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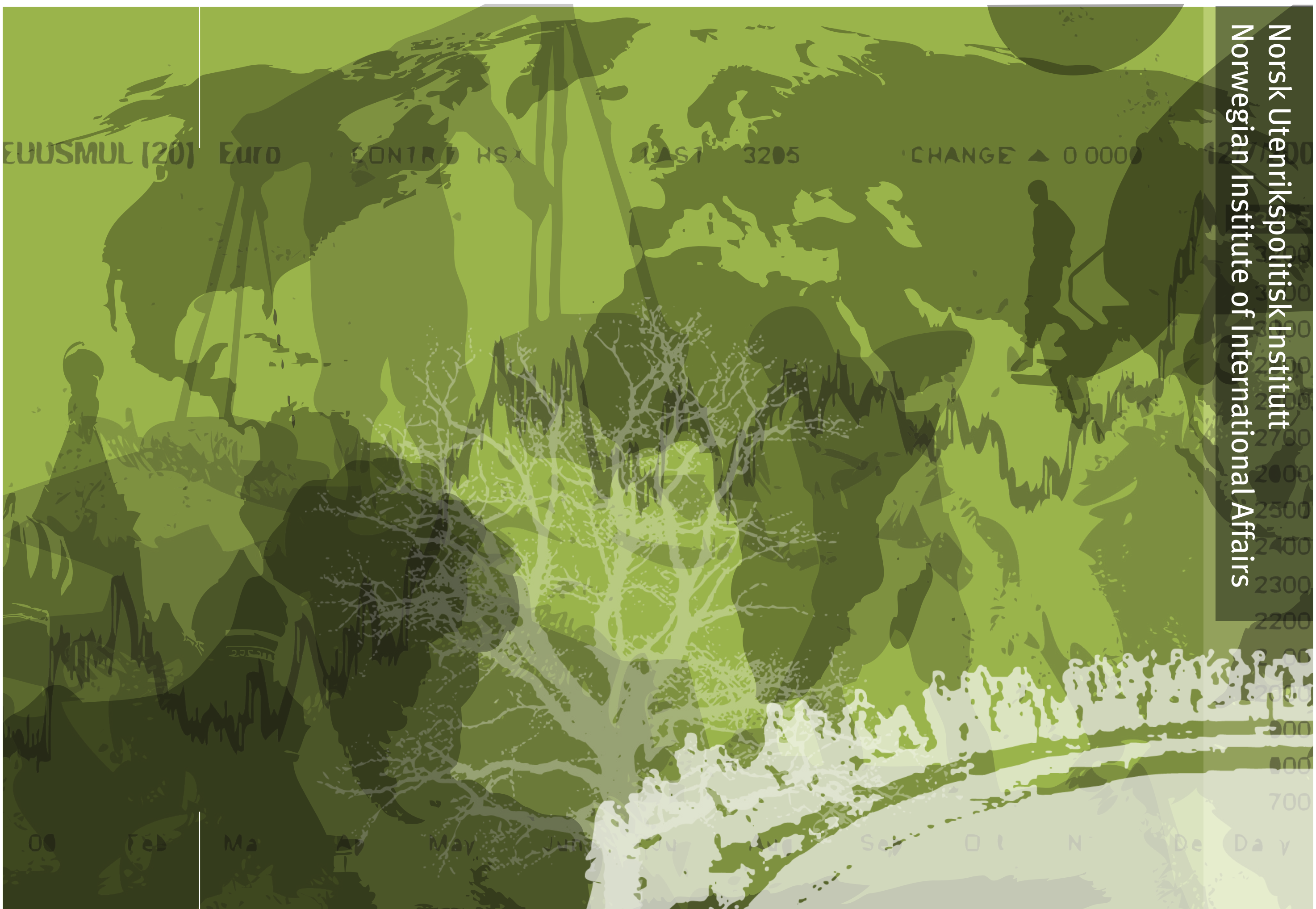

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Innovation, Absorptive Capacity and Complexity along Development Stages

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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 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 important 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 cointegration) 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 modelling 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. This finding of an increasing complexity along the stages of development is related to Hausman and Hidalgo's (2011) recent model, according to which the network structure of economic output becomes more complex over time as countries specialize in a more differentiated and more advanced set of products (see also Hidalgo and Hausman, 2009).

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 are related to older development stages theories. Multiple equilibria models are threshold models that investigate the factors 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 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.

Hausman and Hidalgo (2011) have recently presented a model that does also generate a pattern of increasing complexity, explained by the fact that the network structure of economic output and countries' export activities becomes more complex over time as economies specialize in a more differentiated and more advanced set of products. Since the quality and complexity of products that a country can produce and export is closely related to the set of capabilities that characterizes its national system, economies that are below a given threshold level of capabilities will not easily be able to upgrade their product space and improve their international competitiveness (see also Hidalgo and Hausman, 2009).

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.

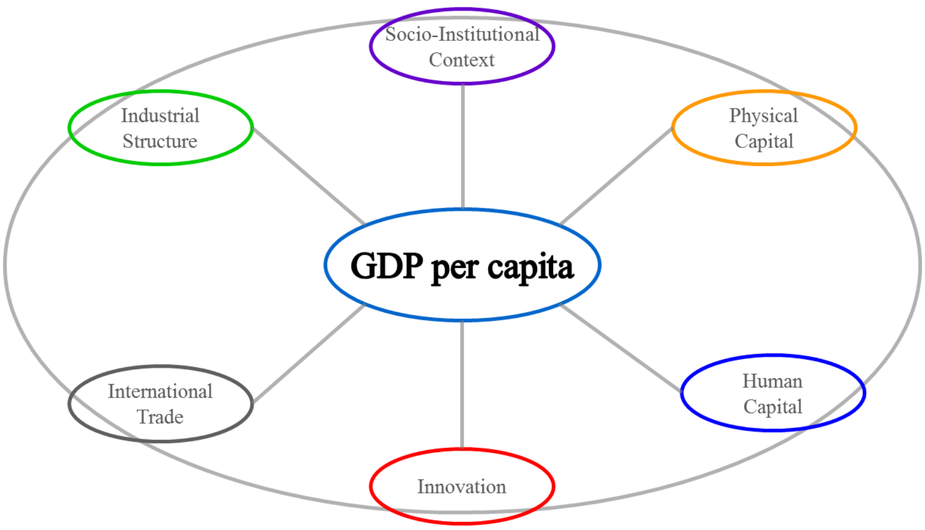
The second fact is that the literature has so far focused on a limited set of factors explaining threshold effects and multiple growth regimes, and it has in particular given much emphasis to the role of human capital and its interactions with technological change, and neglected several other factors that, interacting with absorptive capacity and innovation, may also 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. Models 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 cointegration) 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: Innovation, absorptive capacity and economic growth



Innovation: technological innovation represents the key factor highlighted by Schumpeterian growth models, which is assumed 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***: the accumulation of physical capital has traditionally been singled out as one of the crucial engines of growth in neoclassical models. However, 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*. A higher level of physical capital and technological infrastructures enable a faster and more efficient implementation of foreign advanced technologies. 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 transformation 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 of foreign advanced technologies and their inter-industry diffusion.
- ***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 classification: 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 propositions on the working of our empirical time-series model in these three country groups. These hypotheses 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.

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.

Proposition 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.

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. Further, 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 a key factor to sustain their international competitiveness. Private organizations and public institutions will therefore start to devote more resources to it.

Proposition 2: In middle-income countries, absorptive capacity and GDP per capita growth are linked by a two-way dynamic relationship. In turn, the growth of absorptive capacity sustains the early formation and development of innovative capabilities.

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 changes 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 the resources generated by income dynamics, in turn, are partly reinvested in R&D activities, thus leading to a two-way dynamic and self-reinforcing relationship between innovation and GDP per capita growth.

Proposition 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.

Propositions 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 framework illustrated by propositions 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.

Proposition 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.

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). Hausman and Hidalgo's (2011) recent model, according to which the network structure of economic output becomes more complex over time as countries specialize in a more differentiated and more advanced set of products, is also in line with this idea, and proposes a new interpretation of it based on the relationships between countries' output structure and export performance (see also Hidalgo and Hausman, 2009).

While the proposition we argue here is broadly in line with these previous works, this fourth hypothesis has a specific character and it 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. The intuition is that – as the production structure of countries becomes progressively more complex through processes such as increasing specialization and product and export differentiation – this micro- and industry-level complexity (previously analysed in the literature) will be reflected in the network of economic relationships that characterizes each national system. Countries with a more advanced production and output structure will in general be characterized by a more dense network of (Granger) causal relationships linking together the main variables of interests.

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

Our analysis will investigate dynamic (cointegration) relationships in a large panel of economies, and it is well known that cross-country heterogeneity may turn out to affect the results of dynamic panel model estimations (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.

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, middle-income countries and less 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 typical clustering variable in this literature) and the overall socio-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):

- **Less developed countries:** (1) Sub-Saharan Africa; (2) South Asia; (3) North Africa and Middle-East.
- **Middle-income economies:** (4) Eurasia (former Soviet countries); (5) Latin America; (6) East Asia.
- **Advanced economies:** (7) OECD countries.

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.

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 considering 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

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

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*.

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 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, 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 emerg-

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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, $\boldsymbol{X_t}$ have explanatory power in a regression of a variable $\boldsymbol{Y_t}$ on lagged values of $\boldsymbol{Y_t}$ and $\boldsymbol{X_t}$.

es 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).[4]

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 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.

4 White and Lu (2010) have recently provided an analysis of the relationships between Granger causality analysis and dynamic structural systems, and shown that Granger causal relationships may in fact be interpreted as structural relationships characterizing the system if the so-called *conditional exogeneity condition* holds. White and Lu (2010)'s analysis provides an important complement to the empirical approach that it is adopted in this paper, as well as all previous studies that aimed at deriving structural dynamic relationships based on the results of Granger causality analysis.

Table 1: Summary of model specifications.
Dependent variable: GDP per capita

Model	Innovation	Physical Capital	Human Capital	*Industrial Structure*	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	*Total Industry**	Openness	GINI
6	Patents	Gross Fixed Capital Formation	Tertiary Education	*Total Industry**	Openness	Corruption Perception Index
7	Patents	Gross Fixed Capital Formation	Secondary Education	*Total Industry**	Openness	GINI
8	Patents	Gross Fixed Capital Formation	Secondary Education	*Total Industry**	Openness	Corruption Perception Index
9	Patents	Gross Fixed Capital Formation	Tertiary Education	*Manufacturing*	Openness	GINI
10	Patents	Gross Fixed Capital Formation	Tertiary Education	*Manufacturing*	Openness	Corruption Perception Index
11	Patents	Gross Fixed Capital Formation	Secondary Education	*Manufacturing*	Openness	GINI
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

*Total industry: Manufacturing, mining, construction and public utilities

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 are not included in the paper to save space, but are included in an online Appendix that contains additional material and empirical results. The panel unit root tests indicate 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. 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: Summary of (selected) Johansen cointegration tests

Less developed economies

Group	Model	Lag	Johansen Tests: Trace Statistic	Johansen Tests: Maximun-Eigenvalue Statistic
Sub-Sahara	8	4	56.69616***	31.53753**
North Africa and Middle-East	8	7	140.2898***	51.33442**
South Asia	14	7	160.6065***	46.82462***

Middle-income group

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

Advanced club

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

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.[5]

5 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 devel-

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. Tables 3.1 to 3.7 present the results of Granger causality analysis for each of the seven country groups. In these tables, the first panel reports results of *direct* effects of our set of explanatory variables on GDP per capita growth (and related feedback effects from income dynamics to the explanatory variables), whereas the second panel reports results of the interactions between these various factors (from which we may infer the existence of *indirect* effects of these variables on GDP dynamics).

Figures 2.a, 2.b and 2.c provide a graphical summary of these Granger results for each of the seven country groups. In these diagrams, we draw arrows linking the various variables on the basis of the Granger results reported in tables 3.1 to 3.7. To illustrate, we draw a uni-directional (bi-directional) arrow between, say, the variables X and Y if there is a significant uni-directional (bi-directional) Granger causal relationship linking the two factors for at least five out of the nine lag-specifications we have considered. We will now use these graphical summaries to discuss the results of our propositions 1, 2 and 3 respectively.

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 activi-

oped 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.

ties). 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 yet 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; the latter, 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); in turn, the dynamics of industrial structure has a direct causal impact on GDP per capita growth. The latter has also a feedback effect on capital accumulation (physical and human capital), thus fostering absorptive capacity and the variables enabling growth and catching up. By contrast, innovation does not emerge as an important factor, and its dynamics is not significantly connected to the rest of the system.

Proposition 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 have 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.

Table 3.1: Results of Granger block exogeneity tests – Less developed economies: Sub-Sahara (Model 8)

Less developed economies - Sub-Sahara (Model 8)

I. Interactions with GDP per capita

Causal relationships	Lags									Granger Causality
	1	2	3	4	5	6	7	8	9	
Innovation → GDP per Capita	0.90457	1.206621	1.210754	1.578513	1.273707	2.236612	4.727079	6.275985	11.56453	**No**
GDP per Capita → Innovation	0.000356	1.192403	1.315193	1.566481	1.543766	1.060075	1.99615	2.57383	6.040832	**No**
Physical Capital → GDP per Capita	0.570164	0.238241	0.832908	1.534044	1.229891	2.560381	2.609636	6.425536	5.755627	**No**
GDP per Capita → Physical Capital	0.027551	1.711128	2.558728	2.675835	4.248295	5.518605	4.762332	2.86976	2.370524	**No**
Human Capital → GDP per Capita	0.033708	0.762349	0.389752	2.078991	3.367356	5.75651	7.718596	8.977341	8.82737	**No**
GDP per Capita → Human Capital	3.099715 *	4.701964 *	8.212917 **	4.735884	5.041619	5.228478	7.138237	12.19365	8.801677	**No**
International Trade → GDP per Capita	2.048575	5.12358 *	5.215547	5.595808	6.438542	6.94613	6.791625	4.665829	8.112171	**No**
GDP per Capita → International Trade	0.354397	0.905963	2.468809	3.959785	2.472982	2.557748	9.697213	10.90164	11.64208	**No**
Socio-Institutional Context → GDP per Capita	0.191923	0.360664	0.564006	1.435213	3.01926	4.7465	3.602943	4.421057	9.925446	**No**
GDP per Capita → Socio-Institutional Context	3.22554 *	11.06727 ***	15.6199 ***	29.21999 ***	26.515 ***	26.58817 ***	25.78825 ***	26.66649 ***	27.65223 ***	**Yes**
Industrial Structure → GDP per Capita	0.00851	3.075278	2.240457	4.430477	3.631871	7.723062	9.216293	11.11288	16.80196 *	**No**
GDP per Capita → Industrial Structure	8.934729 ***	10.33969 ***	17.81301 ***	16.12624 ***	16.39718 ***	17.03063 ***	15.1531 **	17.00507 **	17.54398 **	**Yes**

Table 3.1: Results of Granger block exogeneity tests – Less developed economies: Sub-Sahara (Model 8)

Less developed economies - Sub-Sahara (Model 8)

II. Interactions among the explanatory variables of GDP per capita

Causal relationships	**Lags**									**Granger Causality**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Physical Capital → Innovation	0.190535	0.08689	0.344799	2.091178	2.385417	2.860859	2.784964	1.392827	1.241523	**No**
Innovation → Physical Capital	0.034465	0.114783	0.288404	0.26213	0.861125	2.454565	3.491427	3.255139	5.144993	**No**
Human Capital → Innovation	0.138383	5.731186 *	5.557958	9.201586 *	8.956021	13.02347 **	14.66359 **	20.50836 ***	17.74196 **	**Yes**
Innovation → Human Capital	1.647035	0.882806	0.677799	0.90184	5.776438	5.731787	8.318363	13.44128 *	14.48545	**No**
International Trade → Innovation	0.625511	2.691345	3.299228	5.106213	6.282996	6.318259	4.963434	6.408067	8.862463	**No**
Innovation → International Trade	0.055626	0.126149	0.538542	0.943695	2.628277	3.610237	2.299762	3.95731	7.242077	**No**
Socio-Institutional Context → Innovation	0.392476	1.749598	1.148175	1.029885	1.333979	1.541998	2.665433	1.555668	1.328599	**No**
Innovation → Socio-Institutional Context	0.014955	0.137308	1.715558	2.225702	2.229576	0.587571	2.331685	2.393683	5.050581	**No**
Industrial Structure → Innovation	0.041531	0.205398	1.225477	0.838045	1.851058	3.364391	3.947238	1.857165	3.330412	**No**
Innovation → Industrial Structure	1.145107	6.549609 **	6.722013 *	6.913842	8.916439	8.46799	9.032505	8.804885	12.1937	**No**
Human Capital → Physical Capital	0.051454	2.647065	2.996711	3.194107	2.896364	6.101261	6.583588	4.383362	3.884395	**No**
Physical Capital → Human Capital	0.834877	5.65363 *	1.772079	3.720359	4.194373	3.961058	2.342982	2.217802	2.729325	**No**
International Trade → Physical Capital	0.751321	0.984111	0.944942	2.238698	2.774074	3.250616	3.755484	3.374211	3.533968	**No**
Physical Capital → International Trade	0.702882	0.980747	1.766597	5.309642	5.777631	6.427735	4.761452	5.859736	8.003933	**No**
Socio-Institutional Context → Physical Capital	5.744362 **	11.68542 ***	10.67887 **	13.91437 ***	11.9691 **	12.83833 **	18.07177 **	20.79175 ***	20.71454 **	**Yes**
Physical Capital → Socio-Institutional Context	0.001069	2.538829	4.568987	4.359003	2.97605	5.161383	5.87387	6.117344	7.40053	**No**
Industrial Structure → Physical Capital	4.145807 **	10.32551 ***	7.015275 *	8.379655 *	10.15659 *	8.999706	10.15735	9.108257	10.75511	**Yes**
Physical Capital → Industrial Structure	1.338648	0.539624	0.45874	1.878587	1.919063	2.07663	3.422584	4.086736	17.45847 **	**No**
International Trade → Human Capital	1.066891	7.658104 **	5.568751	6.317423	11.35518 **	19.11221 ***	18.25506 **	21.77326 ***	27.28957 ***	**Yes**
Human Capital → International Trade	1.09004	4.526455	6.38783 *	8.596058 *	7.218557	15.997 **	16.00067 **	9.022262	16.61123 *	**Yes**
Socio-Institutional Context → Human Capital	0.183864	0.379589	1.266804	1.260537	1.594363	2.691548	2.333453	4.760746	4.859915	**No**
Human Capital → Socio-Institutional Context	0.058565	0.696531	0.618808	2.093245	2.286449	4.343237	3.519115	6.149149	11.43616	**No**
Industrial Structure → Human Capital	0.207236	0.345817	17.24105 ***	18.52266 ***	22.59465 ***	22.40453 ***	24.83093 ***	21.74926 ***	24.62428 ***	**Yes**
Human Capital → Industrial Structure	0.146882	2.108814	3.513176	7.550218	4.025235	4.772692	7.157845	7.328827	8.22055	**No**
Socio-Institutional Context → International Trade	1.108662	0.987912	0.675515	5.599859	6.349338	6.072641	2.872325	2.59303	5.04484	**No**
International Trade → Socio-Institutional Context	0.063521	2.65569	3.418691	3.019362	3.200841	6.868775	5.593382	13.07497	17.83866 **	**No**
Industrial Structure → International Trade	4.271296 **	2.663105	5.587932	20.15876 ***	19.56881 ***	22.74168 ***	15.51655 **	16.36934 **	17.77747 **	**Yes**
International Trade → Industrial Structure	0.549747	1.377636	6.79862 *	6.941725	10.0202 *	6.653187	8.182345	7.422474	9.725844	**No**
Industrial Structure → Socio-Institutional Context	0.138583	0.599667	0.923664	1.027959	3.362198	6.671717	8.780176	9.670171	12.25693	**No**
Socio-Institutional Context → Industrial Structure	1.507711	2.074118	2.086262	1.037138	2.379411	4.831376	7.805089	7.545729	13.55305	**No**

Table 3.2: Results of Granger block exogeneity tests – Less developed economies: North Africa and Middle-East (Model 8)

Less developed economies - North Africa and Middle-East (Model 8)

I. Interactions with GDP per capita

Causal relationships	Lags									Granger Causality
	1	2	3	4	5	6	7	8	9	
Innovation → GDP per Capita	1.385946	0.754615	6.695217 *	4.927574	1.798842	1.828328	2.332995	5.715785	11.78789	**No**
GDP per Capita → Innovation	0.03497	0.176621	0.228708	0.352803	0.835722	4.355208	10.05813	7.50954	9.745742	**No**
Physical Capital → GDP per Capita	0.608461	1.146651	2.933708	2.772474	3.899418	4.045931	5.372889	6.22815	9.051403	**No**
GDP per Capita → Physical Capital	0.400594	1.111192	0.606656	3.474263	3.250976	1.771812	8.515135	7.045444	6.710405	**No**
Human Capital → GDP per Capita	7.106611 ***	4.396641	5.303259	9.035262 *	10.8305 *	7.514148	6.989557	10.87934	17.25001 **	**No**
GDP per Capita → Human Capital	1.183191	1.204812	2.032746	1.681112	3.350784	3.582717	5.349046	4.319078	9.984384	**No**
International Trade → GDP per Capita	0.348434	1.367531	1.199427	3.56054	4.711284	6.148853	6.36346	4.563893	9.179508	**No**
GDP per Capita → International Trade	0.213061	2.681761	2.574704	4.091378	14.03831 **	14.21928 **	13.76164 *	22.87377 ***	18.47732 **	**Yes**
Socio-Institutional Context → GDP per Capita	0.224871	1.035399	3.632446	1.083633	6.831444	4.261778	4.827209	9.599	10.90912	**No**
GDP per Capita → Socio-Institutional Context	0.445309	1.341489	3.479309	3.779364	3.204135	5.592008	8.110526	4.509258	20.97014 **	**No**
Industrial Structure → GDP per Capita	0.257092	1.120842	6.367567 *	6.309421	10.31116 *	7.565041	4.761296	5.266363	11.48308	**No**
GDP per Capita → Industrial Structure	3.112715 *	4.677821 *	5.481596	11.09981 **	14.20811 **	21.43228 ***	19.27881 ***	29.1756 ***	38.70248 ***	**Yes**

Table 3.2: Results of Granger block exogeneity tests – Less developed economies: North Africa and Middle-East (Model 8)

Less developed economies - North Africa and Middle-East (Model 8)

II. Interactions among the explanatory variables of GDP per capita

Causal relationships	Lags									Granger Causality
	1	2	3	4	5	6	7	8	9	
Physical Capital → Innovation	3.218136 *	9.121041 **	7.308066 *	9.247456 *	11.35528 **	9.972831	13.56931 *	10.4975	15.5361 *	Yes
Innovation → Physical Capital	3.138759 *	5.196255 *	4.533366	13.89927 ***	23.55037 ***	21.84295 ***	20.28313 ***	17.37159 **	17.75112 **	Yes
Human Capital → Innovation	0.087943	0.13423	0.388583	0.994019	1.840336	3.762397	7.626367	6.520583	5.764886	No
Innovation → Human Capital	0.625169	0.239023	0.46841	1.900494	3.856428	2.449583	4.503256	3.395243	5.139403	No
International Trade → Innovation	2.898165 *	3.421967	2.83635	3.470853	4.628983	5.597855	9.858231	6.333247	12.36935	No
Innovation → International Trade	1.062458	1.851794	1.920642	2.018783	4.442231	8.387488	9.331726	19.87622 **	9.07759	No
Socio-Institutional Context → Innovation	4.917635 **	3.160827	3.071252	3.836997	4.735708	2.324374	3.566068	4.55078	11.80106	No
Innovation → Socio-Institutional Context	0.134145	0.348767	0.638946	0.792318	1.165142	2.409826	2.061729	3.857053	4.560625	No
Industrial Structure → Innovation	4.318975 **	4.957259 *	4.516353	5.323909	5.708628	4.798544	6.957053	8.274473	14.28746	No
Innovation → Industrial Structure	1.365818	1.135334	0.782726	1.945045	2.165033	3.280945	2.95427	12.14634	17.16584 **	No
Human Capital → Physical Capital	0.008714	1.378509	0.486342	4.958902	6.893767	11.52208 *	14.48801 **	11.97812	10.54193	No
Physical Capital → Human Capital	1.823459	3.242102	5.05151	5.084135	2.715436	1.489464	5.005894	6.550511	6.909972	No
International Trade → Physical Capital	0.014737	3.175108	3.370503	3.218859	5.503387	4.880256	9.497399	7.863485	10.23473	No
Physical Capital → International Trade	3.717601 *	6.863077 **	5.293247	9.061507 *	8.780366	11.36869 *	15.06482 **	34.7846 ***	15.65521 *	Yes
Socio-Institutional Context → Physical Capital	0.063895	1.552075	3.558425	2.453569	4.226848	5.121068	7.863796	7.34174	7.057083	No
Physical Capital → Socio-Institutional Context	0.728952	1.031914	0.711436	3.114462	2.199506	8.168691	12.38898 *	7.79261	18.38669 **	No
Industrial Structure → Physical Capital	3.613065 *	8.741874 **	7.596699 *	9.392522 *	8.306965	8.699294	7.882906	4.80091	5.401535	No
Physical Capital → Industrial Structure	1.549584	7.882401 **	5.723123	7.130268	6.845327	8.573387	8.345182	23.94224 ***	13.37208	No
International Trade → Human Capital	1.284856	1.528321	1.373328	1.24004	1.821534	3.86209	6.627091	8.478413	11.63539	No
Human Capital → International Trade	0.328986	1.163605	1.013403	1.927536	6.541667	7.172582	8.352948	13.87257 *	12.99538	No
Socio-Institutional Context → Human Capital	0.070449	0.112166	1.419275	1.494725	4.720872	5.885145	5.139558	7.56518	5.855125	No
Human Capital → Socio-Institutional Context	0.712005	0.753877	1.941164	2.54035	2.698697	2.851676	8.97256	5.243171	14.83411 *	No
Industrial Structure → Human Capital	1.56368	0.788166	2.079053	1.775255	2.257139	3.530493	4.299356	5.974842	15.35262 *	No
Human Capital → Industrial Structure	2.688581	3.279567	4.010901	4.165493	3.456551	11.4493 *	10.32595	18.13836 **	4.543275	No
Socio-Institutional Context → International Trade	0.074242	0.123238	0.424814	0.302845	1.439208	4.102616	6.522232	7.442094	6.352051	No
International Trade → Socio-Institutional Context	1.24473	1.388051	2.640378	4.824636	7.181537	11.40066 *	13.19856 *	10.2646	8.153351	No
Industrial Structure → International Trade	0.933485	2.317157	4.70802	12.63329 **	13.42117 **	15.17186 **	14.89434 **	41.03825 ***	7.434249	Yes
International Trade → Industrial Structure	1.241977	3.657104	2.487957	2.608351	6.873136	10.74485 *	9.725032	7.850404	10.38856	No
Industrial Structure → Socio-Institutional Context	0.779542	1.028965	2.476175	2.554499	2.23598	2.991304	2.730677	4.953171	22.22638 ***	No
Socio-Institutional Context → Industrial Structure	1.521366	0.944193	2.547654	3.499519	3.980962	7.840967	8.017127	13.31557	13.11074	No

Table 3.3: Results of Granger block exogeneity tests – Less developed economies: South Asia (Model 14)

Less developed economies - South Asia (Model 14)

I. Interactions with GDP per capita

Causal relationships	Lags									Granger Causality
	1	2	3	4	5	6	7	8	9	
Innovation → GDP per Capita	0.045471	0.428295	1.346413	3.31161	4.028747	2.744319	2.103434	8.875933	24.31978 ***	**No**
GDP per Capita → Innovation	1.193939	4.246948	7.33789 *	3.292284	7.460078	6.527441	6.930804	10.32234	13.55261	**No**
Physical Capital → GDP per Capita	0.804661	1.182975	0.480134	4.065666	7.003098	5.826429	5.452782	2.555737	27.82276 ***	**No**
GDP per Capita → Physical Capital	11.23268 ***	7.572216 **	7.938598 **	13.14136 **	27.18601 ***	24.52526 ***	20.09686 ***	19.36954 **	19.27137 **	**Yes**
Human Capital → GDP per Capita	2.683724	3.612153	4.210346	5.567571	5.300955	7.115727	8.504152	10.74974	30.09979 ***	**No**
GDP per Capita → Human Capital	0.044599	1.450291	2.955305	3.5223	9.393901 *	10.81511 *	9.621303	10.22689	6.557211	**No**
International Trade → GDP per Capita	0.306259	1.971628	1.699404	4.170539	5.061469	6.604135	5.832794	12.31904	47.13245 ***	**No**
GDP per Capita → International Trade	0.282398	2.724942	2.050835	2.302599	2.725546	24.05527 ***	10.47669	47.37567 ***	22.82984 ***	**No**
Socio-Institutional Context → GDP per Capita	2.496281	4.525938	3.860554	2.364132	2.796084	4.684157	5.082778	11.20522	29.50397 ***	**No**
GDP per Capita → Socio-Institutional Context	0.131651	2.617192	3.206868	4.012937	1.054595	1.056197	13.12414 *	2.97897	7.084046	**No**
Industrial Structure → GDP per Capita	6.462563 **	6.314053 **	5.455973	14.581 ***	11.84112 **	14.25534 **	9.96932	15.66687 **	63.63064 ***	**Yes**
GDP per Capita → Industrial Structure	0.908086	1.46074	0.764474	4.954181	9.33102 *	10.74885 *	6.781247	6.935682	3.459971	**No**

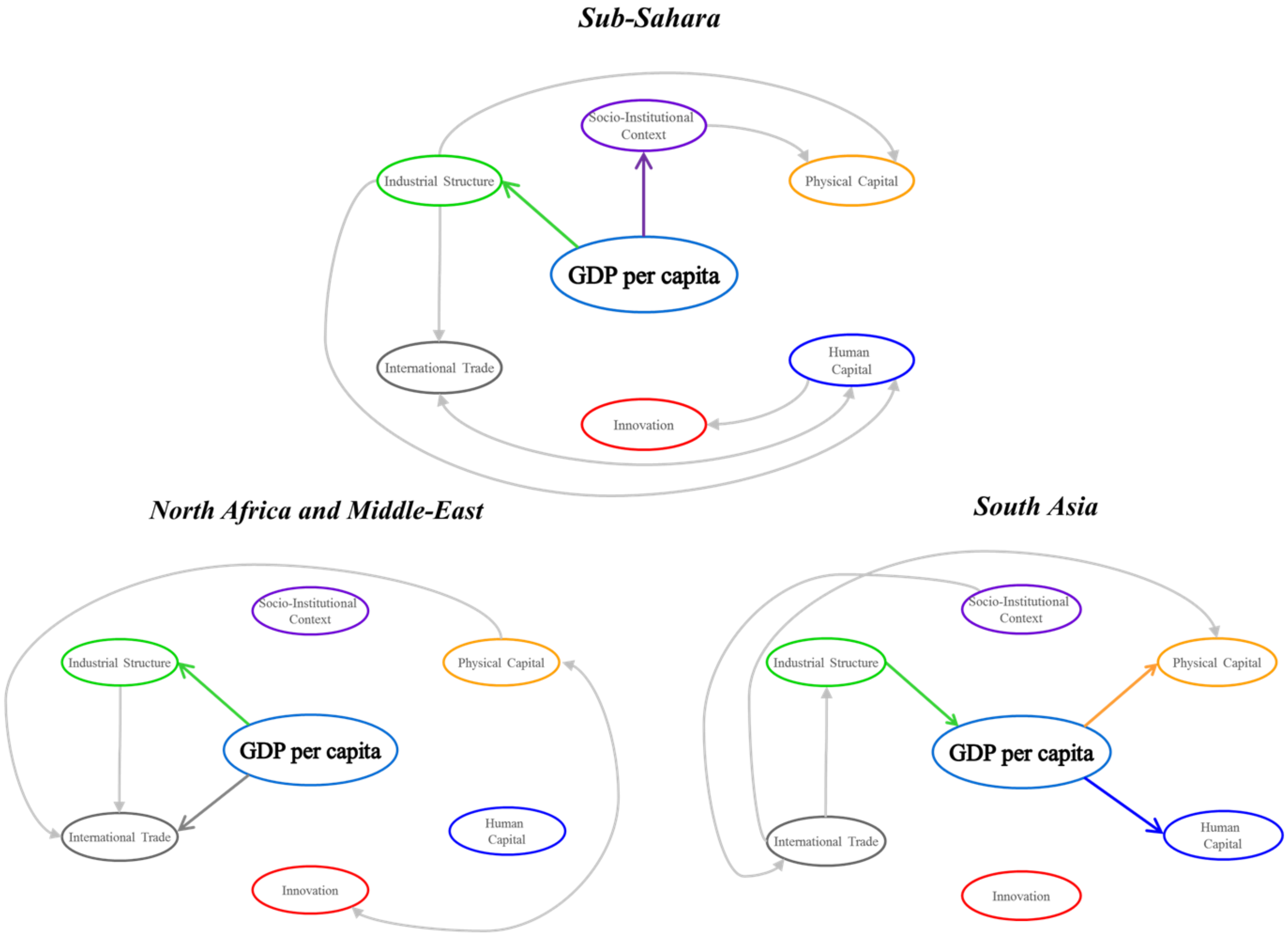
Table 3.3: Results of Granger block exogeneity tests – Less developed economies: South Asia (Model 14)

Less developed economies - South Asia (Model 14)

II. Interactions among the explanatory variables of GDP per capita

Causal relationships	Lags 1	2	3	4	5	6	7	8	9	Granger Causality
Physical Capital → Innovation	3.481739 *	7.164369 **	5.419343	5.493622	8.18625	6.944668	13.79825 *	9.532415	19.90303 **	**No**
Innovation → Physical Capital	0.381976	9.202874 **	8.679667 **	7.662951	14.0824 **	15.6255 **	10.32547	10.71065	8.281523	**No**
Human Capital → Innovation	0.009367	0.244558	3.394512	2.030665	5.206642	5.513539	5.470039	5.343054	8.599204	**No**
Innovation → Human Capital	1.915028	1.740907	2.176548	3.131307	4.893699	2.683128	9.017203	3.678913	3.415388	**No**
International Trade → Innovation	0.017422	2.136566	1.93347	1.779916	5.20656	4.710672	4.504451	6.672	8.692971	**No**
Innovation → International Trade	0.012087	1.72966	3.130769	2.408065	3.552257	22.7552 ***	8.274837	41.83588 ***	18.5813 **	**No**
Socio-Institutional Context → Innovation	0.059933	0.617119	1.912289	2.89213	5.368715	5.79411	6.881264	7.650081	12.43172	**No**
Innovation → Socio-Institutional Context	0.254005	0.631573	1.65787	2.678067	2.3548	2.36728	4.672253	2.818328	8.256058	**No**
Industrial Structure → Innovation	0.016572	0.961114	1.519593	3.952063	7.460193	7.207773	15.79371 **	13.0317	20.2677 **	**No**
Innovation → Industrial Structure	0.000932	2.355524	3.370104	5.968288	7.155563	5.074853	4.243854	5.050503	2.738793	**No**
Human Capital → Physical Capital	0.619795	1.181805	1.764525	3.331115	5.653544	8.591483	10.78851	12.22849	9.836889	**No**
Physical Capital → Human Capital	0.878574	1.180397	0.879394	2.55462	5.970343	7.818448	11.9316	7.443226	7.163603	**No**
International Trade → Physical Capital	5.316624 **	7.831149 **	7.025997 *	7.392503	17.41474 ***	18.95111 ***	23.69521 ***	17.09536 **	15.8742 *	**Yes**
Physical Capital → International Trade	0.287794	0.926323	3.704151	2.325588	1.441127	10.62259	4.526057	25.31059 ***	5.383755	**No**
Socio-Institutional Context → Physical Capital	0.004157	0.418745	2.709417	3.839674	4.239884	8.47216	6.433398	7.306609	5.506432	**No**
Physical Capital → Socio-Institutional Context	0.048196	0.247347	0.34806	0.532358	0.792866	1.783595	4.922628	6.018633	15.63545 *	**No**
Industrial Structure → Physical Capital	0.503673	7.629635 **	7.371942 *	2.752145	6.414911	4.146715	14.8484 **	7.77529	5.856366	**No**
Physical Capital → Industrial Structure	7.601233 ***	9.413033 ***	8.770462 **	10.36819 **	8.23693	7.919626	10.83869	10.29532	9.096117	**No**
International Trade → Human Capital	2.977136 *	4.709771 *	2.98623	1.724384	1.243253	13.37727 **	12.24843 *	10.25993	5.402	**No**
Human Capital → International Trade	0.31019	0.679478	0.143569	1.198862	0.864593	17.74388 ***	11.09403	30.76822 ***	10.49131	**No**
Socio-Institutional Context → Human Capital	2.266639	3.106384	3.565371	5.600068	2.117948	4.882525	8.4889	6.462684	3.877858	**No**
Human Capital → Socio-Institutional Context	3.056166 *	3.808036	6.366492 *	5.23074	6.586254	9.28663	9.313357	7.288773	19.39581 **	**No**
Industrial Structure → Human Capital	0.073775	0.238798	0.507985	1.001085	1.020377	3.664718	9.732689	5.599901	2.376434	**No**
Human Capital → Industrial Structure	2.308058	1.66186	0.746028	3.310963	4.055108	2.272246	2.690949	4.745891	5.991614	**No**
Socio-Institutional Context → International Trade	0.148372	6.300154 **	6.890179 *	8.184914 *	11.61481 **	28.11397 ***	15.04037 **	60.40552 ***	23.59485 ***	**Yes**
International Trade → Socio-Institutional Context	0.073007	2.725868	2.447569	3.042372	4.06153	7.475489	17.09809 **	7.388314	18.11494 **	**No**
Industrial Structure → International Trade	0.491241	4.020271	4.496767	3.386743	4.977984	10.09473	12.55755 *	16.48109 **	11.03114	**No**
International Trade → Industrial Structure	2.427324	6.549249 **	12.40195 ***	11.06807 **	10.15283 *	11.71894 *	8.680311	9.235647	5.362538	**Yes**
Industrial Structure → Socio-Institutional Context	0.067816	4.381092	3.230378	3.247948	2.617297	3.009222	12.46011 *	11.16323	17.68859 **	**No**
Socio-Institutional Context → Industrial Structure	0.168914	0.219645	0.388208	0.431105	1.527022	2.02947	2.324761	1.619684	4.856388	**No**

Figure 2.a: Summary of causal relationships (selected models – Less developed economies



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 (embodied technical progress).

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 feedback 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).

Proposition 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 model specification. Nevertheless, it is possible to extract the key general results that are common to these groups. In line with our proposition 2, in middle-income countries absorptive capacity and GDP per capita growth are indeed linked by a set of two-way causal relationships that 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).

Table 3.4: Results of Granger block exogeneity tests – Middle-income group: Eurasia (Model 8)

Middle-income group - Eurasia (Model 8)

I. Interactions with GDP per capita

Causal relationships	Lags 1	2	3	4	5	6	7	8	9	Granger Causality
Innovation → GDP per Capita	1.256088	1.753681	3.33546	3.173805	5.7322	3.852011	4.500374	7.403352	7.305783	**No**
GDP per Capita → Innovation	0.085303	2.176825	1.982614	2.773364	3.92464	6.769482	7.139918	7.594226	6.811045	**No**
Physical Capital → GDP per Capita	6.606705 **	8.691098 **	8.348682 **	9.828883 **	11.80454 **	17.4857 ***	17.56416 **	20.23966 ***	23.24965 ***	**Yes**
GDP per Capita → Physical Capital	0.85134	1.081269	1.107277	2.288425	3.228486	1.959444	8.707861	8.469537	13.88684	**No**
Human Capital → GDP per Capita	3.546031 *	5.766814 *	6.155807	10.19523 **	16.15096 ***	14.88945 **	16.73801 **	21.76546 ***	21.64191 **	**Yes**
GDP per Capita → Human Capital	0.489203	4.178213	9.491705 **	10.83704 **	11.33098 **	15.16153 **	12.32618 *	12.94067	12.35005	**Yes**
International Trade → GDP per Capita	1.82024	2.814424	3.318474	10.51027 **	12.54068 **	17.98042 ***	15.30264 **	17.15313 **	16.75093 *	**Yes**
GDP per Capita → International Trade	1.002555	36.57303 ***	40.48991 ***	41.36167 ***	42.60899 ***	41.10863 ***	47.06549 ***	55.20259 ***	52.4369 ***	**Yes**
Socio-Institutional Context → GDP per Capita	0.933859	0.972054	1.239285	1.443185	3.658286	4.676375	8.006493	7.929018	8.292946	**No**
GDP per Capita → Socio-Institutional Context	5.476796 **	10.99212 ***	8.925929 **	9.281593 *	8.511339	8.585701	9.107006	8.684674	13.84446	**No**
Industrial Structure → GDP per Capita	7.434335 ***	9.633452 ***	10.37913 **	8.506486 *	7.200801	7.623993	7.470804	7.318141	6.727293	**No**
GDP per Capita → Industrial Structure	22.69409 ***	27.49604 ***	29.55907 ***	26.29687 ***	26.42688 ***	24.76938 ***	22.1744 ***	19.54831 **	20.5354 **	**Yes**

Table 3.4: Results of Granger block exogeneity tests – Middle-income group: Eurasia (Model 8)

Middle-income group - Eurasia (Model 8)

II. Interactions among the explanatory variables of GDP per capita

Causal relationships	Lags									Granger Causality
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Physical Capital → Innovation	0.0008	0.101287	2.164377	2.184653	7.813663	9.728194	11.28591	12.61664	11.82989	**No**
Innovation → Physical Capital	1.30906	3.285886	4.896411	4.500113	4.382155	3.396037	5.154979	6.471199	5.598155	**No**
Human Capital → Innovation	0.986005	2.343412	2.477989	2.205702	3.897059	3.84752	4.62327	3.576795	3.511999	**No**
Innovation → Human Capital	0.00267	0.074925	0.159325	1.505522	3.970615	4.99654	5.488646	5.892891	7.825123	**No**
International Trade → Innovation	2.720053 *	1.584431	1.631617	2.711125	7.32061	6.261691	4.684002	4.760568	4.992033	**No**
Innovation → International Trade	0.353073	0.7602	1.811949	1.757464	2.027278	2.412075	2.337998	6.245847	6.046586	**No**
Socio-Institutional Context → Innovation	0.102769	4.283777	4.900745	6.18625	6.58651	7.862128	9.176734	10.98331	10.95932	**No**
Innovation → Socio-Institutional Context	0.776558	1.464121	0.835615	1.413747	1.550263	0.940714	1.351855	1.848693	1.969146	**No**
Industrial Structure → Innovation	0.368711	1.53302	2.720379	4.620456	3.825589	5.583928	5.966314	6.632023	7.552713	**No**
Innovation → Industrial Structure	1.449248	1.192147	1.911474	2.206853	1.855267	2.220274	1.767584	2.049762	3.312486	**No**
Human Capital → Physical Capital	7.143948 ***	5.919942 *	3.648548	4.698333	5.947145	6.336737	12.4069 *	10.42799	12.47731	**No**
Physical Capital → Human Capital	0.912295	5.697776 *	8.825119 **	12.46177 **	15.27072 ***	14.1314 **	11.71804	12.66638	22.02207 ***	**Yes**
International Trade → Physical Capital	2.948011 *	1.623805	1.066854	12.28596 **	17.63104 ***	17.60059 ***	15.54603 **	17.14471 **	20.91911 **	**Yes**
Physical Capital → International Trade	5.607981 **	4.840571 *	5.876979	6.541689	7.415104	7.773979	9.906368	11.40916	12.356	**No**
Socio-Institutional Context → Physical Capital	2.345949	2.093266	0.976885	4.00716	6.031168	7.638311	15.52391 **	12.42143	15.30215 *	**No**
Physical Capital → Socio-Institutional Context	0.343351	5.699399 *	7.340845 *	7.364011	8.116125	8.087045	9.748096	10.3858	9.792667	**No**
Industrial Structure → Physical Capital	2.784557 *	3.896975	4.3491	3.646904	4.11054	4.185973	8.082147	7.960002	14.79902 *	**No**
Physical Capital → Industrial Structure	12.27902 ***	13.22119 ***	12.47141 ***	12.99913 **	11.40262 **	14.72878 **	15.68915 **	15.46521 *	18.60126 **	**Yes**
International Trade → Human Capital	1.006428	2.43823	8.76498 **	9.136255 *	6.582587	10.84615 *	8.667918	7.033352	7.807257	**No**
Human Capital → International Trade	7.583751 ***	7.137934 **	12.89449 ***	12.02592 **	14.85872 **	15.02361 **	13.20557 *	13.03257	13.06021	**Yes**
Socio-Institutional Context → Human Capital	3.045861 *	1.829354	7.231481 *	7.403258	7.456558	12.19013 *	13.75556 *	15.08747 *	11.94154	**Yes**
Human Capital → Socio-Institutional Context	1.848321	2.100915	1.525151	2.148771	5.400783	7.920114	11.70703	10.2146	15.53413 *	**No**
Industrial Structure → Human Capital	9.33492 ***	12.88559 ***	13.78698 ***	18.14293 ***	24.72786 ***	25.2334 ***	26.69418 ***	30.20928 ***	30.70133 ***	**Yes**
Human Capital → Industrial Structure	2.686556	4.304796	4.979258	6.364368	5.006957	4.78505	5.562942	5.989611	14.50353	**No**
Socio-Institutional Context → International Trade	0.355328	1.35463	1.316021	0.798837	0.657942	1.860809	1.712786	2.043658	2.395934	**No**
International Trade → Socio-Institutional Context	0.988627	0.858848	3.533524	2.560544	5.993047	5.78903	6.029264	5.204209	4.395495	**No**
Industrial Structure → International Trade	0.610997	0.875523	1.593156	4.247571	3.780879	5.161657	6.950547	5.109531	6.85884	**No**
International Trade → Industrial Structure	6.229416 **	5.521738 *	5.544559	6.141806	11.15771 **	14.22382 **	18.80108 ***	15.81819 **	13.10575	**Yes**
Industrial Structure → Socio-Institutional Context	18.70186 ***	21.58792 ***	17.19068 ***	14.6845 ***	13.98901 **	15.03515 **	12.82614 *	13.25297	13.39833	**Yes**
Socio-Institutional Context → Industrial Structure	1.144561	13.24485 ***	12.23155 ***	13.83176 ***	16.73857 ***	15.69122 **	16.12227 **	15.78039 **	18.09236 **	**Yes**

Table 3.5: Results of Granger block exogeneity tests – Middle-income group: Latin America (Model 2)

Middle-income group - Latin America (Model 2)

I. Interactions with GDP per capita

Causal relationships	Lags									Granger Causality
	1	2	3	4	5	6	7	8	9	
Innovation → GDP per Capita	9.038952 ***	4.380415	4.003504	10.18703 **	13.58635 **	16.26115 **	14.30657 **	12.76981	15.51271 *	**Yes**
GDP per Capita → Innovation	2.537719	7.406848 **	8.096016 **	5.784721	4.506155	6.027	7.490076	8.480894	9.884648	**No**
Physical Capital → GDP per Capita	14.09325 ***	17.96337 ***	20.65038 ***	21.80838 ***	26.84105 ***	29.72431 ***	30.8311 ***	25.49007 ***	36.09483 ***	**Yes**
GDP per Capita → Physical Capital	20.38976 ***	14.26215 ***	14.87304 ***	12.05187 **	10.8231 *	10.78254 *	10.97796	12.1049	13.95496	**Yes**
Human Capital → GDP per Capita	0.441794	0.866617	5.840287	5.87023	13.7904 **	18.20144 ***	12.29503 *	10.58608	11.03524	**No**
GDP per Capita → Human Capital	3.82762 *	5.62943 *	14.90504 ***	25.94611 ***	33.58423 ***	39.24325 ***	36.2835 ***	40.39735 ***	27.23769 ***	**Yes**
International Trade → GDP per Capita	3.534459 *	7.562947 **	7.585639 *	9.817659 **	10.67534 *	9.267893	7.439277	5.282107	8.017161	**Yes**
GDP per Capita → International Trade	0.116606	1.836419	6.025191	9.780456 **	10.93871 *	15.22621 **	18.02513 **	15.77703 **	13.75935	**Yes**
Socio-Institutional Context → GDP per Capita	0.367846	0.691946	1.75104	1.490186	2.079168	2.086044	3.466786	3.78578	3.732656	**No**
GDP per Capita → Socio-Institutional Context	1.263478	0.924821	3.181517	4.839806	3.875773	4.167433	4.639512	3.877331	6.882989	**No**
Industrial Structure → GDP per Capita	0.003713	7.612028 **	5.811814	5.86264	6.183483	13.79963 **	15.12189 **	24.5457 ***	19.00456 **	**Yes**
GDP per Capita → Industrial Structure	0.805751	0.68928	4.1782	3.312806	7.132023	8.776975	9.697004	10.52951	7.362059	**No**

Table 3.5: Results of Granger block exogeneity tests – Middle-income group: Latin America (Model 2)

Middle-income group - Latin America (Model 2)

II. Interactions among the explanatory variables of GDP per capita

Causal relationships	Lags									Granger Causality
	1	2	3	4	5	6	7	8	9	
Physical Capital → Innovation	5.73428 **	7.085498 **	6.614032 *	9.146077 *	13.38613 **	18.92227 ***	17.10386 **	17.50154 **	16.98585 **	**Yes**
Innovation → Physical Capital	10.60952 ***	0.370705	0.694498	1.057973	2.731294	3.461625	2.760104	2.591605	2.029269	**No**
Human Capital → Innovation	0.66346	2.020127	2.628833	10.82602 **	10.98236 *	12.85005 **	13.46279 *	16.14207 **	13.96716	**Yes**
Innovation → Human Capital	3.190193 *	7.615379 **	17.06912 ***	15.40268 ***	10.00945 *	14.15075 **	13.44695 *	12.24427	19.87424 **	**Yes**
International Trade → Innovation	8.112836 ***	6.765157 **	9.158946 **	6.398906	7.938271	12.40587 *	12.86618 *	15.87919 **	18.00015 **	**Yes**
Innovation → International Trade	0.00038	0.624608	0.775149	1.073745	2.55965	6.555292	7.043276	10.9861	12.72809	**No**
Socio-Institutional Context → Innovation	0.547909	0.617515	0.562934	0.516169	0.879783	1.385039	3.927443	5.384474	5.395562	**No**
Innovation → Socio-Institutional Context	0.00000443	1.584557	1.213868	1.594506	0.679713	2.212854	4.311211	3.723372	4.237226	**No**
Industrial Structure → Innovation	0.000689	0.695356	2.787992	2.782369	2.153666	8.265818	5.634919	5.122147	8.661438	**No**
Innovation → Industrial Structure	12.1552 ***	17.81375 ***	18.5164 ***	8.364511 *	8.893626	8.435074	13.87224 *	11.71165	16.30849 *	**Yes**
Human Capital → Physical Capital	0.451398	5.32302 *	5.792999	4.597646	6.544058	6.915113	7.07394	8.18772	8.629408	**No**
Physical Capital → Human Capital	0.057605	1.601666	1.39761	14.13597 ***	18.02334 ***	23.81926 ***	19.19876 ***	18.19228 **	15.1688 *	**Yes**
International Trade → Physical Capital	0.204497	5.008488 *	5.538835	8.671985 *	10.3066 *	9.909181	10.40103	12.85054	11.8648	**No**
Physical Capital → International Trade	0.307004	1.049638	0.989689	3.044119	2.489405	5.149029	5.775821	11.06935	9.386546	**No**
Socio-Institutional Context → Physical Capital	0.004206	0.332474	1.843433	2.754951	4.230152	5.905046	4.87909	6.703157	5.840813	**No**
Physical Capital → Socio-Institutional Context	0.329188	0.027795	0.136296	1.366133	1.146931	3.743517	3.379482	3.89963	6.921766	**No**
Industrial Structure → Physical Capital	1.17225	2.728755	2.65741	2.006415	4.369836	4.516496	5.752847	12.92541	10.44882	**No**
Physical Capital → Industrial Structure	0.98236	0.27605	0.381502	0.861918	10.25861 *	10.54451	13.77909 *	12.92085	9.315892	**No**
International Trade → Human Capital	1.895605	3.423065	3.890833	8.330223 *	8.865173	9.304829	16.34499 **	11.32917	4.956665	**No**
Human Capital → International Trade	0.074657	1.113806	0.817759	2.152793	3.887503	4.235041	6.957525	8.407151	8.223003	**No**
Socio-Institutional Context → Human Capital	0.229444	1.359915	2.086943	2.474788	4.468585	4.548958	3.507495	3.776527	8.079179	**No**
Human Capital → Socio-Institutional Context	1.274938	2.375213	1.248653	1.959236	2.090733	3.217935	6.607463	10.27108	15.2171 *	**No**
Industrial Structure → Human Capital	0.427516	0.964536	2.874057	7.794246 *	8.969091	8.763112	11.39525	5.527159	10.63638	**No**
Human Capital → Industrial Structure	1.939018	1.625379	1.279681	8.052914 *	8.837224	9.183601	28.26601 ***	23.75996 ***	13.11527	**No**
Socio-Institutional Context → International Trade	1.240011	0.374872	0.170051	0.548952	0.361546	1.347779	3.544934	8.082801	10.54352	**No**
International Trade → Socio-Institutional Context	0.431755	0.850342	2.327283	4.388135	6.264778	12.04972 *	13.20643 *	15.8607 **	14.59234	**No**
Industrial Structure → International Trade	4.148719 **	2.910178	3.04991	5.995696	10.27424 *	14.01789 **	12.95494 *	26.27606 ***	34.47602 ***	**Yes**
International Trade → Industrial Structure	2.426313	1.716954	1.807747	3.980315	3.873024	1.788803	14.71603 **	13.43545 *	11.53726	**No**
Industrial Structure → Socio-Institutional Context	0.044756	6.534466 **	8.086446 **	7.947963 *	6.283206	6.352034	6.171667	7.003808	9.174469	**No**
Socio-Institutional Context → Industrial Structure	0.072481	3.23961	3.237165	3.654384	4.022999	4.249035	10.24491	12.81245	12.97261	**No**

Table 3.6: Results of Granger block exogeneity tests – Middle-income group: East Asia (Model 2)

Middle-income group - East Asia (Model 2)

I. Interactions with GDP per capita

Causal relationships	Lags									Granger Causality
	1	2	3	4	5	6	7	8	9	
Innovation → GDP per Capita	0.031069	0.497029	0.807589	1.110074	1.35479	2.262416	3.053805	5.270744	9.614476	**No**
GDP per Capita → Innovation	0.257333	0.560631	2.987651	6.90641	6.976332	13.61043 **	17.90513 **	18.59646 **	22.06601 ***	**No**
Physical Capital → GDP per Capita	3.137044 *	2.353688	1.870725	3.290189	3.458543	5.903829	14.36965 **	16.08232 **	11.72746	**No**
GDP per Capita → Physical Capital	38.19327 ***	35.9233 ***	44.70114 ***	40.36395 ***	38.42928 ***	36.94239 ***	33.09701 ***	33.77489 ***	31.92875 ***	**Yes**
Human Capital → GDP per Capita	2.095333	1.244552	1.666068	2.921097	2.690781	1.514837	6.262829	10.05933	15.11117 *	**No**
GDP per Capita → Human Capital	1.132694	7.366293 **	10.06079 **	8.413731 *	9.766969 *	10.88789 *	9.749118	10.92178	8.125261	**Yes**
International Trade → GDP per Capita	0.344061	5.677089 *	6.024818	6.537816	5.568121	7.224593	9.304456	8.676756	13.91093	**No**
GDP per Capita → International Trade	8.275553 ***	8.502037 **	6.422741 *	8.460929 *	10.72662 *	13.70232 **	21.20573 ***	17.158 **	26.33807 ***	**Yes**
Socio-Institutional Context → GDP per Capita	1.156681	3.313034	3.149287	2.803083	2.660248	1.947304	3.797349	6.240508	12.814	**No**
GDP per Capita → Socio-Institutional Context	1.562949	3.340009	4.09257	6.900411	6.593771	6.434885	7.556553	7.684618	8.073363	**No**
Industrial Structure → GDP per Capita	2.167007	2.787553	4.494451	11.64092 **	8.405285	15.68528 **	19.01059 ***	18.29066 **	18.57823 **	**Yes**
GDP per Capita → Industrial Structure	4.345564 **	8.497871 **	18.77975 ***	19.02383 ***	21.98334 ***	18.26425 ***	20.22082 ***	19.30863 **	16.15217 *	**Yes**

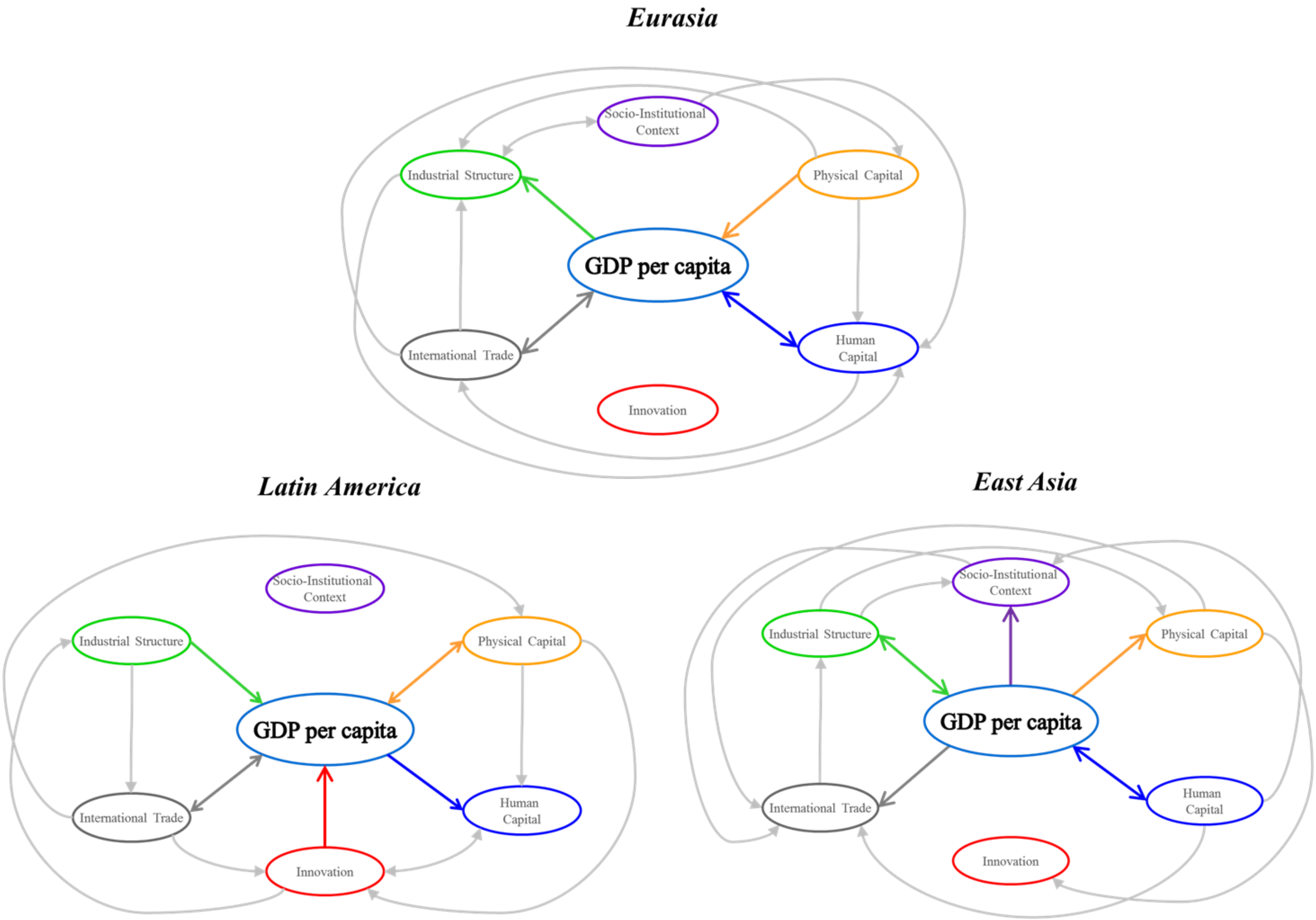
Table 3.6: Results of Granger block exogeneity tests – Middle-income group: East Asia (Model 2)

Middle-income group - East Asia (Model 2)

II. Interactions among the explanatory variables of GDP per capita

Causal relationships	Lags 1	2	3	4	5	6	7	8	9	Granger Causality
Physical Capital → Innovation	0.046784	4.628025 *	10.14749 **	12.98935 **	15.07358 **	16.81691 **	15.35397 **	15.90477 **	14.07089	**Yes**
Innovation → Physical Capital	0.021537	2.345874	3.637672	3.692302	4.590707	5.426355	4.803071	9.084237	10.29263	**No**
Human Capital → Innovation	0.810524	0.693979	1.435601	1.895516	2.095322	5.683615	7.178752	7.296062	10.0785	**No**
Innovation → Human Capital	0.006338	1.961471	2.066032	6.488793	6.914395	3.066451	4.2981	2.167441	3.501458	**No**
International Trade → Innovation	0.891355	1.051985	0.746219	3.568681	4.299283	7.190337	10.76951	8.538163	7.28775	**No**
Innovation → International Trade	1.45947	1.680647	1.691198	6.81323	3.906527	2.575499	6.267132	5.793019	10.74966	**No**
Socio-Institutional Context → Innovation	0.10474	2.118882	1.909767	3.226405	3.598462	4.467328	4.374077	7.025789	5.560929	**No**
Innovation → Socio-Institutional Context	5.462848 **	8.701934 **	10.50202 **	13.58952 ***	17.63548 ***	22.06297 ***	17.50421 **	16.89657 **	15.70431 *	**Yes**
Industrial Structure → Innovation	1.093034	0.243378	0.957658	0.318573	1.166351	5.70941	9.526518	8.336699	8.441276	**No**
Innovation → Industrial Structure	0.815911	0.308408	0.558063	3.769556	5.738511	5.316759	5.90846	7.998942	7.528945	**No**
Human Capital → Physical Capital	0.714587	12.24263 ***	10.05757 **	8.141788 *	9.097884	10.68207 *	13.0874 *	12.23762	13.34105	**Yes**
Physical Capital → Human Capital	0.642274	0.043028	1.076479	3.902103	4.106504	3.486289	4.607823	5.614583	11.35986	**No**
International Trade → Physical Capital	0.132554	1.086462	2.970299	2.634681	6.876061	8.928618	11.62503	15.32985 *	14.94388 *	**No**
Physical Capital → International Trade	3.924606 **	4.223421	7.021339 *	15.65198 ***	11.90424 **	12.7721 **	15.50148 **	23.5166 ***	30.18711 ***	**Yes**
Socio-Institutional Context → Physical Capital	1.089665	4.660824 *	8.290468 **	7.292259	8.864628	10.2067	10.28901	11.29999	12.05293	**No**
Physical Capital → Socio-Institutional Context	0.954287	5.052694 *	5.007226	3.741799	8.538068	8.011567	7.11038	6.71754	5.672291	**No**
Industrial Structure → Physical Capital	5.415623 **	12.35318 ***	17.58875 ***	17.43291 ***	16.01401 ***	12.48579 *	17.06518 **	15.52927 **	19.2743 **	**Yes**
Physical Capital → Industrial Structure	1.956212	5.837493 *	2.749932	4.382378	8.114638	6.921495	10.37741	13.4422 *	12.27167	**No**
International Trade → Human Capital	1.345609	2.024032	5.795701	8.93327 *	13.30767 **	24.706 ***	17.92703 **	20.88709 ***	16.96406 **	**Yes**
Human Capital → International Trade	0.486789	5.191466 *	8.490484 **	5.640048	5.1877	9.098332	13.88283 *	17.13438 **	17.74226 **	**Yes**
Socio-Institutional Context → Human Capital	1.93464	2.680761	4.544933	4.746885	5.517141	4.951467	5.860963	6.808008	5.912234	**No**
Human Capital → Socio-Institutional Context	0.254942	2.771079	7.483242 *	2.975303	13.30614 **	25.09507 ***	17.57774 **	22.12368 ***	21.44857 **	**Yes**
Industrial Structure → Human Capital	0.53044	9.609063 ***	13.82538 ***	7.472632	10.19151 *	8.416788	11.73997	9.872821	11.84008	**No**
Human Capital → Industrial Structure	0.495919	1.77692	7.148214 *	10.28806 **	17.23989 ***	16.4994 **	15.18322 **	14.86689 *	14.21853	**Yes**
Socio-Institutional Context → International Trade	1.203816	1.632975	3.724074	3.622744	3.685388	3.517492	8.372652	5.811068	9.692547	**No**
International Trade → Socio-Institutional Context	0.110959	0.294288	5.168428	7.906136 *	11.08688 **	8.911886	9.172812	17.02309 **	20.04941 **	**No**
Industrial Structure → International Trade	0.065864	1.523185	1.444395	1.059604	0.816771	7.779821	10.98532	9.034153	7.005381	**No**
International Trade → Industrial Structure	22.79675 ***	16.12292 ***	16.32008 ***	18.50395 ***	23.40381 ***	19.31074 ***	19.3079 ***	16.32294 **	17.86797 **	**Yes**
Industrial Structure → Socio-Institutional Context	0.028467	0.204673	2.244218	10.97652 **	8.583648	8.176723	9.899486	13.42706 *	11.63054	**No**
Socio-Institutional Context → Industrial Structure	4.717735 **	5.993797 **	6.835463 *	5.623359	3.375926	3.766587	5.516387	5.105149	7.230453	**No**

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



6.3 Advanced club

In the panel of OECD economies, the set of two-way co-evolutionary 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, as outlined in multiple equilibria models. In addition, innovation has a direct causal impact on the growth of GDP per capita, and the latter variable does in turn sustain technological dynamics further.

Proposition 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.

Table 3.7: Results of Granger block exogeneity tests – Advanced club: OECD (Model 2)

Advanced club - OECD (Model 2)

I. Interactions with GDP per capita

Causal relationships	**Lags**									**Granger Causality**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Innovation → GDP per Capita	4.307803 **	6.068773 **	7.290133 *	8.639795 *	12.17757 **	10.89627 *	16.49938 **	28.47965 ***	34.84322 ***	**Yes**
GDP per Capita → Innovation	4.165173 **	1.820245	2.518875	5.879192	12.83204 **	15.83792 **	17.15795 **	25.51198 ***	20.57311 **	**Yes**
Physical Capital → GDP per Capita	0.902348	3.022746	5.543307	21.20174 ***	30.70042 ***	32.45021 ***	34.56319 ***	16.78681 **	17.60523 **	**Yes**
GDP per Capita → Physical Capital	13.96126 ***	46.79016 ***	51.87806 ***	36.13333 ***	37.18055 ***	33.79698 ***	30.63456 ***	34.76556 ***	23.70289 ***	**Yes**
Human Capital → GDP per Capita	0.008457	2.597724	4.107973	11.65858 **	8.796283	8.160497	9.862774	13.59815 *	19.00129 **	**No**
GDP per Capita → Human Capital	0.045634	6.624226 **	8.419653 **	4.614193	3.719532	4.372777	5.325106	5.642259	6.223919	**No**
International Trade → GDP per Capita	5.610881 **	6.738035 **	6.20064	4.599915	5.690123	10.41541	12.27401 *	23.49524 ***	31.20128 ***	**Yes**
GDP per Capita → International Trade	12.72474 ***	25.47406 ***	20.85261 ***	64.00155 ***	61.22688 ***	44.94459 ***	41.246 ***	43.1488 ***	46.36966 ***	**Yes**
Socio-Institutional Context → GDP per Capita	0.00000013	0.278112	0.319392	3.114495	3.15478	1.707277	1.712558	3.767922	2.44819	**No**
GDP per Capita → Socio-Institutional Context	0.12579	0.402257	3.367808	5.837111	9.03848	8.934397	9.118406	14.16716 *	13.91546	**No**
Industrial Structure → GDP per Capita	1.724471	3.190251	3.577351	6.283448	9.144665	12.79953 **	16.62162 **	25.17575 ***	32.14388 ***	**No**
GDP per Capita → Industrial Structure	0.094945	26.75307 ***	24.78133 ***	26.9281 ***	29.15299 ***	28.10502 ***	21.31655 ***	25.45726 ***	34.86909 ***	**Yes**

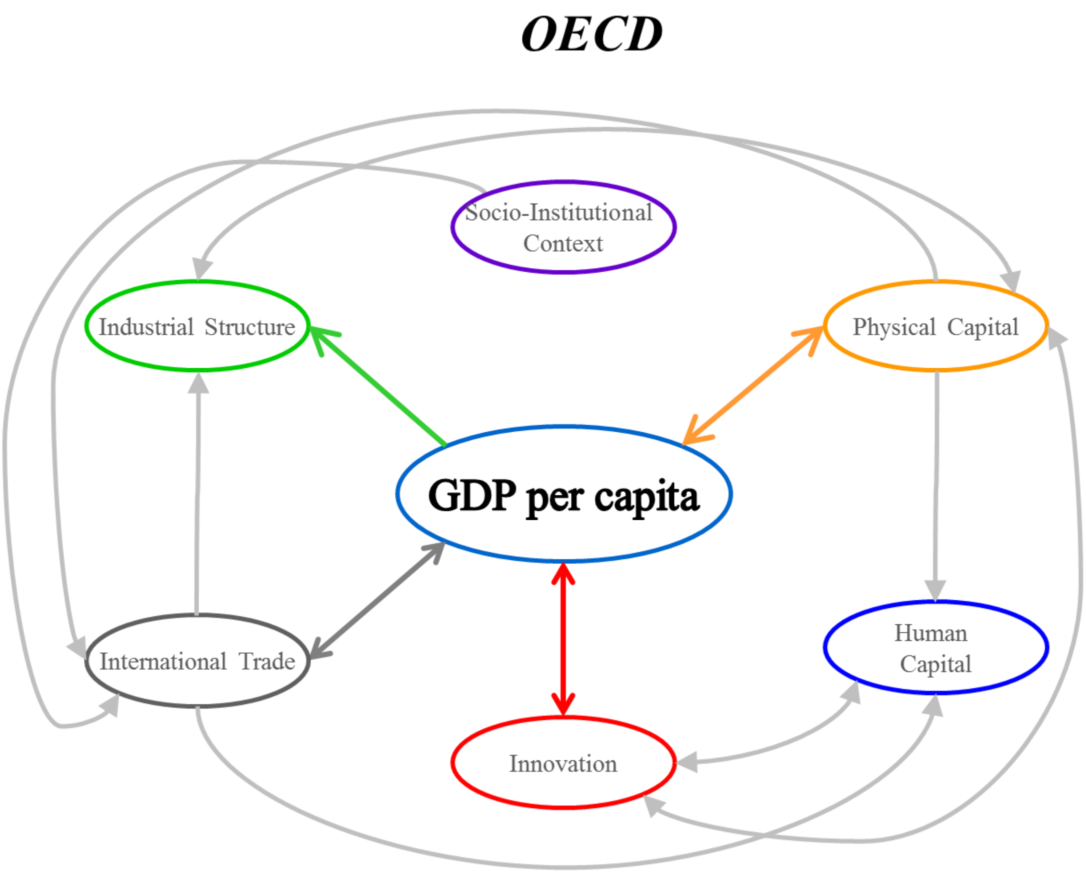
Table 3.7: Results of Granger block exogeneity tests – Advanced club: OECD (Model 2)

Advanced club - OECD (Model 2)

II. Interactions among the explanatory variables of GDP per capita

Causal relationships	Lags									Granger Causality
	1	2	3	4	5	6	7	8	9	
Physical Capital → Innovation	5.538932 **	5.769874 *	5.164011	9.171208 *	15.8245 ***	17.90526 ***	23.90327 ***	40.21283 ***	47.97245 ***	**Yes**
Innovation → Physical Capital	0.698551	2.139518	7.107282 *	6.519687	12.43705 **	10.63357	21.35385 ***	35.65194 ***	44.72846 ***	**Yes**
Human Capital → Innovation	3.569258 *	3.802728	3.121882	4.619532	9.468135 *	17.0082 ***	16.34322 **	14.50623 *	23.47256 ***	**Yes**
Innovation → Human Capital	4.67998 **	6.543277 **	14.77508 ***	14.71174 ***	15.80767 ***	9.418039	8.953719	18.99076 **	18.05644 **	**Yes**
International Trade → Innovation	3.27288 *	2.575631	1.560395	1.489479	3.34916	4.100435	2.227308	10.73142	20.58809 **	**No**
Innovation → International Trade	1.012027	0.854288	1.987522	4.139111	1.903873	12.6658 **	17.42688 **	12.91091	19.99941 **	**No**
Socio-Institutional Context → Innovation	0.321041	0.277377	0.34069	0.67603	0.451773	3.121285	3.130323	1.972784	3.945562	**No**
Innovation → Socio-Institutional Context	0.681401	0.848093	1.56287	1.987142	1.509228	1.768223	1.849263	2.738142	2.59337	**No**
Industrial Structure → Innovation	4.497244 **	3.554514	4.892953	2.570358	2.184925	2.645573	12.26608 *	9.177449	12.00789	**No**
Innovation → Industrial Structure	0.342001	0.159233	1.904911	3.853532	4.732421	5.659237	14.62105 **	14.22221 *	21.2084 **	**No**
Human Capital → Physical Capital	3.84521 **	3.907781	4.170643	6.790705	6.85124	9.892897	20.72158 ***	22.18555 ***	29.87934 ***	**No**
Physical Capital → Human Capital	4.248995 **	3.643313	6.730758 *	8.0383 *	11.76426 **	14.90454 **	16.7358 **	15.49068 *	18.04491 **	**Yes**
International Trade → Physical Capital	0.009256	2.217699	3.183921	1.996678	4.822162	13.41149 **	13.4323 *	10.02432	7.074471	**No**
Physical Capital → International Trade	0.930976	2.208882	3.141333	6.308306	12.84328 **	25.0783 ***	28.2418 ***	22.3975 ***	20.92327 **	**Yes**
Socio-Institutional Context → Physical Capital	0.379977	0.417952	1.808435	3.592829	3.692438	3.22787	4.319188	8.677856	9.068358	**No**
Physical Capital → Socio-Institutional Context	0.012095	0.346297	0.754709	0.77314	0.249628	0.844531	1.583164	4.639492	5.434933	**No**
Industrial Structure → Physical Capital	1.792888	5.795651 *	5.630937	13.69979 ***	16.94442 ***	18.44599 ***	18.10414 **	25.23342 ***	22.91652 ***	**Yes**
Physical Capital → Industrial Structure	0.872861	4.053165	5.991688	11.34314 **	22.25831 ***	28.42438 ***	34.02409 ***	24.80292 ***	31.21314 ***	**Yes**
International Trade → Human Capital	3.598931 *	11.80507 ***	16.71012 ***	14.65955 ***	33.80615 ***	33.98226 ***	29.95926 ***	28.93393 ***	27.22426 ***	**Yes**
Human Capital → International Trade	0.309631	4.248178	3.67437	1.304317	1.757763	3.348232	5.297187	6.816957	18.17693 **	**No**
Socio-Institutional Context → Human Capital	0.102076	5.435975 *	6.674187 *	6.901375	8.239518	7.972655	8.883683	9.605014	10.1562	**No**
Human Capital → Socio-Institutional Context	1.444272	2.146438	2.339701	3.288566	3.813672	3.033639	2.991921	3.308384	2.777609	**No**
Industrial Structure → Human Capital	0.16223	2.635089	3.399044	1.830582	1.400682	1.402372	1.860881	4.43397	9.833985	**No**
Human Capital → Industrial Structure	0.01537	0.440701	0.986435	4.409345	4.375316	3.851169	3.633042	9.882885	20.48862 **	**No**
Socio-Institutional Context → International Trade	1.509699	3.250447	10.39449 **	11.8513 **	14.54992 **	23.67875 ***	23.74882 ***	22.23473 ***	23.48492 ***	**Yes**
International Trade → Socio-Institutional Context	1.026858	4.727801 *	5.580671	5.352217	6.738515	5.874449	9.681841	19.09827 **	16.40096 *	**No**
Industrial Structure → International Trade	2.783808 *	1.373702	1.157929	4.372716	5.298082	16.68156 **	14.08069 **	10.84179	13.70171	**No**
International Trade → Industrial Structure	16.42998 ***	14.38852 ***	14.04809 ***	14.11877 ***	12.90143 **	15.74189 **	16.59366 **	22.34143 ***	40.00545 ***	**Yes**
Industrial Structure → Socio-Institutional Context	0.007372	2.772511	4.495678	5.283035	7.06492	7.711466	8.76633	10.29606	9.159842	**No**
Socio-Institutional Context → Industrial Structure	0.090603	1.288164	1.341213	3.278262	3.672377	5.483068	5.135523	5.56436	5.621876	**No**

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



6.4 Proposition 4: Increasing complexity along the stages of development

As pointed out in section 3, the development-stage theory corroborated by the first three propositions 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 4.a, 4.b and 4.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 argue, is a general implication of the class of multiple equilibria and threshold growth models considered in this paper.

As noted in section 3, this result is also in line with Hausman and Hidalgo's (2011) recent model of the complexity and network structure of economic output. As the production structure of countries becomes progressively more complex through processes such as increasing specialization and product and export differentiation – this micro- and industry-level complexity will be reflected in the network of economic relationships that characterizes each national system. Countries with a more advanced production and output structure will in general be characterized by a more dense network of (Granger) causal relationships linking together innovation, absorptive capacity and GDP per capita growth.

Table 4.a: Number of significant Granger causal relationships: Less developed economies

Model specification	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Average**
Sub-Sahara															
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
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
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
Average Less developed economies															
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**

Table 4.b: Number of significant Granger causal relationships: Middle-income group

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 group															
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 4.c: Number of significant Granger causal relationships: Advanced (OECD) club

Model specification	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
OECD															
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**

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 a possible 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 some-what 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 an indication as to which of these factors and causal relationships are more important than others. White and Lu (2010) have recently provided an analysis of the relationships between Granger causality analysis and dynamic structural systems, and shown that Granger causal relationships may in fact be interpreted as structural relationships characterizing the system if the so-called *conditional exogeneity condition* holds. White and Lu (2010)'s analysis provides an important suggestion of how the methodology employed in this paper could in the future be refined in order to estimate structural dynamic relationships and their different configurations in different country groups.

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 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 results suggest that increasing complexity is an important, though often 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.

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Appendix 1: List of countries included in each group

Less developed economies

Sub-Sahara: Benin, Botswana, Burkina Faso, Burundi, Cameroon, Ethiopia, Gabon, Ghana, Guinea, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Swaziland, Tanzania, Uganda, Zambia, Zimbabwe and Haiti[6].

North Africa and Middle-East: Algeria, Iran, Jordan, Morocco, Tunisia.

South Asia: Bangladesh, India, Nepal, Pakistan, Sri Lanka.

Middle-income group

Eurasia (former Soviet economies): Albania, Armenia, Azerbaijan, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Latvia, Lithuania, Moldova, Poland, Romania, Slovakia, Slovenia, Tajikistan, Ukraine, Uzbekistan.

Latin America: 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 Asia: Cambodia, China, Fiji, Indonesia, Malaysia, Mongolia, Philippines, Singapore, South Korea, Thailand, Vietnam.

Advanced club

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.

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6 Haiti has been included in this country group since its economic conditions make it more similar to the countries there involved.

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