3 "A new panel dataset for cross-country analyses of national systems, growth and development (CANA)" (with Fulvio Castellacci)	*Innovation and Development,* 1(2), 205–226, 2011	Developing a panel dataset (134 countries and 29 years) suitable for time series analyses of innovation, economic development and growth.	Application of a new Multiple Imputation method that generates estimates of the missing points by extracting the existing information from the observed data.
Chapter 4 "Innovation, Absorptive Capacity and Growth Heterogeneity: Development Paths in Latin America 1970–2010" (with Fulvio Castellacci)	*Structural Change and Economic Dynamics* (under review process)	Identifying the driving forces of Latin American development during the last four decades.	Time series analyses of 18 Latin American countries by using Vector Error Correction models (Johansen's approach) to identify long-run causality estimates between economic growth and innovation and absorptive capacity dimensions.
Chapter 5 "The dynamics of national innovation systems: a panel cointegration analysis of the coevolution between innovative capability and absorptive capacity" (with Fulvio Castellacci)	*Research Policy,* *42*(3), 579–594, 2013	Analyzing the coevolution of the subsystems of innovative capabilities, absorptive capacity and economic growth across different levels of development.	Panel cointegration analyses of 87 countries during the last three decades. Heterogeneity was assessed by defining 5 groups of countries according to their geographical and institutional background.

6. CONCLUSIONS, LIMITATIONS AND FUTURE EXTENSIONS

The main topic of this dissertation is the dynamic relationship between innovation, economic growth and development. It is an effort to contribute to the literature by presenting four papers: two of them have a conceptual and methodological orientation, while the others analyze, from an empirical perspective, the structure that unravels over ***time***. This chapter aims at discussing the main conclusions, restrictions and further developments that the compendium of these four papers offer.

6.1. CONCLUSIONS

There still is an ongoing debate about the characterization of innovation systems as a theory, a concept or a framework to understand development and growth from an economic perspective. This issue comes from the need of having solid foundations to study evolutionary processes: Innovation Systems are often criticized for their theoretical underpinnings and lax structure (Niosi et al., 1993). Nevertheless, such criticism does not take into account that evolutionary theorizing should be based on open structures, in which complexity and the information coming from non-static environments must be constantly incorporated in the analysis (Nelson and Winter, 2002, 1977). Bearing this in mind, the survey of the most influential development theories and their interactions with innovation systems, presented in Chapter 2, proposes to switch the focus of the debate on the theoretical bases of innovation systems. The offered alternative suggests taking complementarities between the innovation system approach and the selected development theories under consideration to increase the explanatory power on the development process.

Development theories could represent an interesting perspective to observe and describe the systemic phenomena of innovation. Innovation systems' flexibility is useful to incorporate complexity in the theoretical analysis of economic development and could be a source of adaptation and evolution of the theories that it complements: it offers an open window to constantly revisit the theoretical foundations in which research and policy are being designed (Lundvall et al., 2009).

The empirical analyses here included have been conceived from this viewpoint. The models have been inspired in the distance-to-the-frontier tradition. Naturally, they have been augmented to include the socio-institutional dimensions, the technological capabilities, the internationalization activities and the productive structure as determinants of the development at the national level. Results confirm the validity of the scheme discussed in Chapter 1, as they offer evidence against reductionist approaches: since structures differ across countries, if the multifaceted characteristics of the economic development process are not included in the analysis, there is a high risk of leaving aside critical variables that are central for that particular economy (Foray, 2004).

Without investigating the structure of the system, it is not possible to discriminate *a priori* the relative importance of specific capabilities: a wide spectrum of possibilities to assess the multidimensional characteristic is required. The construction of the CANA dataset, presented in Chapter 3, is a first step to operationalize the analysis: 80 indicators are available to represent the interaction of eight different capabilities. It is still a simplification of the enormous complexity of economic processes, but this approach reduces the gap between theories and the related empirical exercises.

Nowadays, dynamic empirical analyses could get closer to the expectations of theoretical foundations of innovation and economic development. As a start, data is not as problematic as it was in the past. Multiple imputation methods allow the exploitation of available data at country level (Castellacci and Natera, 2011): it does not force the estimations to respond to a particular model; it considers the heterogeneity of the process and the interactions among variables when estimating data-points and; there are robust methods to assess the reliability of the estimations. The ideal situation, of course, would be to have access to fully observed data constructed under equal methodological strategies across countries (Smith, 2005). We acknowledge that there are some risks when we use country level data and that they increase in importance when we estimate the missing data. Multiple imputation is neither a perfect solution for all cases (Abayomi et al., 2008), nor a universal remedy, but it allows us to obtain important information: it gives the opportunity of investigating the revealed structure of innovation and development, an open door to applying truly dynamic econometric methodologies, such as cointegration.

The cointegration methodology is one of the more suitable econometric tools to conduct empirical analyses on development and innovation from a systemic perspective. First of all, it considers how variables co-evolve and react when a shift occurs: it determines the dynamics of non-linear effects among the different relationships. Moreover, cointegration has the advantage of disentangling the long-run structure from the short-run. Given the big challenge of investigating development processes, any opportunity for distinguishing between long lasting and transition effects is useful for interpreting results and deriving policy recommendations.

The application of this methodology has provided new insights on the relationships between innovation and development. We have offered a new vision of the structures that time reveals. In the two different exercises (panel and time series), linkages between different capabilities have been described as having unidirectional or mutual effects, creating a network of intertwined causation. This is a step forward in incorporating history in the econometrics of innovation: present, past and changes in the variables are all considered at once to extract the patterns of their interactions (Hoover et al., 2008).

Our empirical results, we believe, offer a rich source of information, especially for policy issues. Let us begin with the complexity of the economic development. The panel case (Castellacci and Natera, 2013a) showed that there is evidence of coevolution between innovative capabilities, absorptive capacity and economic growth. This highlights that reductionist approaches that do not consider the multidimensional nature of development are likely to fail to provide pertinent recommendations: one change in any part of the system will drive many changes in the other dimensions; consequently, expected results in any specific dimension will also depend on the effects it gets from the rest of the system (Arthur, 1999).

Being this the case, the take away message is clear: development strategies need massive coordination. Evidence suggests that it is just not enough to focus on a particular sector or a reduced part of the system when development is the final objective. Certainly, there are some dimensions that will have a higher impact on the system and, therefore, could be used to prioritize policy actions. Particularly, innovation has always appeared as one of the critical dimensions. Still, feedback loops will remain as crucial sources of causation: innovative activities are inserted in a complex structure of driving forces.

Both the time series and the panel case, respectively Chapters 4 and 5, have shown that complexity and economic development evolve together. Countries that have managed to increase the interactions between their capabilities are those that exhibit a higher development level. This implies that sustainable growth could only be achieved by building bridges between different sources of knowledge, i.e., by having strong connectivity among different agents.

Probably the main implication of the complexity evidenced in the empirical exercise is related to the institutional configuration required to foster innovation. Particularly in developing countries, ministerial bodies have been created to promote Science, Technology and Innovation activities. This decision is not harmful by itself but it carries the risk of allocating the whole responsibility of building innovative capabilities on a constrained organization: the multidimensional characteristic of innovation and development must find counterparts in countries' institutional structures. Of course, because of the high heterogeneity found, the institutional design should be country specific.

The time series exercise (Chapter 4) studies the Latin American case and it remarks why specificity is necessary (Castellacci and Natera, 2013b). Development paths are constructed by the mix of strategic decisions that each country has followed. The combination of innovation and imitation policies is the best practice that, based on the empirical results, could be recommended to policy makers. Indubitably, it is critical not to forget that development strategies heavily rely on historical conditions. Decisions taken over time make impossible to fully reapply proven successful strategies: those actions were time-specific and therefore cannot be replicated blindly. Based on the revealed capabilities and the interactions among them, societies should coordinate and agree on how to construct the competences they need.

The panel analysis, presented in Chapter 5, also confirms the importance of considering heterogeneity in the relationships between economic development and innovation. As pointed out in the paper, allocating countries in a five-group configuration – in which geographical, institutional and development level characteristics are considered – provided the most consistent results. The causal structure that links the selected capabilities changes with the development level (Castellacci and Natera, 2013a). It is not only a matter of finding a higher number of causal interactions in more developed countries: causality is configured differently for each country group, according to their own particular historical path.

6.2. LIMITATIONS

Some limitations have been faced during the development of this dissertation. For instance, capturing the complex dimensions that are implicit in the catching-up process is still a big challenge. Available indicators are not free of shortcomings. This, of course, is part of the nature of many economic analyses, but it is especially relevant when the objective is to investigate evolutionary processes (Kleinknecht et al., 2002). In Chapter 3, there is an effort to overcome this issue; nevertheless, the discussion is far from conclusive. From a methodological point of view, changes in the data collection process and external sources of variation (such as the implementation of new legal procedures, terms redefinition, changes in questionnaires, etc.) might affect the measurement of the indicator and the information that could be extracted from it (Hall et al., 2010): since time series data are used, it is necessary to keep in mind that changes from one year to the other might be caused by methodological updates and not necessarily by changes in the process that we would like to measure. To some extent, this problem is hard to address since methodological changes are not always reported in full detail: it is a risk that time series analysis will inexorably face.

There is still another issue that is more linked to the conceptual approach. The selection of indicators as a proxy for innovation or absorptive capacity processes is a challenging task. As a matter of fact, this is a relevant limitation of Chapter 4. For developing countries, using patents as an indicator of innovative activities is a matter of heated debates (Archibugi and Coco, 2004; Archibugi et al., 2009; Vaitsos, 1972): because of the low propensity to patenting activities, innovation results are underestimated by this proxy. Also, measuring absorptive capacity as a combination of indicators is not obstacle free: we need to consider its multifaceted nature and this is only possible when different dimensions are incorporated in the analysis. The main question is where to stop. Literature review was carefully executed and the CANA dataset was constructed with a wide vision in order to cope with the selection bias, and sensitivity analyses have shown the reliability of the results. Nevertheless, we acknowledge that different proxies might also be suitable for the analysis presented here and remain open for additional exercises.

Other limitations are related to the characterization of the time structure. First of all, the inclusion of structural breaks in panel analyses has not been completely developed

(Banerjee, 2006; Banerjee et al., 2004): it is not possible to fully control for changes in variables behavior (step-like patterns, collapses or changes in the trend) when analyzing groups of countries jointly, as we did in Chapter 5. Second, even in the time series case (Chapter 4), in which structural breaks can be described, the structures revealed by this analysis could change over time: it is important to continuously revisit the model by adding new information that could improve and change the results. We are not facing static processes, we are living in an ever changing environment in which agents learn and transform themselves and their ways to interact. On this regard, at least for the time series case, there are available recursive tests in which the stability of the parameters can be assessed (Juselius, 2006). However, reliability of these tests is limited by the time spam currently available: future data collection will offer the opportunity of nurturing the database on this respect as well.

6.3. Future extensions

Including ***time*** in the analysis has been essential to deliver these policy recommendations. Other characteristics of the time structure could also be studied. So far, we have used time to evaluate the structures behind economic development and innovation. We could also use this information to analyze the responsiveness of the system; we could try to answer the following question: how long does it take to see the reaction of the system when one dimension changes? Do all of the dimensions react exactly at the same pace? This could have important implications for policy making. It might be the case that we evaluate policy effectiveness too soon (or too late) to capture its real impact. If we assess how fast the system reacts, we would be able to adjust evaluation timing accordingly, instead of using an *ad hoc* – and not evidence supported – criteria. Impulse Response Functions (IRF) could provide this information (Hamilton, 1994): they show how changes propagate in the system and how variables reach different levels at particular points of time.

Besides the cointegration analysis, there are other alternative dynamic econometric exercises. Foster and Wild (1999) present an interesting one: by a applying an augmented logistic diffusion model (ADLM), they propose a characterization of economic systems in which structural change could be evaluated as a result of self-organizing structures. The beauty of this novel approach is the possibility of endogenizing those critical points in which disruptive processes arise.

Other possibilities of extensions are related to economic complexity studies. Complexity could be assessed from many different perspectives. For instance, by looking at countries' product space, Hidalgo and Hausmann (Hidalgo and Hausmann, 2009; Hidalgo et al., 2007) rendered conclusions related to ours. They state that countries with a higher level of development have managed to increase the network of products they produce and export. They also propose that this complexity increase is supported by the required capabilities to enjoy a diversified and interconnected network of products. Building bridges between this type of complexity and the one we propose would be a useful project: it could help policymakers to understand which key actions are needed in order to develop those contiguous sectors that will sustain countries' economic growth. Hausmann and Hidalgo use a metaphor to explain how their economic complexity works: firms are represented by monkeys that jump from one tree (sector) to another, in search of more profitable activities; to put in simple words, combining their analysis with the capability approach would be a way of understanding what kind of diet the monkeys should follow.

A final set of future developments is devoted to the assessment of simulation models (both in terms of their design and reliability testing). The innovation system tradition would greatly benefit from simulation exercises: by analyzing different configurations of the relationships between agents or capabilities, it is possible to draw conclusions about the impacts that each part of the system could have on the rest of the components and their interactions. One of the main challenges when modeling complex systems is defining the causal structures that represent the interactions between different variables (Borshchev and Filippov, 2004; Wu et al., 2010). Econometric analyses presented in this thesis are a contribution to overcome or reduce these barriers: following the same scheme of Chapters 4 and 5, the main relationships could be taken from empirical evidence, giving a more solid foundation for the model setting (Karnopp et al., 1976). Simulation models could be an enormous source of information about the relationship between innovation and economic development: assessment of intermediate processes, description of the aggregation structure, evaluation of the different speeds within the system and the levels reached by selected variables, are open possibilities.

Hopefully, the limitations outlined will be solved in the future and some of the possible extensions of this research work will be undertaken. Complexity in the relationships between innovation, development and economic growth is still far to be fully understood. Nevertheless, evidence up to this point provides a clear message: strong interactions are a common characteristic of developed economies.

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