Paper to be presented at the DRUID Academy Conference 2016 in Bordeaux, France on January 13-15, 2016

Micro Dynamics of National Innovation System: A Panel Cointegration Analysis

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Abstract

Title: Micro Dynamics of National Innovation System: A Panel Cointegration Analysis By Jurgita Staniulyte, 2nd year PhD student in Economics (expected to finish by Dec 2016) E-mail: jurg.stan@gmail.com Abstract The purpose of this paper is to test whether the dynamics of national innovation system (NIS) is driven by coevolution of four different innovation proxies: product, process or design inventions (measured by patents), product innovation (measured by high-tech exports), research innovation (measured by scientific publications) and process innovation (measured by labour productivity). A four step panel cointegration method is used to investigate a long term relationship and coevolution patterns amongst them. The empirical analysis employs innovation indicators of 87 countries for the period of 1980-2008 from an existing CANA database. Econometric results indicate that the dynamics of NIS is driven by a long run relationship amongst the four innovation variables. The results confirm three two-way relationships: between patents and high-tech exports, patents and scientific publications, labour productivity and scientific publications. A one-way relationship is confirmed between patents and labour productivity. Overall, these results indicate that the four innovation variables draw on each other while moving through different stages of the innovation diffusion process within the system. Therefore, further analysis of social, institutional and economic factors linking the four innovation proxies may lead to an even better understanding of the NIS dynamics. Keywords: National innovation system, innovation diffusion, non-price competitiveness, capabilities, coevolution, panel cointegration analysis.

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Micro dynamics of national innovation system: a panel cointegration analysis

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Abstract

The purpose of this paper is to test whether the dynamics of national innovation system (NIS) is driven by coevolution of four different innovation proxies: product, process or design inventions (measured by patents), product innovation (measured by high-tech exports), research innovation (measured by scientific publications) and process innovation (measured by labour productivity). A four step panel cointegration method is used to investigate a long tem relationship and coevolution patterns amongst them. The empirical analysis employs innovation indicators of 87 countries for the period of 1980-2008 from an existing CANA database. Econometric results indicate that the dynamics of NIS is driven by a long run relationship amongst the four innovation variables. The results confirm three two-way relationships: between patents and high-tech exports, patents and scientific publications, labour productivity and scientific publications. A one-way relationship is confirmed between patents and labour productivity. Overall, these results indicate that the four innovation variables draw on each other while moving through different stages of the innovation diffusion process within the system. Therefore, further analysis of social, institutional and economic factors linking the four innovation proxies may lead to an even better understanding of the NIS dynamics.

Keywords: National innovation system, innovation diffusion, non-price competitiveness, capabilities, coevolution, panel cointegration analysis.

1. Introduction

National governments and international organizations (IMF, OECD, and EU) are increasingly concerned with a sustainable national growth and competitiveness. The recent global crisis revealed a long-term ongoing unsustainable growth patterns leading to high unemployment, stress in financial markets, overall growth and competitiveness decrease. As noted by IMF (2015) the global economy is slowing down and may never return to its pre-crisis growth levels. Especially Europe is facing increasing external and internal pressures. A decreasing global demand is shrinking potential export markets, a prolonged post-crisis recession, an aging population and increasing divergence within the region slows down growth and innovation processes. An accelerating growth of large developing countries (like BRICS) poses a big challenge for Europe and other regions to stay competitive and catch up with their growth. Therefore, many economist (Stiglitz, Porter, Fagerberg, Mazzucato, Lundvall, Nelson, Kim etc.) agree that only a high-quality innovation based growth, not just any growth could lead to a long-term sustainable economic success.

Stiglitz and Greenwald (2014) argue that sustainable national competitiveness would not be possible without a constantly learning economy and continuous innovation. Innovation starts at an individual and firm level (Rogers, 1995 and 2003; Dosi 1988 and 1994). However, neoclassical economists are sceptical about macro policies influencing innovation at micro level. They assume efficiently operating markets, perfect information available to all individuals and firms, as well as equal abilities to learn and innovate. In contrast, the evolutionary theory economists argue that historical evidence does not support these neoclassical assumptions about learning and innovation. The evolutionary theory (Nelson and Winter, 1982), and NIS approach (Lundvall 1992, Edquist 1997, Nelson 1993) suggest that individuals have different learning capabilities and skills, nations have different histories, social norms, institutional structures and different development paths. Innovation diffusion conceptual model (Rogers, 2003) also provides helpful theoretical insights by suggesting analysis of innovation as a multi-stage and multi-level process that is communicated through various channels amongst members of social system.

These theoretical insights about innovation diffusion, national competitiveness and national innovation system lead to the following question: are social and institutional factors equally or even more important compared to economic factors in knowledge creation, innovation and long-term sustainable growth? This paper attempts to answer this question by testing coevolution amongst four different measures of innovation: patents, high-tech exports, scientific publications and labour productivity. An existing CANA database by Castellacci and Natera (2011) is used for the empirical analysis. It has panel data of 87 countries for the period of 1980-2008. It provides a broad dataset of human capital, economic equality, infrastructure, institutional quality and economic competitiveness variables (table 1, appendix 1).

The panel cointegration analysis confirms that the dynamics of NIS is driven by a long run relationship amongst the four variables. The results also confirm, that patents and high-tech exports, patents and scientific publications, and labour productivity with scientific publications are linked by a two-way relationship. A one way relationship is confirmed between patents and labour productivity. Overall, these results indicate that the four innovation variables draw on each other while moving through different stages of the innovation diffusion process within the national innovation system. Therefore, further analysis of social, institutional and economic factors linking the four innovation proxies may lead to an even better understanding of the NIS dynamics.

The paper is organized in the following order. Part 2 explores the recent literature about national competitiveness and innovation. Part 3 describes methodological approach, data and proposed hypotheses. Part 4 describes the econometric method. Part 5 explores empirical results. Part 6 concludes theoretical and empirical analysis of this paper, also, propose steps of further research.

2. Literature review

National innovation system studies focus on components of the system and interaction amongst them. Understanding dynamics and evolution of these components is the main motivation for this paper. However, most NIS studies are conceptual and quantitative, based on historical and case study analysis. Qualitative studies of NIS are not so popular due to lack of long run data and econometric methods to measure and investigate innovation. Literature of endogenous growth theory (Romer, 1990), Porter's (1990) competitive advantage theory and NIS approach (Nelson, 1993) provide basis for most econometric studies of national competitiveness, growth and innovation.

In general, economic studies linking long-term national competitiveness with innovation and analysing innovation components are relatively recent. Only in 1980s and 1990s, studies connect innovation with competitiveness (Fagerberg 1987, Dosi and Soete 1988, Porter 1990, Patel and Pavitt 1994) and distinguish between the unsustainable short-term price competitiveness and the long-term sustainable competitiveness concepts. Porter

(1990) argues that sustainable national competitiveness is not short-term price based, it can only be achieved through constant learning and innovation. Firms, sectors, regions and national economies learning faster and better become more competitive since their knowledge becomes scarce and cannot be immediately imitated. Storper (1997) as well as Stiglitz with Greenwald (2014) argue that a learning economy is necessary for innovation, high wage and high quality employment and overall sustainable national growth.

Romer's (1990) new growth theory has been very influential and inspired many econometric studies linking R&D and innovation. However, the new growth model focus on the role of knowledge in macroeconomic growth, but it leaves knowledge in a 'black box' of the aggregate production function. The NIS approach, on the other hand, analyses microeconomic context within 'the box', especially by focusing on the role of the state, social and institutional factors within the system. Another drawback of most empirical neoclassical studies is their focus on comparative cross country perspective. As a result, they neglect importance of history and path dependency, social and institutional factors in national competitiveness analysis. In summary, new growth models focus on simple input-output analysis and neglect analysis of structural changes and innovation system dynamics.

The most recent empirical NIS literature focus on absorptive capacity and innovative capability analysis (Castellacci and Natera, 2013; Fagerberg and Srholec, 2008; Filippetti and Peyrache 2011) at regional or national level; or studies of factors leading to innovation at firm or industry level (Faustino and Matos, 2015; Lee and Narjako, 2015; Felsenstein, 2015). Econometric studies of national capabilities and NIS efficiency use a broad set of social, institutional and economic and factors. However, most of them (except by Castellacci and Natera, 2013) still focus on comparative cross-country perspective and neglect analysis of factor dynamics within NIS, relationships and links of human capital, infrastructure, quality of institutions etc. Also, none of these studies analyse innovation as a multi-stage and multi-level process. Rogers (2003) innovation diffusion conceptual model, on the other hand, provides theoretical basis to view innovation as a multi-stage and multi-level process. He argues that the same innovation diffusion model is true for new innovations, as well as for adoption of existing innovations.

Rogers (2003) describes innovation diffusion as a process of four elements: "(1) an innovation that is (2) communicated through channels (3) over time (4) amongst members of a social system" (Rogers, 2003, 11). There are different players in four elements of diffusion. Innovation as an idea, object or a process is identified by an individual or a firm. Channels of communication or means by which new information is shared within social system include mass media and interpersonal, industry channels. Time measures rate at which innovation is diffused and adopted by members of society. Social systems include all units (individuals, organization, agencies) engaged in problem salving to accomplish a common goal; also units adopting innovation and further sharing it within social system and with other systems (industries, countries). Rogers (2003) also identifies five stages of innovation diffusion: knowledge, persuasion, decision, implementation and confirmation (table 2). He recognizes different players and factors at various stages that move innovation forward until it is fully adopted and distributed to other firms, industries and countries.

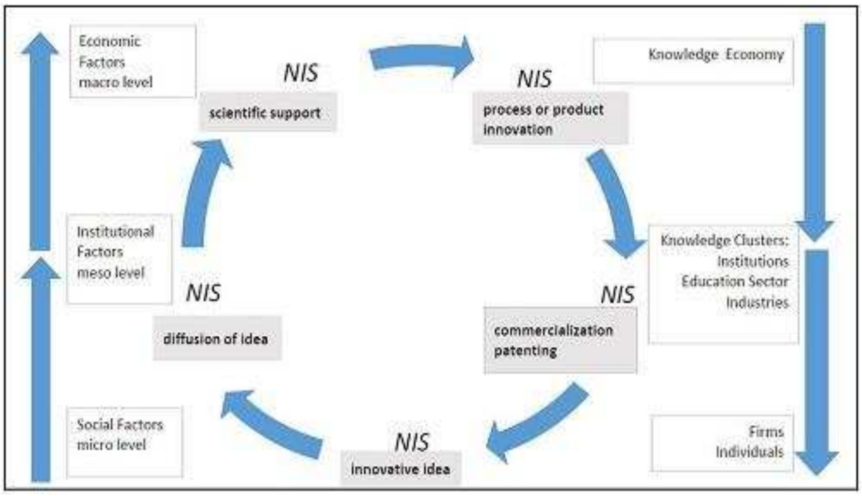
Table 2: Conceptual innovation diffusion model adopted from Rogers (2003) enhanced by factors limiting or enhancing innovation.

Innovation outcome	Innovation diffusion stages	Innovation diffusion channels	Social, institutional and economic factors limiting or enhancing innovation diffusion and outcome
Idea of innovation. Recognition and understanding of it.	**1 stage: KNOWLEDGE** occurs when an individual (or a firm) recognises existence of innovation and understands how it functions. At this stage individual can answer 3 questions: **what** is innovation, **how** does it work and **why** does it work.	Individual, firm and mass media channels.	Education level and quality, social equality, innovative and technical skills, previous practices, family values, feeling of happiness, political and institutional system.
Evaluation of innovation and formation of attitude towards it.	**2 stage: PERSUASION** occurs when an individual (or a firm) forms a favourable or an unfavourable attitude towards innovation. Evaluation of advantages or disadvantages of innovation, discussions with near peers.	Individual, firm, local and interpersonal channels.	Support from social system, level of trust, networking and research skills to advance innovative idea, political and institutional system.
Adoption or rejection of innovation. If adopted: possible patenting and commercialization.	**3 stage: DECISION** occurs when an individual (or a firm) engages in activities leading to adoption or rejection of innovation. At this stage a firm might do a small scale trial of new product or process by giving free samples to clients.	Individual, firm, local, interpersonal channels, experts/ scientists.	Funds for research, advanced research and implementation skills, trust level and corruption perception.
New invention is put into daily practice: patenting and commercialization.	**4 stage: IMPLEMENTATION** occurs when an individual (or a firm) puts a new idea into daily use. This stage may also include a further scientific research, re-invention or modification of an innovation.	Firm, industry, scientists, supporting public and government institutions.	Capabilities to commercialize innovation, firm, industry or government funds for R&D, national scientific research capabilities, the triple helix networking amongst university, government and industry.
The innovation is promoted to others: high-tech exports.	**5 stage: CONFIRMATION** takes place when an individual (or a firm) seeks reinforcement of an innovation decision already made and recognition of the benefits of using the innovation. At this stage the innovation is promoted to others.	Firm, industry, mass media, supporting public and government institutions	Capabilities to commercialize innovation, domestic credit availability, support from local institutions and infrastructure, trade openness, political and institutional system.

Based on this theoretical insight we could assume that innovation may be understood and analysed differently at every stage (table 2). Therefore, we could use four different measures of innovation. We could also assume that these different types of innovations draw on each other while moving through innovation diffusion process within the NIS. For example: a technical scientific research may lead to a process innovation, which allows a product innovation and later on leads to patents and high-tech exports. We may look at this example in more detail while going through all Rogers (2003) innovation diffusion stages.

An individual at a firm might have a great idea of a technical process innovation (knowledge stage). If his supervisor and colleagues support the idea (persuasion stage), the management may decide to contact a local university regarding further research (decision stage). If the university has scientist and funds (or a firm might need to provide funds) to do the required research, the company might implement process invention (implementation stage) and later on produce more advanced products. The company may also decide to apply for a patent (confirmation stage) for the product innovation with some support from local government institutions. The company may also decide to export the patented products (confirmation stage) assuming that the home country has favourable trade relationship with foreign countries or regions of interest. As described in the example, there are many social, institutional and economic factors that may limit or enhance innovation diffusion process within the NIS. Graph 2 presents this internal NIS flow chart. It captures how different types of innovations may draw on each other via different social, institutional and economic factors while moving through innovation diffusion process.

Graph 2: National innovation system (NIS) flow chart through micro/ macro levels.



This brief literature review summarises existing opportunities to advance analysis of the NIS dynamics. In summary, the existing literature gap is threefold. The current mainstream economic studies focus on comparative cross country perspective and neglect internal dynamics of social and institutional factors in national competitiveness analysis. The current NIS studies do not analyse innovation as a multi-stage and multi-level process. Also, there is a clear divide between macro and micro analysis in all innovation literature. Therefore, we employ Rogers (2003) innovation diffusion model which combines micro and macro factors limiting or enhancing innovation process. Innovations starts with an idea at an individual or a firm level, but then it goes through all levels and draws on many social, institutional and economic factors. In other words, innovation diffusion model together with NIS approach allows an in depth analysis of innovation system flow (graph 2), enhancing or limiting factors, relationships amongst them and players involved at various stages of innovation process.

3. Methodology, proposed hypotheses and data

This section presents theoretical framework for my empirical analysis of NIS dynamics; relationship amongst social, institutional and economic factors leading to better capabilities and higher innovation potential. First, it is important to note that a wide definition of innovation concept (following Schumpeter) is used for the purpose of this paper. Innovation could be defined as a new process, a new method of production, a new market, a new source of supply, a new organization, a new industry and a new product. Second, we assume that innovation starts with an idea at individual/ firm level following Rogers (2003) innovation diffusion model. Therefore, identifying major players and diffusion channels in innovations process is very important. Third, we accept that there is no single best measure of innovation. Therefore, four different variables are used to capture innovation at different innovation diffusion stages following the innovation diffusion conceptual model.

Labour productivity is the most controversial proxy for innovation because of the way it is calculated. However, Pires and Garcia (2012) argue that productivity is responsible for technical efficiency, innovation and growth differences between countries. Recent econometric studies (Faustino and Matos, 2015; Lee and Narjako, 2015; Felsenstein, 2015) confirm a two-way positive relationship between productivity and exports, as well as productivity and R&D. Studies also confirm that higher productivity may lead to process innovation. Labour productivity may be increased by better human capital factors (Felsenstein, 2015), trade openness, higher R&D and better quality of institutions (Nelson, 2006). For the purpose of this paper we use labour productivity as a measure of process innovation, since most of it might be unrepresented by the most commonly used innovation measures like patents or high-tech exports.

Scientific and technical journal publications is another recent and not very popular measure of innovation. Castellacci and Natera (2013) define it as a result of research and innovation activities by public system. Cai (2011), Pan Hung and Lu (2010) and Chang (2015) use it as a proxy for knowledge generation and diffusion in NIS efficiency analysis. As noted by Castellacci and Natera social cohesion and economic equality (free education), higher public spending on education sector may positively influence advanced knowledge adoption, research and diffusion within education sector and country. Scientific publications may be a very important scientific innovation outcome as already discussed within innovation diffusion process context. However, it is not directly captured by patents or high-tech exports, since there are many further steps and factors leading from scientific results/ publications to actual patented products. Therefore, scientific and technical journal publications are used as a separate proxy for research innovation in this paper.

High-tech exports is one of the most popular proxies for innovation and NIS efficiency (Naser and Afzal, 2014; Cai, 2011). Naser and Afzal consider high-tech exports as commercialization of valuable knowledge creation. Fan (2011) uses high-tech exports together with patents as a measure of overall national innovation capacity and economic development. Overall, a variable of high-tech exports incorporate many aspects of private and public sector efficiency. A firm (or industry) is the most active player in innovation commercialization process, but the ability to sell high-tech products in foreign markets also depends on many other factors like trade policy, supporting national institutions, chambers of commerce, embassies in foreign countries and diplomatic relations to help firms and industries reach international markets. High-tech exports may also draw of previous innovation outcomes like research or process innovation. Therefore, it is one of the most complete innovation measures. However, for the purpose of this paper, we use high-tech exports as a measure of product innovation since it is a ratio of total manufacturing exports in our dataset.

UPSTO patents is the most popular proxy for innovation in econometric papers. It is analysed as a measure of innovative activities by private firms (Castellacci and Natera, 2013), overall innovation system efficiency (Cai, 2011) or more specifically as a measure of technical NIS efficiency (Pan, Hung and Lu, 2010). By the official definition, UPSTO (www.upsto.gov) recognizes three types of patents: utility, design and plant. Utility patents are granted for any process, machine, article of manufacture and composition of matter inventions. Design patents are granted for new and original design for any article of manufacture. Plants patents are granted for inventions of a new variety of plant.

UPSTO patents may be a very useful measure of inventions in some, but not all industries. Some industries like services, food and beverage, textiles, plastics do not use many patents. Therefore, for the purpose of this paper, UPSTO patents are used as a measure of inventions in high-patent industries. It is also the most complete or widest measure of innovation since it may incorporate all other innovation outcomes like research, process, product and design innovations in some industries. However, most authors in econometric studies focus on R&D as the most important factor leading to more patents and dismiss human, education, infrastructure and institution factors.

Innovation starts with an idea in individual's head. His or her education, skills and prior experiences may lead to the idea. The individual then shares the idea with his peers at work or university research lab. Further action, could be influenced by R&D funds available, but more importantly it will depend on institutional support from local government agencies, universities, networks with other firms or industries. This relationship is recognized as a triple helix of academic-industry-government in innovation studies (Etzkowitz and Leydesdorff, 2000). Therefore, institutional quality, infrastructure and education factors are even more important compared to funds available for R&D. High R&D funds will not lead to more innovations if people at all levels of innovation diffusion do not have relevant skills to move the potential idea further towards patenting and commercialization.

Following the NIS approach enhanced by Rogers (2003) innovation diffusion model we recognise and analyse not only economic, but also social and institutional factors leading to more innovation. Therefore, the main model of innovation could be defined as a function of social, institutional and economic variables:

Innovation = Social + Institutional + Economic factors

(1) $I = F(S, I, E)$

(2) $I_t = \alpha_1 S_{t-1} + \ldots \alpha_p S_{t-p} + \alpha_1 I_{t-1} + \ldots \alpha_p I_{t-p} + \alpha_1 E_{t-1} + \ldots \alpha_p E_{t-p} + \varepsilon_t + \mu_t$

Based on our conceptual analysis, the following **hypothesis** is investigated:

- Higher education system and human capital, political and institutional system quality, infrastructure and economic competitiveness indicators have positive impact on all types of innovations.

The proposed hypothesis attempts to capture internal dynamics of NIS as captured by graph 2. It presents innovation as a multi-level and multi-stage process with many different players, diffusion channels and many social, institutional and economic factors limiting or enhancing it. The proposed hypothesis also links the four innovation proxies into the innovation diffusion process, since they draw on each other while moving through different stages of the innovation diffusion process within the system.

The panel data from the CANA database of 87 countries for the period of 1980-2008 (http://english.nupi.no/Activities/Projects/CANA) is used for the econometric analysis. Data variables are organized into four groups: proxies for innovation, as well as, social, institutional and economic factors linking innovation variables (table 1, appendix 1) Table 1 provides a brief overview of definitions and indicates input effect towards innovation.

4. Econometric Method

First, panel cointegration analysis is performed to investigate dynamic relationship amongst the four proposed innovation proxies within NIS as represented in graph 2. Cointegration analysis may help discover the relationship among non-stationary time series by analysis of a long run relationship and a short run adjustment. Variables are cointegrated if two or more of them have a long run relationship. To illustrate this possible long run relationship among the four innovation proxies, graphs of a few selected countries are presented in graph 3 (appendix 1). As discussed in previous sections, innovation variables draw on each other while moving through different stages of the innovation diffusion process within the system. Scientific research innovation may lead to process or product innovation, patenting and commercialization.

The methodology of the panel cointegration approach includes four steps: panel unit root test, Pedroni cointegration, panel vector error correction (VECM) and Granger causality analysis. Panel root test helps verify whether panels are stationary at the first order difference, which is the main pre-condition for panel cointegration model. Pedroni cointegration test is used to check whether a long-term relationships exist amongst variables by looking at within and amongst dimension of the panel. Panel vector error correction model helps estimate both long run relationship and short term adjustment processes from external shocks. Granger causality analysis investigates the direction of causality amongst variables and allows to detect one way and two way relationships. To summarise, this four-step econometric methodology is an attempt to operationalize the concept of coevolution within the panel cointegration context. The coevolution amongst variables is defined by: 1) an existing long-run relationship (cointegration); and by 2) existing two-way causal relationship between variables (Granger two-way direction causality).

For the second part of the econometric analysis **(not presented in this paper**), dynamics of social, institutional and economic factors (table 1, appendix 1) leading to more innovation (patents, high-tech exports, labour productivity and scientific publications) is performed. We start with factor analysis to detect variance shared among many variables in the dataset. We then use cluster analysis to capture variation between country groups. A five-group structure by income and development level (based on a traditional growth and convergence clubs method) and geographical area (based on evolutionary economics and NIS theory) is used for further analysis.

5. Empirical Results

First, Table 3 presents the results for Breitung and Harris-Tzavalis panel unit root tests. Results at the first order difference confirm that we may strongly reject the null hypothesis of a unit root in favour of the alternative hypothesis that panels are stationary. We chose these two tests since they best fit balanced panels with small T (time period) and large N (number of panels). The Breitung test has good results even with very small datasets where N=25 and T=25 (Breitung, 2000; Breitung and Das 2005), while Harris-Tzavalis test is recommended for datasets where N is significantly large than T (Harris-Tzavalis, 1999). Both tests were performed for all variables at level and the first order difference with 1 lag specification. Results indicate that panels contain unit roots at level, but become stationary at the first order difference, which is the main precondition for panel cointegration test.

Table 3: Results of panel unit root tests at the first order difference with1 lag specification. Note: * indicate 1% significance level.**

	Breitung panel unit root test	Harris-Tzavalis panel unit root test
Variable	**First order difference**	**First order difference**
patents	-33.5735***	-0.2510***
lproductivity	-21.5977***	0.2592***
spublications	-27.0025***	-0.2867***
htexports	-33.6199***	-0.2476***

Second, we run Pedroni cointegration test to investigate the existence of a long run relationship amongst the four variables. This test investigates cointegration at within and between dimensions of panels. Table 4 presents results for seven tests of Pedroni cointegration (Pedroni, 1999). Null hypothesis for Pedroni cointegration test states no cointegration. Out of seven tests five of them show significant values. Therefore, due to the majority tests we reject the null hypothesis and accept alternative. Overall, results of Pedroni cointegration test confirm cointegration or existence of one or more long run relationship amongst the four measures of innovation: patents, high-tech exports, labour productivity and scientific publications.

Table 4: Perdoni cointegration test with 2 lag specification. Note: *, ** and * indicate 1%, 5% and 10% significance levels for k statistics.**

7 Tests	Results
Pavel-v	4.2504***
Panel-rho	-2.648**
Panel-PP	-5.7921***
Panel-ADF	0.5414
Group- rho	-2.2114**
Group-PP	-10.8341***
Group-ADF	2.2009

The third step in our econometric analysis is VECM and estimation of a long run cointegration equation. VECM model with two lags and four variables reports relationship that could be written as:

Inventions = + 420.87 (capabilities to commercialize innovations)

-367.99 (process and product innovations)

+ 209.74 (research and innovation diffusion capabilities)

Table 5: VECM long run cointegration equation with 2 lag specifications. Note: *, ** and * indicate 1%, 5% and 10% significance levels for t statistics.**

Cointegrating Eq:	**CointEq1**
patents (-1)	1.0000
htexports (-1)	420.8775 (100.097) [4.2047]***
lproductivity (-1)	-367.9953 (160.269) [-2.2961]**
spublications (-1)	209.7443 (57.0905) [3.6738]***

VECM results indicate that a long-run and positive, econometrically and economically significant relationship exists between inventions (patents), product innovations (high-tech exports) and research innovations (scientific publications). However, the estimated long-run relationship between inventions and process innovation has negative significant coefficient which is in contrast with the typical expectation that higher productivity leads to more innovation (Pires and Garcia, 2012). One possible explanation could be that these two variables have different relationship dynamics in countries with different development levels.

Table 6 presents error correction equations for the four measures of innovation with two lags. It is interesting to note, that patents have negative significant relationship with patents of the 1st lag, but positive relationship with patents of the 2nd lag as well as positive relationship with the 1st and the 2nd lag high-tech exports. High-tech exports have positive relationship with the 2nd lag patents, the 1st and 2nd lag high-tech exports. Labour productivity has positive relationship with the 1st lag productivity. Scientific publications is positively influenced with the 1st lag patents, the 1st lag productivity and the 1st lag publications. We could conclude that three out of four variables (except patents) are positively related to their own 1st lagged values. Also, patents, high-tech export and scientific publication variables are all influenced by other variables as well, while results for labour productivity indicate relationship only with the 1st lag productivity values.

Table 6: Error correction estimates with 2 lag specification. Note: *, ** and * indicate 1%, 5% and 10% significance levels for t statistics.**

Error Correction:	D(patents)	D(xtexports)	D(lproductivity)	D(spublications)
CointEq1	0.0000 (0.0000) [3.4126]***	0.0000 (0.0000) [-2.4985]**	0.0000 (0.0000) [3.3962]***	0.0000 (0.0000) [1.0048]
D((patents (-1))	-1.9213 (0.02762) [-6.9551]***	-0.0011 (0.0122) [-0.08596]	0.0042 (0.0039) [1.0676]	-0.0267 (0.0101) [-2.6340]**
D((patents (-2))	0.1509 (0.0288) [5.2274]***	0.0354 (0.0127) [2.7743]***	-0.0011 (0.0041) [-0.2754]	0.0009 (0.0106) [0.0879]
D((xtexports (-1))	0.141053 (0.0651) [2.1651]**	-0.1788 (0.0288) [-6.1998]***	-0.0073 (0.0094) [-0.7831]	-0.0202 (0.0239) [-0.8456]
D((xtexports (-2))	0.1542 (0.0669) [2.3060]**	0.0666 (0.0296) [2.2482]**	-0.0037 (0.0096) [-0.3903]	-0.0346 (0.0246) [-1.4098]
D((lproductivity (-1))	0.0182 (0.1956) [0.0930]	0.0297 (0.0866) [0.3436]	0.08831 (0.0283) [3.1209]***	0.1308 (0.0719) [1.8195]*
D((lproductivity (-2))	0.2085 (0.1954) [1.0672]	0.1234 (0.0865) [1.4263]	-0.0019 (0.0282) [-0.0686]	-0.0996 (0.0718) [-1.3864]
D((spublications (-1))	-0.0560 (0.0742) [-0.7548]	0.0473 (0.0328) [1.4406]	0.0044 (0.0107) [0.4107]	0.1308 (0.0719) [1.8195]*
D((spublications (-2))	-0.0524 (0.0692) [-0.7572]	-0.0016 (0.0306) [-0.0536]	0.0083 (0.0100) [0.8292]	0.0234 (0.0254) [0.9227]
R squared	0.10	0.05	0.04	0.04

The fourth step is to investigate the direction of causality and determine whether one way (Y -> X) or two way(Y<->X) relationship exist between the four innovation variables. Granger causality test results with 5 lags based on VECM model are presented in table 7. Results indicate three two-way relationships between patents and high-tech exports, patents and scientific publications, also, labour productivity and scientific publications. More high-tech exports lead to more patents at all lags, but more patents lead to more high-tech exports only with three, four and five year lags. Also, one two way relationship is confirmed between patents and scientific publications. Relationship between patents and productivity is significant only one way. More patents lead to higher productivity at all lag specifications, but higher productivity does not lead to more patents (which is in line with VECM results).

Table 7: Granger causality test results based on VECM model with 5 lag specification. Note: * indicate 1% significance level for F statistics.**

Causal relationship	Lag 5	Granger causality
htexports ---> patents	3.0394***	Yes
patents ---> htexports	4.8381***	Yes
lproductivity ---> patents	1.3461	No
patents ---> lproductivity	3.6408***	Yes
spublications ---> patents	8.1142***	Yes
patents ---> spublications	6.8763***	Yes
spublications ---> htexports	1.3404	No
htexports ---> spublications	0.8529	No
lproductivity ---> htexports	0.9757	No
htexports ---> lproductivity	0.7274	No
lproductivity ---> spublications	3.5728***	Yes
spublications ---> lproductivity	3.6696***	Yes

A grand summary of empirical results indicate that the four innovation outcomes (patents, high-tech exports, labour productivity and scientific publications) are linked by three two-way long term relationships. These results indicate that the four innovation variables draw on each other while moving through different stages of the innovation diffusion process within the system. Therefore, further analysis of social, institutional and economic factors linking the four innovation outcomes together may lead to an even better understanding of the NIS dynamics.

6. Conclusions

The paper has argued that dynamics of NIS is driven by co-integrating relationship of four different innovation outcomes: inventions measured by patents, process innovations measured by labour productivity, research innovations measured by scientific journal publications and product innovations measured by high-tech exports. The NIS approach together with the innovation diffusion conceptual model was used to analyse this internal dynamics of the NIS. A set of indicators for 1980-2008 from the existing CANA database for 87 countries was used to explore these arguments. The empirical methodology was based on the panel cointegration approach. The empirical operationalization of cointegration concept was analysed by investigating the existence of a long-run relationship amongst the four innovation variables and by analysing the direction of causality for each pair of variables.

The empirical results indicated an existing long run relationship amongst all four innovation proxies for the period of 1980-2008. Specifically, the causality test confirmed three two-way relationships between patents and high-tech exports, patents and scientific publications, labour productivity and scientific publications. A one-way relationship was confirmed between patents and labour productivity. These results indicate that the four innovation variables draw on each other while moving through different stages of the innovation diffusion process within the system. There are many different channels, various economic, social and institutional factors enhancing or limiting this process. Therefore, these results have important implications for further NIS theory building as well as for policy making.

Appendix 1

Table 1: The proposed four indicators for innovation. Source: The existing CANA database.

Indicator and Definition	Scope	Code
Ratio of **UPSTO patents** per capita: number of utility, design and plant patents granted by UPSTO by year and inventor's country of residence.	**Proxy for inventions** (product, process and design)	patents
High-tech exports as % of manufacturing exports: Exports of products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery.	**Proxy for product innovation**	htexports
Ratio of **scientific and technical publications** per capita: articles published in physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.	**Proxy for research innovation**	spublications
Labour productivity per hour worked: average output produced by unit of labour. Estimated by dividing GDP by labour input.	**Proxy for process innovation**	lproductivity
Public Expenditure on Education as % of GDP. Total public (Current and capital) expenditure on education as % of GDP. May enhance overall national capabilities.	Economic	
R&D as % of GDP Spend. Percentage of the R&D Expenditure over GDP. May influence national innovation potential level.	Economic	
GERD - financed by Business enterprise %. Total domestic intramural expenditure on R&D during the reference year, financed by business enterprise expressed as a percentage of GDP. Represents finances towards innovation potential at firm level.	Economic	
GERD - financed by Government %. Total domestic intramural expenditure on R&D during the reference year, financed by government expressed as a percentage of GDP. Represents finances towards innovation potential at national level.	Economic	
GERD - financed by Higher education %. Total domestic intramural expenditure on R&D during the reference year, financed by higher education expressed as a percentage of GDP. Represents finances towards innovation potential at institutional level.	Economic	
GERD - financed by Private non-profit %. Total domestic intramural expenditure on R&D during the reference year, financed by private non-profit organizations expressed as a percentage of GDP.	Economic	
Gini Index represents income distribution and measures level of inequality. O represents perfect equality and 100 perfect inequality. May impact opportunities for education and skill formation.	Social	
Trade Openness Indicator. Ratio of (Import+ Export)/GDP. Measures integration into the world economy. May open external sources of knowledge and enhance capabilities of local firms and institutions.	Economic	
Domestic Credit by Banking Sector as % GDP. Includes all credit to various sectors on a gross basis, with the exception of credit to the central government, which is net.	Economic	

Ratio of royalty and license receipts as % of GDP. These royalty and license receipts (as % of GDP) are between residents and non-residents for the authorized use of intangible, non-produced, nonfinancial assets and proprietary rights and for the use, through licensing agreements, of produced originals of prototypes. May limit creativity and innovation potential.	Social	
Ratio of trademark applications, total per capita. Applications to register a trademark with a national or regional Intellectual Property (IP) office. It may measure national innovation capabilities.	Social	
GERD - performed by Business enterprise %. Total domestic intramural expenditure on R&D during the reference year, of institutions corresponding to business enterprise, independent of the source of funds and expressed as a percentage of GDP. Could be an indicator of advanced capabilities at a firm level.	Social	
GERD - performed by Government %. Total domestic intramural expenditure on R&D during the reference year, of institutions corresponding to government, independent of the source of funds and expressed as a percentage of GDP. Could be an indicator of advanced capabilities at national level.	Social	
GERD - performed by Higher education %. Total domestic intramural expenditure on R&D during the reference year, of institutions corresponding to higher education, independent of the source of funds and expressed as a percentage of GDP. Could be an indicator of advanced capabilities at institutional level.	Social	
GERD - performed by Private non-profit %. Total domestic intramural expenditure on R&D during the reference year, of institutions corresponding to private non-profit organizations, independent of the source of funds and expressed as a percentage of GDP. Could be an indicator of advanced capabilities at firm level.	Social	
Gross Tertiary Enrolment Ratio. May enhance overall national scientific and innovative capabilities.	Social	
Primary School Pupil-Teacher Ratio. Number of pupils enrolled in primary school divided by the number of primary school teachers. May enhance overall national capabilities.	Social	
Corruption Perception Index. Transparency International Index. Index from 0 (High Corruption) to 10 (Low or None Corruption). May limit or enhance entrepreneurial and innovation potential.	Social	
Women's rights. Index constructed from the Economic, Political and Social indicators for Women's rights. It ranges from 0 (no gov. respect) to 9 (full gov. respect). May influence entrepreneurial, creative and innovative abilities.	Social	
Friends important in life. Index constructed using scales for each Importance level. Index from 3 (Very Important) to 0 (Not Important). May influence entrepreneurial, creative and innovative abilities.	Social	
Family important in life. Index constructed using scales for each Importance level. Index from 3 (Very Important) to 0 (Not Important). May influence entrepreneurial, creative and innovative abilities.	Social	

Marriage is an outdated institution. Percentage of answers "Disagree". May influence entrepreneurial, creative and innovative abilities.	Social	
Most people can be trusted. Percentage of people that answered "Most people can be trusted". May influence entrepreneurial, creative and innovative abilities.	Social	
Feeling of Happiness. Index constructed using scales for each happiness level. Index from 3 (Very happy) to 0 (Not happy).May influence entrepreneurial, creative and innovative abilities.	Social	
Enforcing Contracts: Time. Number of days needed to enforce a contract. Days are counted from the moment the plaintiff files the lawsuit in court until payment. Could be used as a measure of policy and institutional efficiency and quality.	Institutional	
Enforcing Contracts: Cost. Percentage of the claim needed to proceed with it. Could be used as a measure of policy and institutional efficiency and quality.	Institutional	
Finance Freedom Indicator, scored on a 100-point scale (100 - no interference, 0 - repressive government interference). Measures banking efficiency as well as independence from government control and interference in the financial sector. State ownership of banks leads to lower index. May be innovation limiting or enhancing factor based on type of finance available.	Institutional	
Gross fixed capital formation (% of GDP). Includes land improvements, plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings.	Institutional	
Internet users per 1000 people. People with access to the worldwide network divided by the total amount of population for the correspondent year. May improve business infrastructure and benefit overall national creativity and capabilities.	Institutional	
Mobile and fixed-line subscribers. Total telephone subscribers (fixed-line plus mobile) per 1000 inhabitants. May improve overall infrastructure.	Institutional	
% Paved Roads. Paved roads are those surfaced with crushed stone (macadam) and hydrocarbon binder or bituminized agents, with concrete, or with cobblestones, as a percentage of all the country's roads, measured in length. May improve overall infrastructure.	Institutional	
Registered carrier departures worldwide. Domestic take-offs and take-offs abroad of air carriers registered in the country per 1000 inhabitants. May improve overall infrastructure.	Institutional	
Freedom of Press. Index assesses the degree of print, broadcast, and internet freedom in every country in the world, analysing the events of each calendar year. Index from 0 (Total Freedom) to 100 (No Freedom)	Institutional	
Freedom of Speech. Extent to which freedoms of speech and press are affected by government censorship, including ownership of media outlets. Index from 0 (strong censorship) to 2 (no government censorship).	Social	

Physical integrity of human rights. Index constructed from the Torture, Extrajudicial Killing, Political Imprisonment, and Disappearance indicators. It ranges from 0 (no gov. respect) to 8 (full gov. respect).	Social	
Political Rights. People's freely participation in political processes. It ranges from 1 (total free) to 7 (not free). May influence entrepreneurial, creative and innovative abilities.	Social	
Civil Liberties. People's basic freedoms without interference from the state. It ranges from 1 (total free) to 7 (not free). May influence entrepreneurial, creative and innovative abilities.	Social	
Freedom of Association. Extent to which the freedoms of assembly and association are subject to actual governmental limitations or restrictions (as opposed to strictly legal protections). Index from 0 (total restriction) to 2 (no restriction). May influence entrepreneurial, creative and innovative abilities.	Social	
Electoral Self-Determination. Indicates to what extent citizens enjoy freedom of political choice and the legal right and ability in practice to change the laws and officials through free and fair elections. It ranges from 0 (no free) to 2 (total free). May influence entrepreneurial, creative and innovative abilities.	Social	
Index Democracy and Autocracy. In democracy, political participation is fully, competitive, executive recruitment is elective, and constraints on the chief executive are substantial. Autocracies restrict/suppress political participation. It ranges from +10 (democratic) to -10 (autocratic). May influence political and institutional efficiency and quality.	Institutional	
Intensity of Armed Conflicts. It assesses magnitude of conflicts developed within the territory (internal or external). It goes from 0 (no conflict) to 2 (war). May influence entrepreneurial and innovative abilities, political and institutional efficiency and quality.	Economic	
Legislative Index of Electoral Competitiveness. Competitiveness of elections into legislative branches. It ranges from 7 (Countries in which multiple parties compete in elections and the largest party receives less than 75% of the vote) to 1 (countries without or with unelected legislature). May influence political and institutional efficiency and quality.	Institutional	
Executive Electoral Competitiveness. Competitiveness for post in executive branches in government, which takes into account a balance of power between legislature and executive. It ranks from 1 (low comp.) to 7 (high Comp). May influence political and institutional efficiency and quality.	Institutional	

Graph 3: Time series of four innovation proxies (standardized) for selected countries 1980-2008. Source: The existing CANA database.

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