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Innovation, Absorptive Capacity and Complexity along development stages

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Abstract
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Abstract:

Most of the previous empirical literature on economic growth and technology has so far focused on the cross-country dimension, and largely neglected the time series dimension. The existing literature, therefore, points out how country-groups differ but it does not make it possible to understand how these patterns evolve over time, and how each of them may shift from a development stage to a more advanced stage. In this paper we aim at evaluating the complex systemic interactions that characterize growth. It is our objective to contribute with the convergence club literature by considering the time dimension in this empirical analysis. Specifically, we aim at describing the relationship of the GDP per capita with innovation and absorptive capacity.
We defined absorptive capacity as multifaceted sub-system composed by human capital, international trade, industrial structure and the socio-institutional context. We outlined three hypotheses: the first one evaluates the relationship between GDP per capita and Innovation across different development stages; the second evaluates absorptive capacity relationship with economic growth and the third hypothesis proposes that the economic system complexity (interactions

among variables) increases with economic development.

In order to test our hypothesis, we selected 116 countries from the CANA Dataset, a rich panel dataset that includes complete observations (observed and estimated data) from 1980 to 2008. Our first step was to cluster country in seven different groups, using geographical areas as the main criteria. Then we applied a cointegration analysis as intermediate procedure to investigate Granger-causal relationships among different variables.

Our results indicate that the relationship between the economic growth and innovation varies across country groups. In most advanced economies there is a clear strong linkage between these two dimensions. As the development stage decreases, the role of innovation within the economic system heavily follows this trend: we found no evidence between the generation of new technology and economic growth at least developed economies. The relevance of absorptive capacity is also proportional to the development level, but it does have a greater impact on economic growth evolution in middle income countries: there is support to state that the catching-up process heavily relies on the interaction between these multi-natured capacity and economic growth. Another relevant implication from this exercise is the confirmation of consistent increase of systemic interactions, namely direct and indirect causal relationships to GDP level, as the economic development stage increases. This is an important sustain to how systemic the economic development process is and the importance of setting integrated policy actions in order to foster it.

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Innovation, Absorptive Capacity and Complexity along Development Stages

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Abstract

The paper presents an empirical analysis of the time series properties of Schumpeterian multiple equilibria models. It considers a panel of 116 countries over the period 1980-2008, and makes use of panel cointegration analysis and Granger causality tests to identify the set of dynamic relationships linking together innovation, absorptive capacity and economic growth in different country clubs. The results provide general support for this class of models and show that absorptive capacity and innovation progressively become more important engines of growth as the development process unfolds over time. Relatedly, the complexity of the economic system (measured by the number of significant Granger causal relationships driving economic growth) increases as we move from the less-developed, to the middle-income and then to the advanced country clubs.

Keywords: innovation; absorptive capacity; complexity; economic growth; multiple equilibria models; development stages; panel cointegration analysis; Granger causality.

JEL codes: O1, O3, O4

1. Introduction

Cross-country heterogeneity represents one of the most important issues that are currently under investigation in the field of growth theory. Since countries in the world economy are characterized by widely different initial conditions, structural characteristics and growth trajectories, growth scholars have in the last couple of decades shown an increasing dissatisfaction with the standard convergence regression approach, and experienced with a number of different methods and approaches in the attempt to provide a better treatment of the cross-country heterogeneity issue (Temple, 1999; Durlauf et al., 2005).

One of these approaches is provided by the convergence clubs literature. Durlauf and Johnson (1995) opened up this stream of research by showing the existence of different groups of countries with substantially different initial conditions and growth behavior. Subsequent applied studies refined this approach and pointed out a number of factors that may determine the existence of multiple growth regimes, among which international trade, human capital and technological capabilities (Papageorgiou, 2002; Stokke, 2004; Castellacci and Archibugi, 2008; Castellacci, 2011; Filippetti and Peyrache, 2011).

In parallel to these advances in the applied growth literature, a new class of theoretical models flourished in the attempt to explain these empirical facts on clustering, polarization and convergence clubs. Azariadis and Drazen (1990) presented a seminal multiple equilibria model in which threshold externalities in the accumulation of human capital explain non-linearities in the growth process and the existence of different convergence clubs. More recently, Schumpeterian multiple equilibria models pointed out the important role of technological innovation and the imitation capabilities of nations, and showed that these explain the existence of three distinct groups of countries as well as the shift from a given development stage to a more advanced one (Galor, 2005; Howitt and Mayer-Foulkes, 2005).

Despite the considerable progress of research in this field, there is one striking fact that has not been adequately addressed yet: there exists a sharp contrast between empirical studies and theoretical models in this field. Multiple equilibria growth models have adopted a truly *dynamic* approach in the attempt to uncover the mechanisms that may explain why a given country may (or may not) shift from a given development stage to a more advanced club. By contrast, applied works have largely focused on the *cross-country* dimension – pointing

out what are the critical factors of success for different groups of countries. This contrast between theoretical and empirical research represents an important gap in this literature. Empirical studies of convergence clubs and multiple growth regimes should have a more explicitly dynamic focus and adopt time series methods and approaches to a much larger extent than it has been the case so far. This is the route we take in this paper.

The paper presents an empirical analysis of the time series properties of Schumpeterian multiple equilibria models. It considers a panel of 116 countries over the period 1980-2008, and makes use of panel cointegration analysis and Granger causality tests to identify the set of dynamic relationships linking together innovation, absorptive capacity and economic growth in different country clubs.

Our empirical analysis presents three main novel aspects: it addresses the *dynamics*, *heterogeneity* and *multi-dimensionality* of the growth process. Its main objective is to investigate *dynamic* (time series) relationships among growth factors in a large panel of economies over the last three-decade period, in the attempt to close the gap between theoretical and applied models in this field. It addresses the *heterogeneity* issue by investigating how the model differs in distinct country groups (three major clubs, plus a few sub-groups within each country club). This is intended to shed new light on the factors that enable a country to shift from one development stage to a more advanced one, rather than simply comparing the characteristics of different country clubs in a static cross-sectional fashion. Finally, the model adopts a *multi-dimensional* approach by simultaneously considering several main drivers of economic growth at different development stages rather than focusing on only one or few of them as typically done in the literature. As such, our empirical model does not aim at testing a specific multiple equilibria growth model among those that have been presented in this field, but it rather provides a more general and flexible framework to investigate the empirical validity of the Schumpeterian multiple growth regimes literature in a time-series perspective.

The results provide general support for this class of models and show that absorptive capacity and innovation progressively become more important engines of growth as the development process unfolds over time. Relatedly, the complexity of the economic system (measured by the number of significant Granger causal relationships driving economic

growth) increases as we move from the less-developed, to the middle-income and then to the advanced country clubs.

The paper is organized as follows. Section 2 reviews the literature on convergence clubs and multiple equilibria models, section 3 presents the empirical model and hypotheses, section 4 describes the data and indicators, section 5 explains the empirical methods, section 6 presents the empirical results, and section 7 concludes by discussing the main contributions and limitations of the paper.

2. Literature: convergence clubs and multiple equilibria models

In the last two decades, applied growth theory has largely reconsidered the convergence hypothesis and criticized its standard formulation by focusing on the heterogeneity issue (see overviews in Temple, 1999, and Durlauf *et al.*, 2005). Countries differ greatly in terms of their growth performance as well as the underlying set of economic and institutional factors that may explain it. Inspired by the seminal study of Baumol (1986) that pointed out the existence of three distinct *convergence clubs*, Durlauf and Johnson (1995) opened up a new stream of applied growth literature studying the factors that may explain the emergence of different country groups, and how the growth performance of these differ over time.

A few recent empirical studies have extended the convergence clubs literature and pointed to innovation and international technology diffusion as the main factors that may explain the existence of multiple growth regimes. This new literature on *technology clubs*, rooted in the Schumpeterian growth tradition, investigates how the technology-growth relationship differs across country groups, and what is the role of innovation and absorptive capacity for countries at different stages of technological development (Castellacci, 2008; Castellacci and Archibugi, 2008; Castellacci, 2011; Filippetti and Peyrache, 2011).

These empirical findings on polarization and non-linearities in the growth process have inspired a class of theoretical models that seek to achieve a more thorough understanding of the mechanisms generating multiple growth regimes. These are the so-called *multiple equilibria growth models*, which may be seen as a recent version of older development stages theories. Multiple equilibria models are threshold models that investigate the factors

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that explain why a country may (or may not) shift from a given development stage to a more advanced one, and whether the interactions between different engines of growth may play a role to explain non-linearities in the growth process.

A seminal model in the field is the one proposed by Azariadis and Drazen (1990). This model augments the neoclassical growth model with a new feature that produces multiple growth paths: threshold externalities in the accumulation of human capital. The threshold property and non-linearity of the model are explained by the mechanism through which individual agents accumulate human capital. Individual investments in education are assumed to depend on two factors: the time invested in human capital formation by each individual, and the private yield on education. The latter factor, in turn, is assumed to be a positive function of the average (aggregate) level of human capital in the economy. This formalization generates threshold externalities because the private incentives to invest in education increase rapidly above a certain threshold level of aggregate human capital, whereas below this given threshold low private yields cause stagnant growth of aggregate human capital and, hence, economic growth. In this model, different initial conditions in terms of human capital levels may therefore explain long-run dynamics of national economies that cannot be defined by a single set of parameters.

Nelson and Phelps (1966) and Verspagen's (1991) models introduced the important idea that threshold and non-linearities in the growth process may be explained by the interaction between human capital and technological dynamics, i.e. they pointed out an exponential diffusion mechanism according to which a country's absorptive capacity is affected by its level of human capital. Galor and Moav (2000) did also present a model in which non-linearities in the growth process are determined by the interaction of human capital and technological change. The basic idea is that an increase in the rate of technical progress tends to raise the relative demand for skilled labor and, hence, to increase the rate of return to private investments in education. The subsequent increase in the supply of educated individuals, in turn, acts to push technological change further. It is such a dynamic interaction between the processes of skill formation and technological upgrading that is at the heart of the cumulativeness of aggregate growth trajectories.

A related idea was proposed by Galor and Weil (2000) and Galor (2005), whose "unified growth theory" models seek to explain the long-run transition of national economies from

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backward to more advanced stages of development. These models identify three main development stages – a 'Malthusian', 'post-Malthusian' and a 'modern growth regime' – and study the mechanisms explaining the transition across these long-run phases. In particular, a key insight of these studies is the observation that during the post-Malthusian phase a demographic transition occurred. The faster pace of technological change progressively increased the returns to human capital accumulation. This determined a change in parental attitude towards children's education, favoring a shift from quantity to quality, i.e. a higher preference for a small number of well-educated children. The resulting slowdown in population growth, in combination with the acceleration in human capital and technological accumulation, thus led many economies into a modern growth regime characterized by stable growth of per capita incomes. In this development stage framework, the existence of different country groups is explained as the outcome of different timing of transitions experienced by national economies in the shift from the post-Malthusian to the modern growth regime. Again, the emergence of thresholds implies that multiple sets of parameters are needed to describe the convergence processes correctly.

The model by Galor and Tsiddon (1997) is also consistent with this view, but it refines the multiple equilibria analysis by studying the interactions between technological progress, intergenerational earnings mobility and economic growth. In this overlapping-generations model economic agents live two periods. In the first of these, they must decide in what sectors to work and the level of education they seek to achieve in the future. As opposed to the previously discussed models, economic agents' human capital dynamics depends here on two main factors: their individual ability and their parental sector of employment (since empirical evidence indicates that earnings possibilities for a worker are higher if there is a close match with the parents' sector of employment). In periods of sustained technological progress, individual ability stands out as the more crucial factor for a worker's success, and high-skills agents tend to cluster in more technologically advanced sectors. This introduces greater inter-generational mobility in the economic system, and the concentration of talented individuals in high-tech branches fosters technological change and human capital even further. The cross-country implication of this cumulative dynamics is that initial differences in human capital endowments (and in the distribution of human capital across sectors) may lead to diverging dynamics of national economies.

Howitt (2000) and Howitt and Mayer-Foulkes (2005) refined the Schumpeterian growth model by arguing that cross-country differences in the rates of return to investments in human capital may shape the dynamics of absorptive capacity (see Abramovitz (1986) and Basu and Weil (1998) for related expositions) and thus generate three distinct convergence clubs: an *innovation*, an *implementation* and a *stagnation* group. The first is rich in terms of both innovative ability and absorptive capacity. The second is characterized by a much lower innovative capability, but its absorptive capacity is developed enough to enable an imitation-based catching up process. The stagnation group is instead poor in both aspects, and its distance *vis-à-vis* the other two groups tends to increase over time. Papageorgiou (2002) and Stokke (2004) suggest that the ability of a country to shift from the imitation to the innovation stage may be affected by the openness of the national system to international trade. Acemoglu *et al*. (2006) argue that a crucial source of dynamics for countries in the innovation group is constituted by the availability of a skilled pool of managers and entrepreneurs. The competition and selection process through which skilled managers emerge represents a crucial growth mechanism for countries that are already close to the technological frontier.

A different explanation for the existence of multiple growth paths is provided by Durlauf (1993) and Kelly (2001). Their formalizations focus on the dynamics of industrial sectors and the importance of intersectoral linkages to sustain the aggregate dynamics of the economic system. The main idea of Durlauf's (1993) model is that when intersectoral linkages among domestic industries are sufficiently strong, the growth of leading sectors propagates rapidly to the whole economy, whereas if such technological complementarities are not intense enough the aggregate economy follows a less dynamic growth path. Kelly (2001) refined this framework by building up a Schumpeterian quality-ladder model in which economies evolve by continuously producing new goods and progressively becoming more complex over time. Intersectoral linkages tend to become more complex and intense as new products are introduced in the economy, and threshold externalities thus emerge as the result of different degrees of complexity that characterize different groups of national economies.

This brief review of the literature on convergence clubs and multiple equilibria growth models highlights two facts that provide the main motivations for our study. The first fact is

that there is a sharp contrast between empirical studies and theoretical models in this field. Applied works have largely focused on the *cross-country* dimension – pointing out what are the critical factors of success for different groups of countries. By contrast, multiple equilibria growth models have adopted a truly *dynamic* approach in the attempt to uncover the mechanisms that may explain why a given country may (or may not) shift from a given development stage to a more advanced club. This contrast between theoretical and empirical research represents an important gap in this literature. We argue that empirical studies of convergence clubs and multiple growth regimes should have a more explicitly dynamic focus and adopt time series methods and approaches to a much larger extent than it has been the case so far. This is the route we take in this paper.

The second fact is that the literature has so far focused on a limited set of factors explaining threshold effects and multiple growth regimes, and it has in particular given too much emphasis to the role of human capital and its interactions with technological change, and neglected several other factors that, interacting with absorptive capacity and innovation, may determine non-linearities in the growth process (e.g. international trade, industrial structure, socio-institutional factors). In the attempt to take a broad multi-dimensional view of the determinants of multiple growth patterns, our empirical study will not focus solely on one or few growth engines but consider several factors that may simultaneously interact and explain the long-run dynamics of economic systems.

3. Model and hypotheses

Our empirical model has three key characteristics: it addresses the *dynamics*, *heterogeneity* and *multi-dimensionality* of the growth process. Its main objective is to investigate *dynamic* (time series) relationships among growth factors in a large panel of economies over the last three-decade period. It addresses the *heterogeneity* issue by investigating how the model results differ in distinct country groups. This is intended to shed new light on the factors that enable a country to shift from one development stage to a more advanced one, rather than simply comparing the characteristics of different country clubs in a static cross-sectional fashion. Finally, the model tackles the *multi-dimensionality* issue by simultaneously considering several main drivers of economic growth at different development stages rather

than focusing on only one or few of them. As such, our empirical model does not aim at testing a specific multiple equilibria growth model among those noted in the previous section, but it rather provides a more general and flexible framework to investigate the empirical validity of the multiple growth regimes literature in a time-series perspective.

The diagram in figure 1 shows a stylized view of our empirical model. The growth of GDP per capita over time is linked by a set of two-way dynamic relationships to two main sets of dimensions: innovation (at the bottom of the diagram) and absorptive capacity (the other five factors surrounding the economic growth box).

<< Figure 1 here >>

Innovation: technological innovation represents the key factor highlighted by Schumpeterian growth models, which is likely to become more and more important as national economies evolve from early development stages to more advanced growth clubs.

Absorptive Capacity: this is a broad and composite concept, originally developed by Abramovitz (1986) to denote the wide set of technological, economic and social factors that shape the ability of a country to imitate and absorb foreign advanced technologies. Although the concept has been increasingly used, particularly in the Schumpeterian growth literature, it is a multifaceted and multidimensional construct, and several distinct dimensions may be considered important in shaping a county's absorptive capacity. Our study points out five factors that, individually and in interaction with each other, may explain threshold externalities and multiple growth regimes related to the dynamics of absorptive capacity.

- *Human capital*: as noted in section 2, this is the absorptive capacity variable typically emphasized in the literature on multiple growth regimes and convergence clubs (Azariadis and Drazen, 1990; Galor, 2005).

- *Physical capital*: although the accumulation of physical capital has traditionally been singled out as one of the crucial engines of growth in neoclassical models, it may also play an important role in a Schumpeterian perspective since investments in physical capital enable innovative activities and technology diffusion through so-called embodied technical progress. We therefore consider it appropriate to include this among the variables defining the absorptive capacity of a country.

- ***Industrial structure***: during the development process, national economies undergo a process of structural change and industrial transformations in which labour and capital resources are gradually shifted from low-tech and traditional activities (e.g. agriculture) towards more technologically advanced manufacturing and service sectors (Durlauf, 1993; Kelly, 2001). A more advanced industrial structure does arguably represent an important factor enabling the absorption and implementation of foreign advanced technologies.

- ***International trade***: the openness of the economic system represents an important pre-condition for the international diffusion of advanced technologies. When trade openness is matched with the other structural factors noted here, a country's absorptive capacity is enhanced and international technology diffusion through the import and imitation of foreign advanced technologies emerges as an important driver of economic growth (Papageorgiou, 2002; Stokke, 2004).

- ***Socio-Institutional context***: the quality of institutions and, broadly speaking, the social context in which economic relationships unfold have been pointed out as a key dimension in recent applied growth theory. In a Schumpeterian perspective, in particular, the socio-institutional context provides the fundamental building block upon which national innovation systems develop over time (Fagerberg and Srholec, 2008).

Our model investigates the dynamic relationships that link each of these variables to economic growth (*direct effects* on GDP per capita dynamics), the interactions and co-evolutionary processes linking together innovation and absorptive capacity factors (*indirect effects* on the growth process), and it highlights how these direct and indirect effects differ along development stages. In line with the literature, and in order to provide a simple operationalization of the (admittedly complex) concept of development stages, we make use of a standard three-group typology: we focus on the three country groups traditionally defined as *less developed economies*, *middle-income countries* and *advanced economies* (as further explained in section 5.1).

We formulate four hypotheses on the working of our empirical time-series model in these three country groups. These propositions are to a large extent based on the theoretical models outlined in section 2, but extend them further by highlighting the possible co-

existence of a complex set of direct and indirect relationships linking innovation, absorptive capacity and economic growth.

Hypothesis 1: In less-developed economies, neither innovation nor absorptive capacity is an important driver of GDP per capita dynamics. By contrast, it is income dynamics that sustains the early formation and development of absorptive capacity.

In the less developed country club, both innovative capabilities and the absorptive capacity of nations are typically too low, below a minimum threshold level, and they are therefore not likely to emerge as important drivers of GDP per capita growth. Income dynamics and economic development may instead be fostered by other factors not directly related to innovation and absorptive capacity, such as e.g. population growth and the availability and use of natural resources (factors that are typically unaccounted for in a Schumpeterian model framework). The growth of GDP per capita, in turn, may sustain the early formation and development of absorptive capacity, i.e. by enabling public investments in physical and human capital, industrial activities and institution building.

Hypothesis 2: In middle-income countries, absorptive capacity and GDP per capita growth are linked by a two-way dynamic relationship. The growth of absorptive capacity does also sustain the early formation and development of innovative capabilities.

As the process of absorptive capacity building proceeds spurred by GDP growth, at some point some of the factors that contribute to define the absorptive capacity of a nation pass a given threshold level, after which they increase their pace and start to have a direct feedback effect on income per capita dynamics. This is what suggested by the threshold externalities models reviewed in section 2. For instance, threshold effects may arise in the process of capital accumulation (Azariadis and Drazen, 1990; Galor, 2005), international trade openness (Papageorgiou, 2002; Stokke, 2004) or industrial upgrading (Durlauf, 1993; Kelly, 2001). If such increased dynamics of absorptive capacity sets in, the latter will be linked by a set of two-way dynamic relationships to GDP per capita growth. This self-reinforcing cumulative mechanism and the co-evolutionary dynamics of absorptive capacity and income

per capita will also enable the development of innovative capabilities. As a country undertakes a catch up process, private agents and public authorities will increasingly look at technological innovation and R&D investments as the key factor to sustain their international competitiveness. Private organizations and public institutions will therefore start to devote more resources to it.

Hypothesis 3: In advanced economies, innovation is linked by a two-way dynamic relationship to absorptive capacity, on the one hand, and to GDP per capita, on the other.

As the process of innovation capability building proceeds, a nation may reach a threshold level beyond which R&D and innovation investments emerge as a crucial driver of GDP per capita growth. This is what pointed out by recent Schumpeterian threshold growth models (Howitt, 2000; Howitt and Mayer-Foulkes, 2005; Acemoglu et al., 2006), and it is also in line with empirical studies of technology clubs (Castellacci, 2008; 2011). In this advanced club setting, innovation-based competition leads to two main differences in the set of dynamic relationships driving the growth of economic systems *vis-a-vis* the previous two country groups. On the one hand, innovation dynamics feeds back and sustains further the growth of absorptive capacity (e.g. human capital, international trade, structural and industrial change), so that the two dimensions start to be linked by a two-way dynamic relationship over time. On the other hand, an analogous process arises for the links between innovation and GDP per capita. The former becomes an important causal driver of the latter in this advanced country club, and income dynamics, in turn, is partly reinvested in R&D activities, thus leading to a two-way dynamic and self-reinforcing relationship between innovation and GDP per capita growth.

Hypothesis 4: The complexity of the economic growth process – measured by the number of causal relationships linking together innovation, absorptive capacity and GDP per capita growth – increases along the stages of development.

Hypotheses 1 to 3 do implicitly tell a story of increasing complexity of the economic growth process along subsequent development stages. The causal relationships, both direct

and indirect, driving GDP per capita dynamics in our Schumpeterian model are assumed to be only few in the less developed club, and progressively increase and become two-directional links as countries move to a middle-income and then an advanced stage. So, if the simple story illustrated by hypotheses 1 to 3 holds true, a more general proposition may be put forward: as national economies shift from lower to upper stages of development, the complexity of the growth process – as measured by the number of causal relationships linking together absorptive capacity, innovation and GDP per capita – tends to increase. That is to say, the process of economic development entails an increasing level of systemic complexity.

The general idea that economic dynamics is related to the complexity of the system is not by itself new. Classical economists as Herbert Spencer and Adam Smith put forward this general argument more than two centuries ago, and evolutionary economics pointed it out as one of the main pillars of evolutionary models of social and economic systems (Nelson and Winter, 1982; Castellacci, 2007). However, while the proposition we argue here is broadly in line with these more general arguments, this fourth hypothesis has a more specific character, which has not been previously formulated as such in the growth literature. Our empirical model aims at testing causal dynamic relationships among a large set of variables of interest (innovation, absorptive capacity factors, GDP per capita growth), and then investigate whether the number of (statistically significant) causal relationships increases along subsequent development stages.

4. Data and indicators

The empirical analysis makes use of the CANA database, a newly released cross-country panel dataset containing a large number of indicators for the period 1980-2008 (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 considers a sample of 116 countries (listed in Appendix 1) and a set of 11 selected indicators, which are listed as follows.

GDP per capita: GDP per capita, purchasing power parity.

Innovation: Number of patents registered at the USPTO per million people.

Absorptive Capacity:
- *Human capital***:** Secondary and tertiary enrolment ratios.
- *Physical capital***:** Gross fixed capital formation, percentage of GDP.
- *Industrial structure***:** Agriculture, manufacturing and services value added, percentage of GDP.
- *International trade***:** Openness: (Import + Export) / GDP.
- *Socio-Institutional context***:** We make use of two indicators: (1) The GINI Index as a measure of a country's economic inequalities and cohesion; (2) The Corruption Perception Index as an indicator of the quality and functioning of institutions.

5. Methods

Our empirical methodology consists of three steps, each of which corresponds to the three salient features of the model highlighted in section 2: heterogeneity, dynamics and multi-dimensionality. The first step points out different groups of countries belonging to the three development stages (less-developed, middle-income and advanced economies). The second investigates, for each country group, dynamic relationships among the variables of interest over the last three-decade period through panel cointegration analysis and Granger causality tests. The third step defines a set of model specifications where, in order to tackle the multi-dimensionality of the growth process, different indicators are used for the time-series tests.

5.1 *Heterogeneity*: Identification of country clubs

We have chosen to cluster countries in a hierarchical two-step manner. First, we identify three major country clubs, which are broadly in line with the models discussed in section 2: advanced economies, catching-up countries and least-developed economies (Howitt and Mayer-Foulkes, 2005; Castellacci and Archibugi, 2008). Secondly, in order to achieve a finer characterization of the widely different nature of economies within these three heterogenous clubs, we further divide them into a few sub-groups. We make this based on an exogenous and intuitive criterion: we follow broad geographical areas, which on the whole group together countries that are similar with respect to both the initial GDP per capita level (the usual clustering variable in this literature) and the overall institutional context and capitalist mode of development[1]. All in all, we end up with a total of seven sub-groups, defined as follows (see Appendix 1 for a list of countries included in each group):

- **Least developed countries:** (1) Sub-Saharan Africa; (2) South Asia; (3) North Africa and Middle-East.

- **Catching-up economies:** (4) Eurasia; (5) Latin America; (6) East Asia.

- **Advanced economies:** (7) OECD countries.

Although it is clear that no clustering exercise is faultless, the advantage of the intuitive clustering method described here is twofold: it is broadly in line with the three-club specification adopted by most theoretical models in this field, and at the same time, by working with seven internally homogenous sub-groups, it deals in a satisfactory manner with the cross-country heterogeneity issue.

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[1] We have also tried several different sub-groups specifications based on the results of hierarchical cluster analysis (some of which are closely related and very similar to the groups presented here).

5.2 *Dynamics***: Investigation of causal relationships over time**

The second step of our empirical analysis is to investigate the set of dynamic relationships between the main variables of interest and the direction of causality of each of these. For this purpose, we make use of panel cointegration analysis and Granger causality tests, and apply these in each of the seven country groups noted above.

Cointegration analysis is a useful tool to analyse 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).[2] 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, while at the same time enabling to deal with the issue of cross-country heterogeneity by including fixed effects and country-specific trends in the econometric specification.

The methodology adopted in this second phase of our empirical analysis consists of four steps. First, since cointegration analysis can by definition only be used to study the relationships between time series variables that have the same order of integration, we start by carrying out a battery of *unit root tests* (Levin, Lin and Chu; Breitung; Im, Pesaran and Shin; augmented Dickey-Fuller; Phillips-Perron), in order to make sure that our variables are stationary after removing the time trend by first-differencing (i.e. they are I(1) series).

Secondly, we test the existence of long-run equilibrium relationships between our variables of interest by means of the *Johansen cointegration test*, which adopts Trace Test and Maximun Likelihood specifications to determine the number of cointegrating relationships. We repeated both the first and the second step for 9 different lags (from 1 to 9), in order to make sure that the results are robust and not too sensitive to the lag specification that is used for each test (which is a well-known problem for this type of time series analyses).

The third step is the estimation of a *vector error correction model* (VECM). This model is useful because it makes it possible to estimate 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 our paper, though, the

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[2] 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*.

focus is not to uncover long-run equilibrium relationships but rather to point out causal dynamic relationships. Therefore, we will not present the results of the VECM as such (which are available upon requests), but rather use the VECM model to test for causal relationships in the fourth and crucial step of our methodology.

The fourth step is to investigate the *direction of causality*, i.e. to analyse whether the relationships previously identified between each pair of variables Y_t and X_t is a uni-directional type of causality ($Y_t \rightarrow X_t$, or $Y_t \leftarrow X_t$) or rather bi-directional ($Y_t \leftrightarrow X_t$). 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 (and for each of the seven country groups), a Granger block exogeneity test.[3] Since the results of Granger causality analysis are typically quite sensitive to the lag specification that is adopted, for each pair of variables we, once more, carry out block exogeneity tests for 9 different lags (from 1 to 9), and we only consider reliable those results for which we obtain significant evidence of a causal relationship for at least five of the nine lag specifications.

The panel cointegration methodology that we have adopted enables to investigate the *direct* and *indirect* causal effects from innovation and absorptive capacity to economic growth. A *direct* relationship emerges when a given explanatory variable X (innovation or absorptive capacity) has a direct causal impact on GDP per capita growth. An *indirect* relationship exists when a given variable X (e.g. innovation) affects another explanatory variable Y (e.g. absorptive capacity), and the latter does in turn have an impact on GDP per capita dynamics. By using Grange Causality tests, we study not only the factors that are important drivers of GDP dynamics at each development stage (the *reduced form* of the growth model) but also how these engines of growth are related to each other and evolve along the development process (the *structural form* of the growth model).

5.3 *Multi-dimensionality*: Different model specifications

The third methodological issue we face is multi-dimensionality: many different factors may simultaneously be relevant, and distinct variables may represent good indicators in a

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[3] Granger (1984) proposed a method to determine if changes in one variable could impact (predict) the performance in time of another variable of interest. We might say that there exist *Granger-causality* when lagged values of a variable, X_t, have explanatory power in a regression of a variable Y_t on lagged values of Y_t and X_t.

development stage but not in others (e.g. secondary vs. tertiary education; agriculture, industry and service shares of GDP). We have therefore specified 14 different model specifications and run our panel cointegration analysis in each of them. Table 1 reports a summary.

<< **Table 1 here** >>

6. Empirical results

Before presenting the results of the tests of the four hypotheses outlined in section 3, let us briefly summarize the results of the first three steps of our empirical methodology, which are preparatory phases for the fourth and crucial step of the analysis (Granger causality analysis). First, we have run a large battery of panel unit root tests (Levin, Lin & Chu; Breitung; Im, Pesaran & Shin; ADF; PP), each of which was repeated for all the variables included in the model and for nine different lag specifications. The results indicated consistently that, in our 116 countries panel sample for the period 1980 to 2008, all the variables of interest for our analysis are I(1) series (trend stationary), thus confirming that it is correct to apply a panel cointegration and VECM methodology.

The second step was to carry out a set of Johansen cointegration tests, which analyse the existence of cointegration relationships among the variables. Again, each Johansen test was repeated for nine different lags in order to check for the robustness of the results. Table 2 presents the results of some selected cointegration tests, among many others that we have produced but do not report here to save space. Most Johansen tests, including those not reported in table 2, provide evidence suggesting the existence of (at least) one long-run cointegration relationship linking together GDP per capita, on the one hand, and the set of innovation and absorptive capacity variables, on the other.

<< **Table 2 here** >>

Thirdly, we estimated a vector error correction model (VECM), where GDP per capita growth is the dependent variable and innovation and absorptive capacity factors are the explanatory variables (see the 14 model specifications previously reported in table 1). As noted in section 5, though, we will not report detailed results of the VECM estimations here. The reason is that our main objective is not to uncover long-run *equilibrium* relationships through the VECM results, but rather to point out *causal* dynamic relationships. Therefore, we have used the VECM estimation results only as a preparatory step to derive the Granger causal tests that represent the main step of our empirical analysis.[4]

The fourth and crucial step of the analysis was to carry out, for each pair of variables included in the VECM model (and for each of the seven country groups), a *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 have run block exogeneity tests for 9 different lags (from 1 to 9), and have only considered reliable those results for which we obtain significant evidence of a causal relationship for at least five out of the nine lag specifications. Thus, the presentation of these results below here will only rely on what we consider to be *robust* causal relationships, and disregard all other results that are not stable across different lags and model specifications.

All in all, we have run a very large number of Granger tests, evaluating the causal relationship between all pairs of variables for 14 model specifications, 9 lag specifications, and 7 country panels. Since this empirical material is too large to be reported here, we provide a graphical summary of the results and focus only on those causal relationships that turn out to be more stable and significant in several model and lag specifications. Figures 2.a, 2.b and 2.c report this graphical summary, which we will use to discuss the results of our hypotheses 1, 2 and 3 respectively.

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[4] An interesting pattern emerging from the panel cointegration and VECM estimations is that the results are more stable and robust in the advanced club panel of economies, and less so in the other two groups (and particularly the less-developed one). This pattern is reasonable and in line with the main idea of the development stages and multiple equilibria models considered in this paper. Long-run equilibrium relationships (as identified in a panel cointegration and VECM context) are stable only in the OECD country group, because this is the club of countries that has already undergone its long-run process of transformation and economic development for a long period of time. By contrast, less developed and middle-income economies, which are still in a transition process towards higher development stages, are characterized by unstable and out-of-equilibrium long-run development paths.

6.1 Less developed economies

Sub-Sahara: In this panel of countries, we do not find any direct causal relationship from innovation or absorptive capacity variables to GDP per capita growth (see figure 2.a). By contrast, it is income dynamics that fosters the early development of absorptive capacity, particularly through its impacts on socio-institutional building and industrial upgrading (e.g. the shifting from agriculture to industrial activities). The industrial structure variable, in turn, feeds back and sustains the growth of physical capital, human capital and international trade. Hence, the absorptive capacity variables are related to each other and co-evolve over time, although they do not lead to have any direct causal impact on GDP per capita growth.

North Africa and Middle-East: Similarly to the previous group, the panel Granger results for this bunch of oil-rich countries show that none of the explanatory variables considered in our model has a direct effect on GDP dynamics, while the latter has a causal impact on both international trade openness and the industrial structure variable. Innovation and physical capital dynamics are linked by a two-way relationship, e.g. explained by embodied technical progress in the accumulation of physical capital, and the latter does in turn fosters the openness of the system to international trade. The other absorptive capacity variables, such as human capital and the socio-institutional context, are instead not significantly connected to the dynamics of the national system.

South Asia: Similarly to the previous two groups, industrial structure (agriculture and industry shares of GDP) turns out to be a central variable in the system: its growth is affected by the dynamics of the socio-institutional system (indirectly) and international trade (directly), and in turn it has a direct causal impact on GDP per capita growth. The latter has then a feedback effect on capital accumulation (physical and human capital), thus fostering absorptive capacity and the variables enabling growth and catching up in the future. By contrast, innovation does not emerge as an important factor, and its dynamics is not significantly connected to the rest of the system.

Hypothesis 1: Although the three groups of less-developed economies are characterized by slightly different causal relationships, a summary overview of the results reported in figure 2.a provides clear support for the first general proposition that we put forward in section 3. In less-developed economies, neither innovation nor absorptive capacity turns out to be an

important driver of GDP per capita dynamics. By contrast, it is income dynamics that sustains the early formation and development of absorptive capacity, particularly through its effects on industrial structure and international trade. The growth of these variables prepares the conditions for the shift to a more advanced development stage in the future.

<< Figure 2.a here >>

6.2 Middle-income group

Eurasia: In the group of former Communist economies, income per capita dynamics is driven by physical capital accumulation, international trade and human capital. In turn, GDP growth fosters the further building of absorptive capacity factors such as industrial structure, human capital and trade openness. The innovation variable is not significantly related to any other variable in the system.

East Asia: GDP per capita growth is in this group driven by the dynamics of industrial structure and human capital. In turn, GDP growth affects all five absorptive capacity factors considered in the model. The absorptive capacity variables are also closely related to each other and appear to co-evolve over time, as evident from the intense web of causal links depicted in figure 2.b. However, the innovation variable is not as integrated as the other factors, and turns out to be only related to physical capital accumulation.

Latin America: GDP per capita growth is sustained by the dynamics of three absorptive capacity variables: industrial structure, international trade and physical capital. Income per capita dynamics does in turn feed back and sustains the further growth of absorptive capacity. Differently from the previous group, however, the innovation variable does also emerge as an important factor determining GDP growth (a specific result which is more in line with the advanced club model results than the middle-income group).

Hypothesis 2: Similarly to what observed for the less developed country club, the three groups included in the middle-income club do also present a variety of relationships and do not conform easily to any single and simple growth model. Nevertheless, it is possible to extract the key general results that are common to these groups, and provide a simple summary of them. In line with our hypothesis 2, in middle-income countries absorptive capacity and GDP per capita growth are linked by a set of two-way causal relationships that

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drive the dynamics of the system over time. The growth of absorptive capacity does also sustain the early formation and development of innovative capabilities. Innovation, in turn, does not emerge yet as a crucial and significant driver of economic growth (with the exception of the results for Latin America, as noted).

<< Figure 2.b here >>

6.3 Advanced club

In the panel of OECD economies, the two-way co-evolutionary set of relationships linking together GDP per capita and absorptive capacity still holds. Further, the absorptive capacity factors are also closely linked to each other by a complex web of causal relationships (see figure 2.c). The main difference in this advanced group *vis-à-vis* the other two is the role of innovation, which emerges as an important and fully integrated variable. Innovation is in fact linked by a two-way causal relationship to both human capital and physical capital. In addition, it has a direct causal impact on the growth of GDP per capita, while the latter variable does in turn sustain technological dynamics further.

Hypothesis 3: This panel of economies is more internally homogenous than the other two, and the results for this group are on the whole easier to interpret and more in line with Schumpeterian multiple equilibria models (e.g. Galor, 2005; Howitt and Mayer-Foulkes, 2005). The overview depicted in figure 2.c supports our third general hypothesis: in advanced economies, innovation is linked by a two-way dynamic relationship to absorptive capacity, on the one hand, and to GDP per capita, on the other. The two-way dynamic and self-reinforcing relationship between innovation and GDP per capita growth is an important growth engine in knowledge-based economies.

<< Figure 2.c here >>

6.4 Hypothesis 4: Increasing complexity along the stages of development

As pointed out in section 3, the simple development-stage story corroborated by the first three hypotheses leads implicitly to a more general implication of this model framework. Since the role of absorptive capacity and innovation becomes more visible and more

significant as we move from the less-developed group towards the middle-income and then the advanced club, the number of direct relationships (direct causal drivers of GDP per capita growth) and the number of indirect links (i.e. feedback effects and relationships between innovation and absorptive capacity dynamics) should hence be expected to increase along these three subsequent development stages. This is the fourth hypothesis we formulated in section 3. In fact, a simple comparison of the diagrams in figures 2.a, 2.b and 2.c suggests that this is indeed the case.

To provide a more thorough examination of this proposition, tables 3.a, 3.b and 3.c report an overview of the total number of significant causal relationships that we have found in all our Granger tests (i.e. considering all the 14 model specifications and the seven country groups). These tables provide strong support for our fourth hypothesis. The number of significant causal relationships – considering both direct and indirect links to GDP per capita – visibly increases as we move from the less-developed, to the middle-income and then the advanced country club. The total number of Granger relationships for the three groups, in particular, amounts to 6, 12 and 18 respectively.

Our interpretation of this pattern, as explained in section 3, is that as the process of economic development unfolds, the growth of absorptive capacity and innovation capability building proceed in a non-linear fashion, speeding up and assuming a more central role at the point at which threshold effects are achieved. Beyond these threshold levels, absorptive capacity and innovation start to co-evolve with GDP per capita dynamics, and this complex (and multi-dimensional) co-evolution drives the dynamics of the economic system in the long-run. Increasing systemic complexity, we believe, is a general implication of the class of multiple equilibria and threshold growth models considered in this paper.

<< Tables 3a, 3b and 3c here >>

7. Conclusions

The paper has presented an empirical analysis of the time series implications of multiple equilibria and convergence clubs models. It has considered a panel of 116 countries over the period 1980-2008, and made use of panel cointegration analysis (VECM and Granger causality estimations) to identify the set of dynamic relationships linking together innovation, absorptive capacity and economic growth. The Granger results provide general support for this class of Schumpeterian multiple equilibria models, and point out four main results: (1) In the less-developed country club, neither innovation nor absorptive capacity is a crucial driver of GDP per capita; (2) In the middle-income group, absorptive capacity emerges as an important factor fostering GDP per capita dynamics and innovation capability building; (3) In the advanced club, there exists a complex set of two-way relationships linking together innovation and absorptive capacity, on the one hand, and GDP per capita growth, on the other; (4) The complexity of the economic system – measured by the number of significant Granger causal relationships – increases as we move from the less-developed, to the middle-income and then to the advanced country clubs.

We believe that the empirical model and approach adopted in this paper provide three original contributions to the literature, but each of these contributions does also present an important limitation and challenge for future research in this field. Let us briefly point out these three contributions and related issues.

The first important aspect refers to the *heterogeneity* of the growth process. While the convergence clubs literature and multiple equilibria models typically provide a stylized view of cross-country heterogeneity – most often by means of a three-club typology – our analysis has made use of a two-tier approach and further divided each of the three clubs into a few sub-groups of countries, which are internally homogenous as they belong to different geographical and socio-cultural areas (Sub-Sahara, North Africa and Middle-East, South Asia, East Asia, Eurasia, Latin America, OECD countries). The advantage of this approach is to show that there is indeed a great deal of cross-country heterogeneity within the three clubs of countries usually adopted in the literature, and that it is important to take this into account by means of finer typologies and clustering methods to the extent possible. However, the flip side of the coin is that the empirical results that we have obtained for each of the seven sub-groups of countries are not always clear cut, and the set of identified

relationships differ somewhat across the groups. This point shows, in more general terms, a limitation of the class of multiple equilibria models considered in this paper. These models provide an interesting and appealing dynamic story, which is of course a simple and general metaphor describing the dynamics of the economic system but does not hold true for all countries included in a given club or development stage.

The second aspect we like to highlight is that the paper has made an explicit effort to uncover *dynamic* relationships by investigating the time-series implications of multiple equilibria and convergence clubs models. Our panel cointegration and Granger analyses have identified the existence of a complex web of relationships linking together innovation, absorptive capacity and economic growth, and shown that these relationships vary substantially across country groups. A drawback of our methodology, however, is that while we have focused on the existence and direction of causality among different growth engines, we have not estimated the structural form of the model and hence we are not able to identify the relative strength (or weakness) of the various causal links. In other words, our results point out the main engines of growth that are relevant at different development stages but do not provide any clue as to which of these factors and causal relationships are more important than others.

Finally, the third contribution of the paper refers to the *multi-dimensionality* and *complexity* of the growth process. While most multiple equilibria models and convergence clubs empirical studies typically focus on one or a few key explanatory factors, and the interactions among them, our empirical results indicate that many dimensions are simultaneously important and turn out to be causally linked to the GDP per capita dynamics: innovation, physical and human capital, industrial structure, international trade, and socio-institutional factors. Further, these dimensions are not equally important for different country clubs: the number of relevant dimensions and the number of significant causal relationships among them tend to increase as we move from lower to more advanced development stages. Therefore, our paper results suggest that increasing complexity is an important, though neglected, implication of multiple equilibria models. This idea is appealing, but the corresponding limitation of our empirical strategy is equally important. Our results may be interpreted as providing general empirical support to the class of multiple equilibria models taken as a whole, but they do not represent a thorough test of

any specific model among those reviewed in section 2. The time series and panel cointegration approaches adopted in this paper could be used in future research to carry out empirical tests of the time series implications of each of these models.

Appendix 1: List of countries included in each group

Advanced Countries

OECD Countries: 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.

Catching up Countries

Latin American Countries: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela.

East Asian Countries: Cambodia, China, Fiji, Indonesia, Malaysia, Mongolia, Philippines, Singapore, South Korea, Thailand, Vietnam.

Eurasian Countries: Albania, Armenia, Azerbaijan, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Latvia, Lithuania, Moldova, Poland, Romania, Slovakia, Slovenia, Tajikistan, Ukraine, Uzbekistan, Bangladesh.

Least Developed Countries

South Asian Countries: Bangladesh, India, Nepal, Pakistan, Sri Lanka.

North African and Middle East Countries: Algeria, Iran, Jordan, Morocco, Tunisia, Turkey.

Sub-Saharan Countries: Benin, Botswana, Burkina Faso, Burundi, Cameroon, Ethiopia, Gabon, Ghana, Guinea, Haiti, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Swaziland, Tanzania, Uganda, Zambia, Zimbabwe.

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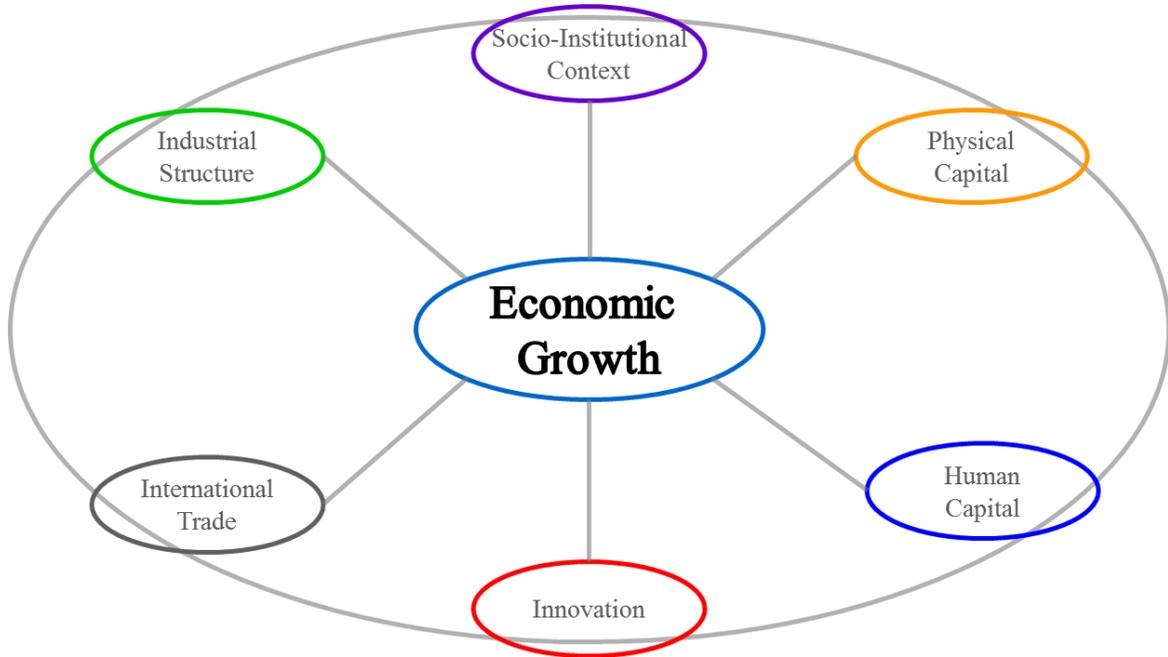**Figure 1: Innovation, absorptive capacity and economic growth**

Table 1: Summary of model specifications

	Innovation	Absorptive Capacity				
		Physical Capital	Human Capital	Industrial Infrastructure	International Trade	Socio-Institutional Context
1	Patents	Gross Fixed Capital Formation	Tertiary Education	Service	Openness	GINI
2	Patents	Gross Fixed Capital Formation	Tertiary Education	Service	Openness	Corruption Perception Index
3	Patents	Gross Fixed Capital Formation	Secondary Education	Service	Openness	GINI
4	Patents	Gross Fixed Capital Formation	Secondary Education	Service	Openness	Corruption Perception Index
5	Patents	Gross Fixed Capital Formation	Tertiary Education	Industry	Openness	GINI
6	Patents	Gross Fixed Capital Formation	Tertiary Education	Industry	Openness	Corruption Perception Index
7	Patents	Gross Fixed Capital Formation	Secondary Education	Industry	Openness	GINI
8	Patents	Gross Fixed Capital Formation	Secondary Education	Industry	Openness	Corruption Perception Index
9	Patents	Gross Fixed Capital Formation	Tertiary Education	Manufacturing	Openness	Corruption Perception Index
10	Patents	Gross Fixed Capital Formation	Secondary Education	Manufacturing	Openness	GINI
11	Patents	Gross Fixed Capital Formation	Secondary Education	Manufacturing	Openness	Corruption Perception Index
12	Patents	Gross Fixed Capital Formation	Secondary Education	Manufacturing	Openness	Corruption Perception Index
13	Patents	Gross Fixed Capital Formation	Secondary Education	Agriculture	Openness	GINI
14	Patents	Gross Fixed Capital Formation	Secondary Education	Agriculture	Openness	Corruption Perception Index

Table 2: Summary of (selected) Johansen cointegration tests

Least Developed Economies

Group	Model	Lag	Trace Statistic	Maximun-Eigenvalue Statistic
				Johansen Tests
Sub-Saharan Africa	8	4	56.69616***	31.53753**
South Asia	14	7	160.6065***	46.82462***
Islamic	8	7	140.2898***	51.33442**

Catching-up Economies

Group	Model	Lag	Trace Statistic	Maximun-Eigenvalue Statistic
				Johansen Tests
Eurasia	8	6	47.86217**	42.48968**
Latin America	2	6	82.88312***	35.66159**
East Asia	2	6	125.7114**	52.01002**

Advanced Economies

Group	Model	Lag	Trace Statistic	Maximun-Eigenvalue Statistic
				Johansen Tests
OECD	2	3	113.2632***	38.10318***

Figure 2.a: Summary of causal relationships (selected models – Less developed country club)

Sub-Saharan Africa – Model 8
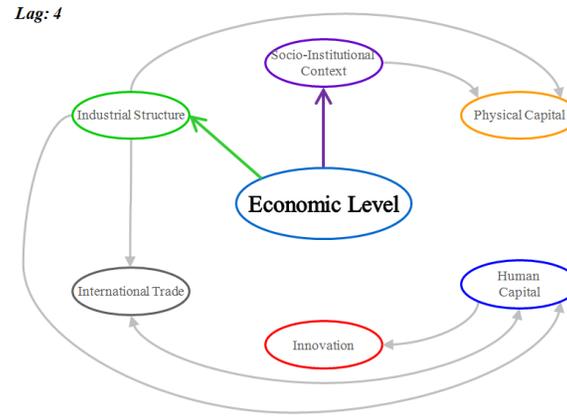
Islamic – Model 8
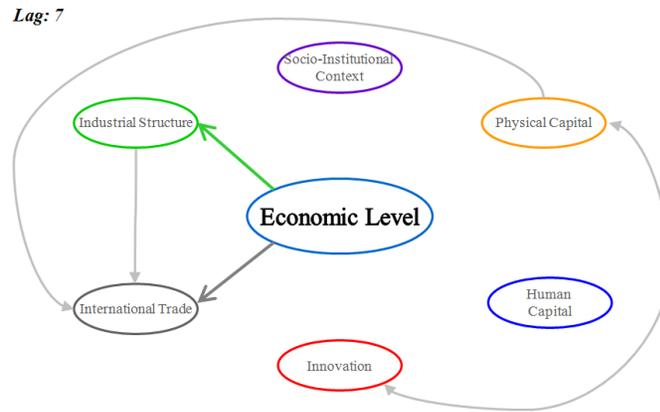
South Asia – Model 14

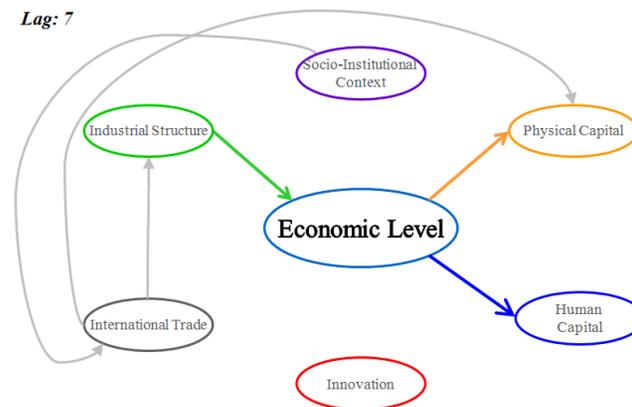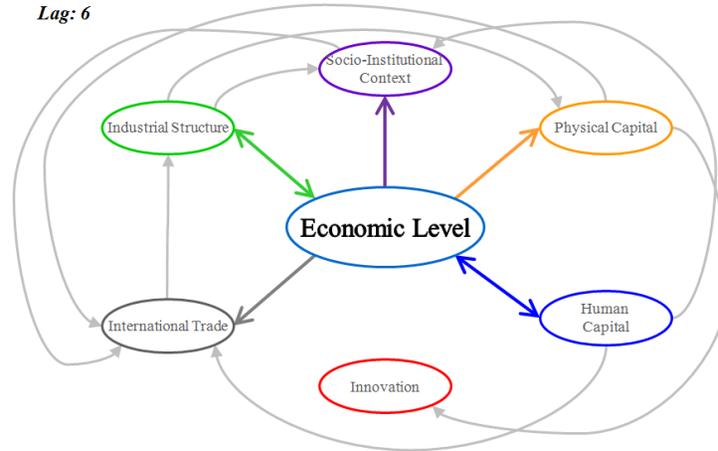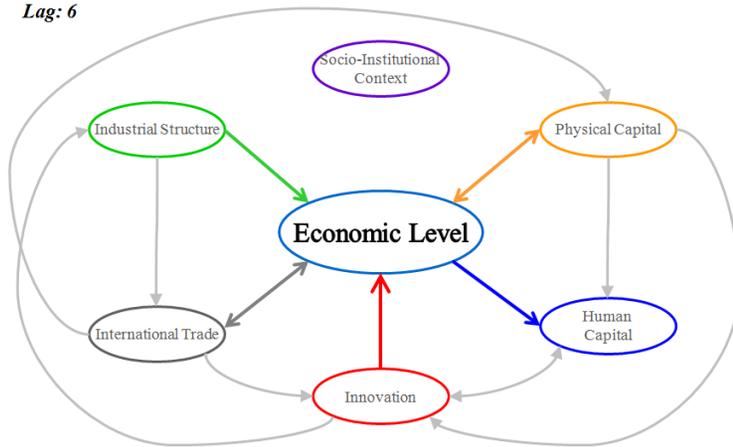**Figure 2.b: Summary of causal relationships (selected models – Middle-income club)**

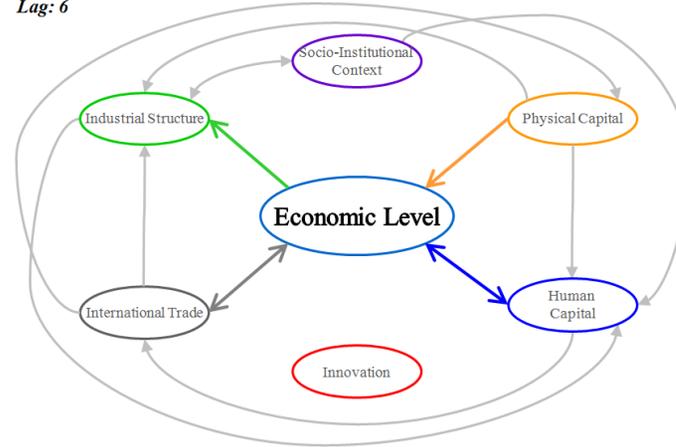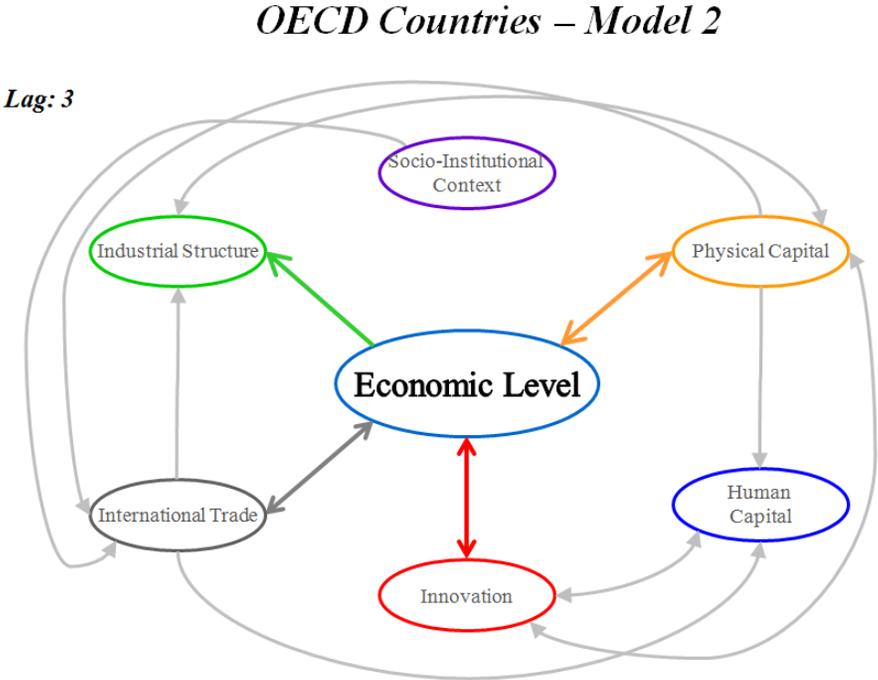*East Asia – Model 2*

Latin America – Model 2

Eurasia – Model 8

Figure 2.c: Summary of causal relationships (selected models – Advanced club)

OECD Countries – Model 2

Table 3.a: Number of significant Granger causal relationships: Less developed country club

Model specification	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
Subsharan Africa															
Direct links to GDP	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Indirect links	4	4	5	4	5	7	7	9	6	6	8	9	6	6	6
Total causal links	5	4	5	4	5	7	7	9	7	6	8	9	6	6	6
South Asia															
Direct links to GDP	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Indirect links	6	7	6	7	8	10	8	7	6	8	10	9	7	4	7
Total causal links	6	7	6	7	8	10	8	7	6	8	10	9	7	5	7
North Africa & Middle-East															
Direct links to GDP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indirect links	4	5	4	6	4	3	7	6	3	4	7	6	5	3	5
Total causal links	4	5	4	6	4	3	7	6	3	4	7	6	5	3	5
Average Less developed club															
Direct links to GDP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Indirect links	5	5	5	6	6	7	7	7	5	6	8	8	6	4	**6**
Total causal links	5	5	5	6	6	7	7	7	5	6	8	8	6	5	**6**

Model specification	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
Eurasia															
Direct links to GDP	3	1	3	4	3	2	4	3	3	2	4	3	4	3	3
Indirect links	7	8	8	7	8	9	9	12	7	6	8	9	9	7	8
Total causal links	10	9	11	10	10	11	13	15	10	8	12	12	13	10	11
Latin America															
Direct links to GDP	4	4	4	4	4	4	3	3	5	5	3	3	3	3	4
Indirect links	11	10	7	9	11	13	8	8	9	12	10	8	11	9	10
Total causal links	15	14	11	13	15	17	11	11	14	17	13	11	14	12	13
East Asia															
Direct links to GDP	1	1	0	0	2	0	1	1	2	0	1	1	0	1	1
Indirect links	13	14	13	8	8	11	8	11	11	11	11	10	8	12	11
Total causal links	14	15	13	8	10	11	9	12	13	11	12	11	8	13	11
Average Middle-income club															
Direct links to GDP	3	2	2	3	3	2	3	2	3	2	3	2	2	2	**3**
Indirect links	10	11	9	8	9	11	8	10	9	10	10	9	9	9	**10**
Total causal links	13	13	12	10	12	13	11	13	12	12	12	11	12	12	**12**

Table 3.c: Number of significant Granger causal relationships:
Advanced (OECD) country club

Model specification	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
OECD countries															
Direct links to GDP	2	3	5	5	3	3	4	4	3	3	4	4	4	4	**4**
Indirect links	14	15	14	13	15	17	14	15	13	15	15	13	11	11	**14**
Total causal links	16	18	19	18	18	20	18	19	16	18	19	17	15	15	**18**