SCIENCE, TECHNOLOGY AND INNOVATION COMPOSITE INDICATORS FOR DEVELOPING COUNTRIES

A Thesis
Presented to
The Academic Faculty

by

Chinawut Chinaprayoon

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Public Policy in the
School of Public Policy

Georgia Institute of Technology
August 2007

SCIENCE, TECHNOLOGY AND INNOVATION COMPOSITE INDICATORS FOR DEVELOPING COUNTRIES

Approved by:

Dr. Susan Cozzens, Advisor
School of Public Policy
Georgia Institute of Technology

Dr. Alan Porter
School of Public Policy
Georgia Institute of Technology

Dr. John Walsh
School of Public Policy
Georgia Institute of Technology

Date Approved: July 9th, 2007

ACKNOWLEDGEMENTS

I am indebted to the members of my thesis committee, Professor Susan Cozzens, Professor Alan Porter, and Professor John Walsh, for their valuable suggestions and comments on draft versions of this thesis. I am also thankful to my family and friends for their supports. All remaining errors in this thesis are my own.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

This thesis aims to propose a policy-relevant science, technology and innovation indicator for developing countries. I firstly develop a model to examine the determination of innovativeness for a sample of 38 developing countries, based on endogenous growth theory and innovation systems literature. From econometric estimation, I find that R&D inputs, technology imports, and international connectedness are influential determinants of innovativeness in these countries. From this finding, I develop the Predicted Innovativeness Index for Developing Countries (*INNÔDEX*), a composite indicator that ranks countries according to their innovative capabilities.

.

CHAPTER 1

INTRODUCTION

"*The Commission observed that in many least developed countries, there is still a lack of appreciation of the critical role that science and technology plays in development. The Council thus calls on national governments to ensure that science, technology and innovation strategies are incorporated in national development strategies, especially those addressing in the Millennium Development Goals. To this end, it is recommended that countries review and upgrade their existing science, technology and innovation policies, with a view to making them more effective in serving the specific needs of national development goal*" (Commission on Science and Technology for Development, United Nations, 2006)

Science, technology and innovation (STI) policies have played an increasingly important role shaping our knowledge-based society, and it has been recognized that countries need to upgrade their technological capabilities in order to remain competent in today's world economy. The recommendation made by United Nations above delivers a clear statement that such development is strongly needed for developing world. However, as UN requested these developing countries to *review and upgrade their existing science, technology and innovation policies*, these countries need to be capable of evaluating impacts of their exiting STI policies. They also need potential to assess the level of their STI capacities to order to develop new policies and to benchmark these capacities with more successful countries in order to catch up. In other words, they need to have efficient and effective measures of science, technology, and innovation, simply referred to STI indicators.

STI indicators have been developed over time since 1950s, especially through the effort of the Organization of Economic Cooperation and Development (OECD). However, most of the existing STI indicators are more compatible to developed countries context. Only until recently that there have been attempts to construct STI indicators which are more appropriate with developing world. In addition, developing countries are usually constrained by their lacks of financial resources to facilitate the collection of STI statistics. Therefore, STI indicator systems in developing countries still need to be fulfilled. Besides, the globalization phenomenon has increase the demand for using such indicators. Globalization intensifies the competition among nations in almost all aspects, and it is believed that only countries operate at technology frontiers will be real champions. Inarguably, developing countries need immediate measurement of their STI capacities in order to be able to tailor their STI policies that help upgrade their technological capabilities.

In response to this need, this paper aims to develop policy-relevant STI indicators for developing countries, with specific focus on STI composite indicators that provide “the overview of technological capabilities for developing countries”. On one hand, this study intends to develop a model to examine relevant determinants of innovativeness in developing countries. Later, this study intends to use such model to construct robust STI composite indicators for developing countries.

CHAPTER 2

LITERATURE REVIEW

International community has long been employing individual indicators to assess and monitor national technological capabilities and also used them to compare and benchmark against other countries. The most widely-used indicators to date are R&D expenditures that are used to determine the "scientific and technological intensity" of countries (e.g. R&D expenditure as percentage of GDP). Other universally employed indicators include science and technology workforce, high education enrollment, scientific journal publications and citations, intellectual property statistics, technology balance of payments, and high technology trade values.[1]

However, these individual STI indicators are mostly for either input or output measurement. One notorious problem of using these indicators singularly is that, quite often, policymakers employ these indicators on the basis of "research-in, technology-out." (UN, 2003b) In other words, they sometimes perceive innovation outputs and other technological advancements as products of linear production process driven by the supply of R&D resources and other inputs.[2] As they lift up the level of supplies of inputs, they expect that countries will be moving to achieve higher level of technological capabilities (UNU-INTECH, 2004). In contrast, recent theories based on evolutionary economics suggest that innovation outputs and other technological achievements are not simply the results of increases in certain inputs but are rather the

---

[1] For a comprehensive survey of STI indicators, see UN (2003b)
[2] These conventional economic models of innovation sometimes are referred as "the pipeline model of innovation." (UN, 2003b)

products of complex and interrelated activities of productive system. The environment in which these activities are supported and empowered is referred as "national STI system", which incorporates "the body of policies, regulations, institutional and infrastructure arrangements and activities concerned with the creation, acquisition, dissemination and utilization of scientific and technological knowledge" (UN, 2003b)

As the competitiveness of nations becomes more technological-oriented and existing statistics are often inadequate to measure STI activities in globalized era (Colecchia, 2006), several international organizations have initiated to come up with new STI indicators that can facilitate policy development in knowledge-based economy. The OECD, regarded as the most active organizations devoting to develop STI indicators, is among the frontrunners, as it addresses in the background paper of the Blue Sky II Forum[3] that:

"*The Science and Technology Ministerial in 2004 confirmed the need to develop a new generation of indicators which can measure innovative performance and other related output of a knowledge based economy with special attention to the data required for the assessment, monitoring and policy making proposes*" (Colecchia, 2006)

As OECD initiates to develop new STI indicators, on the global scale, United Nation Educational, Scientific and Cultural Organization (UNESCO), through its Institute of Statistics (UIS), launched "the Immediate, Medium and Longer-term

[3] The OECD Blue Sky II Forum entitled "What Indicators for Science, Technology and Innovation Policies in the 21st Century?" was taken place in Ottawa, ON during September 25 – 27, 2006. As stated in OECD website, "The Blue Sky II 2006 Forum examines new areas for indicator development and set a broad agenda for future work on science, technology and innovation (STI) indicators. Emphasis is placed on indicators of outcomes and impacts in order to support monitoring, benchmarking, foresight activity, and evaluation, applied to policies and programs, and their economic and social impacts (http://www.oecd.org/document/24/0,2340,en_2649_34451_37075032_1_1_1_1,00.html)"

Strategy in Science and Technology Statistics" in 2003 to prioritize the need for STI statistics in international development. In contrast to OECD, the special consideration is given to developing countries, as UIS addresses that:

"*Government should promote the further development or setting up of national statistical services capable of providing sound data, disaggregated by gender and disadvantaged groups, on science education and R&D activities that are necessary for effective S&T policy making. Developing countries should be assisted in this respect by the international community, using technical expertise of UNESCO and other international organizations*." (Science Agenda – Framework for Action, World Science Conference, Budapest, 1999 cited in UNESCO, 2003)

Its two major goals behind this strategy is "to revitalize efforts at both the international and national levels to construct S&T statistical system that is highly responsive to policy development" and "to strengthen UNESCO's role in process of standardizing and harmonizing international S&T statistics" (UNESCO, 2003). In the immediate term, UIS intends to collect data on "input indicators" including human resource indicators and financial resource indicators. Furthermore, it will give special attention to statistical capacity building in developing countries. In the medium term, UIS, in collaboration with OECD and Eurostat, will give special focus on innovation indicators at global scale. UIS also intends to adapt international methodologies and indicators that are more relevant to developing countries, such as measurement of innovation in agricultural sector, measurement of regional innovation systems, and measurement of incremental innovation. Eventually, in the longer term, UIS intends to collect comprehensive *output indicators*, including scientific outputs, bibliometric data, and technology outputs and impact indicators, including social impact indicators, public perception towards S&T, and indicators for STI impacts by sectors. (UNESCO, 2003)

2.1 Innovation Survey and Developing Country Initiatives

Despite its initiative, UIS currently produces only "hard statistics" for science, technology, and innovation, providing aggregate data at the country level. It is apparent that UIS will be unlikely to achieve its strategic goals in the near future[4]. Another trend towards indicators of STI capacities emerged recently is the adoption of "innovation survey" to measure science, technology and innovative activities at firm level. The innovation survey was firstly developed by OECD countries and the first international standard for innovation survey was also prepared by OECD, in collaboration with the Statistical Office of the European Communities (Eurostat). It is known as the Oslo manual, with the development of Community Innovation Survey (CIS) based on this manual. The Oslo manual was introduced in 1992 and has been revised overtime. The latest version of Oslo manual is the third edition completed in 2005. Based on the Oslo manual, the CIS has been carried out across Europe for several times. Innovation surveys are considered effective tools providing policy relevant information on innovative capacities and technological performance of nations. As a result, during the past decade, many developing countries and other non-OECD countries have also employed innovation surveys, and most of these surveys

[4] Godin (2001b) identifies problems that impede UNESCO's ambition to complete international science and technology statistics. He argues that, contrary to the case of OECD, "the real difficulty facing UNESCO was the absence of a community of views between UN member countries".

were guided by the Oslo manual. Until 2004, a total of 21 developing or non-OECD countries have carried out innovation surveys (UNU-INTECH, 2004)

However, there are major concerns for conducting innovation surveys in developing countries using developed countries standard and procedures. The pattern of innovative process in developing countries is different from developed ones and even different among themselves. While the adoption of the Oslo manual has been praised for bringing harmonization in STI data, it leads to the less relevant innovation surveys for developing countries. As a consequence, there are recent attempts by groups of developing countries to devise innovation survey that truly response to their needs.

The most significant attempt to develop an innovation survey manual for developing countries was initiated in Latin America by the Iberoamerican Network of Science and Technology Indicators (RICYT) and the Columbian Institute for the Development of Science and Technology (Colciencias). Based on the OSLO manual, they developed innovation survey standard, known as the Bogotá Manual. (UNU-INTECH, 2004) The Bogotá Manual has become the basis of innovation surveys carried out in Latin American countries. Furthermore, the Bogotá manual also inspires the development of the Annex of the Oslo manual third edition, which layouts the guideline for conducting innovation surveys in developing countries. Essentially, the Bogotá manual and the Annex of the Oslo manual focus on four characteristics of the innovation process in developing countries (Intarakumnerd and Viotti, 2006), including the acquisition of embodied technology, minor or incremental innovation, organization innovation, and innovation in agricultural sector.

Another strong initiative has begun in Africa, where the New Partnership for Africa's Development (NEPAD), in collaboration with the United Nations University Institute for New Technologies (UNU-INTECH)[5], determines to develop a common framework and methodology for a policy-relevant innovation survey for the region. The goals of this initiative are "to enhance policy relevance of the innovation survey, to emphasize on processes of learning, linkages and investment by actors within the innovation system, and to assure the quality of data" (UNU-INTECH, 2004). NEPAD also initiates to develop the African Science, Technology and Innovation Indicators (ASIII) and African Indicator Manual and aims to publish the African Innovation Outlook (AIO) that will become a regional STI database for public use. ASIII composes of core indicators (including knowledge creation, knowledge transfer, knowledge use, knowledge infrastructure, and knowledge governance) and wider scope indicators, while the African Indicator Manual will be based on the study done by UNU-INTECH (NEPAD, 2005).

Apart from Latin America and Africa case, other initiatives to develop policy-relevant innovation survey for developing countries are very at starting points. The Association of Southeast Asian Nations (ASEAN) declares its interest to develop STI indicator system, but the main focus is still on the development of STI composite indicators (Intarakumnerd and Viotti, 2006). The United Nations Economic and Social Commission for Western Asia also produces a plan to establish the national database on STI indicators for Western Asian countries (UN, 2003b). It also promotes the implementation of "knowledge management methodology" in its member

[5] This institute has later become known as UNU-Merit, a joint research and training centre of United Nations University (UNU) and Maastricht University, The Netherlands.

countries, based on the consideration that knowledge is a source that can create wealth and enhance quality of life (UN, 2003a). However, so far there is no attempt to develop the standard for innovation survey in ESWAR countries. Another UN agency, the United Nations Economic Commission of Latin America and the Caribbean (ECLAC), determines to encourage its member countries to better the design, data collection and treatment of innovation surveys and expects for more standardized information. (Intarakumnerd and Viotti, 2006)

Another significant attempt to bring all developing countries together for the development of STI indicators is initiated by the Indicator Group of the Catch-up Project. Intarakumnerd and Viotti (2006) released a proposal to develop new STI indicators that are more appropriate for catching-up economies. In their proposal, they develop a timeline for the project. They propose to organize brainstorming sessions to come up with appropriate STI indicators, following by the implementation of pilot innovation survey. The innovation survey will then be evaluated and revised, follow by the development of guidelines for collecting and interpreting innovation survey (Intarakumnerd and Viotti, 2006).

2.2 Composite Science, Technology Composite Indicators

Despite the strong trend towards the implementation of innovation surveys in developing countries, it can take years for these countries to devise such effective and relevant surveys. Policymakers in developing countries still need to rely heavily on ‘hard statistics’[6] to tailor their STI policies. Another popular trend of using hard statistics is to select and combine them, sometimes even with survey of opinions, into meaningful composite indicators. The composite indicators are used primarily to create awareness of opportunities, threats, and challenges on national basis. Policymakers use composite indicators to identify policy actions and strategies to enhance national capabilities to compete with other nations in the world borderless economy. (UN, 2003b)

The most widely known composite indicator to date is gross domestic product (GDP), which indicates a country’s performance to generate goods and services. There are other composite indicators that are used in various fields, such as a business climate indicator, a risk assessment indicator, and an environmental sustainability index. One of the most obvious benefits of composite indicators is to provide an overview of a country’s performance based on various factors, especially important in the era of diverse knowledge-based economy. However, there are many drawbacks of employing composite indicator techniques, essentially if the policymakers fail to interpret the information from composite indicators correctly and thoroughly. Saisana (2004) and Nardo *et al* (2005a) have summarized advantages and disadvantages of composite indicators, as shown in Table 2.1.

[6] Hard statistics refer to data that are collected on country aggregated level (from entire population when country is a unit of analysis). In contrast, Survey of opinion is referred as “soft data” and is usually collected from survey samples (not entire populations).

Table 2.1: Advantages and Disadvantages of Composite Indicators

Advantage	Disadvantages
• Summarize complex or multi-dimensional issues. • Are easier to interpret than trying to find a trend in many separated indicators. • Place countries' performance at the centre of policy arena. • Offer a rounded assessment of countries' performance. • Enable judgments to be made on countries' efficiency. • Facilitate communication with ordinary citizens. • To be used for benchmarking countries of best performances. • To indicate which countries represent the priority of improvement effort • To stimulate the search for better data and better analytical efforts.	• May send misleading, non-robust policy messages • May invite stakeholders to draw simplistic conclusions. • Involve judgmental decision • Increase quantity of data needed • May disguise serious failings in come parts of some systems. • May rely on very feeble data in some dimensions • May ignore dimensions of performance that are not measurable and lead to wrong policies.

Source: Quoted from Saisana (2004) and Nardo *et al* (2005a)

For science and technology policy community, the composite indicator approach has recently been adopted by various studies by combining individual STI indicators into indices that provide the overview of national technological performance. The development of STI composite indicators is reflected the shared perception that there is no single number that could be used to measure national technological capabilities. Archibughi and Coco (2005) state that "one of the key features of technology is its variety". In other words, technological capabilities are composed of heterogeneous elements, including research activities, research infrastructures, knowledge stock, human resources, and other components (Archibughi and Coco, 2005). Therefore, one cannot use a single targeted indicator to explain technological capabilities of a nation. Especially for developing countries, the use of targeted indicators alone provides little information regarding their stages of technological development, as Wagner *et al* (2002) argue that:

"*While it is possible to list countries solely by the percentage of investment in GERD, or by scientific papers or patents, which are direct measures of the outcome of S&T, many countries would not be represented in such a list. This would not represent a measure of capacity; it would be a measure of outcomes. Such a list would provide little insights into the ability of less developed countries to conduct science and technology in the future, to join international collaborations, or to use existing resources to build additional capacity*" (Wagner *et al*, 2002)

The complexity of technology makes composite indicators useful, though the construction of composite indicators has to deal with various technical issues, including the selection of components, the method of calculation and weights, the treatment of missing values, etc. Only composite indicators that are built upon sound methodologies can be beneficial, otherwise such indicators can deliver flawed messages to policymakers, leading to the introduction of mistaken policies. To the most publishers of STI composite indicators, they agree upon that composite indicators should not be used as goals; rather such indicators should be used to capture public concern (Nardo *et al*, 2005a; Archibugi and Coco, 2005). Furthermore, composite indicators are not developed to replace targeted indicators. Instead, policymakers should use composite indicators as the supplements to targeted indicators.

The creation of STI composite indicators is based on several assumptions. Composite indicators built in this paper share the common ground with others, as discussed by Archibugi and Coco (2005), that international comparisons are meaningful, regardless their differences in social, cultural and geographical contexts. Furthermore, various statistics on technological capabilities can be aggregated, given that each individual indicator is a complimentary rather than a substitute to each other (Archibugi and Coco, 2005).

Although composite indicators subject the several limitations, many of them have already proven to bring attention from policymakers. The best examples are the works of World Economic Forum (WEF) and International Institute for Management and Development (IMD). Their indicators on international competitiveness, which are released annually, have consistently drawn interest from policymakers around the world. Many countries even compete to improve their positions in WEF and IMD leagues. (Intarakumnerd and Viotti, 2006)

IMD is the first organization to develop international competitiveness series. Its World Competitiveness Yearbook (WCY) has been published since 1989 aiming to "analyze and rank the capability of nations to create and maintain an environment that sustains the competitiveness of nations". The current issue (WCY 2006) provides the ranking for 61 economies (IMD, 2006). The index is based from 4 components, including economic performance (77 criteria), government efficiency (72 criteria), business efficiency (68 criteria), and infrastructure (92 criteria). These components include both hard statistics and opinion survey data.

WEF has consistently published its Global Competitiveness Report (GCR) since 2001 and the publication currently includes two measures of competitiveness of countries, using both hard statistics and opinion survey. The first indicator is the

Growth Competitiveness Index (Growth CI) developed by Jeffrey Sachs and John McArthur in 2001 aiming to assess the competitiveness of nations. Growth CI is a combined indicator from 3 component indexes, namely technology index, public institution index, and macroeconomic environment index. (WEF, 2001) WEF uses different formulas to calculate Growth CI for two different groups of countries, referred as core and non-core economies. However, the recent versions of WEF reports have replaced Growth CI with its predecessor, the Global Competitiveness Index (GCI).[7] GCI is advanced by Sala-i-Martin and Artadi (2004) aiming to adjust methodology used in the Growth CI for a more coherent one. The GCI provides a holistic overview of determinants that drive productivity and competitiveness of nations. GCI comprises of data from 9 categories, including institutions, infrastructure, macroeconomy, health and primary education, higher education and training, market efficiency, technological readiness, business sophistication and innovation (WEF, 2006).

However, there are several concerns of using these competitiveness indicators, especially from developing countries. One of the major critics is from Lall (2001). Lall argues that the definitions of competitiveness used in WEF analyses are too board and the methodology is questionable. He continues that the board definition of "competitiveness" creates little analytical advantage, while the flawed methodology makes the competitiveness ranking unreliable and unjustifiable. According to Lall, the assumption of WEF indexes that markets are efficient ignores the consequence of market failure condition existing almost everywhere, especially in developing countries. Furthermore, the data collection and aggregation processes are also

[7] WEF keeps reporting the Growth CI in the appendix of the report. (WEF, 2006)

"disappointed", since "data are not collected rigorously, and are likely to be misleading as a base for ranking countries" (Lall, 2001). He concludes that these competitiveness indicators fail to provide useful information on the core driving forces that enhances to competitiveness of nations, especially scientific and technological capabilities.

Recently, there are several attempts to measure national technological capabilities based on the composite index approach. One key feature that distinguishes STI composite indicators from competitiveness indicators is that the latter also include the measurement of production capacity of an economy. According to Archibugi and Coco (2005), there is a consensus that differentiates technological capabilities from production capacity. While the two concepts are strongly interconnected, technological capabilities are specific to the generation and diffusion of the stock of knowledge.

The well-known STI composite indicators include attempts by United Nations agencies, other international organizations, as well as individual scholars. Indicators considered here include the WEF Technology Index (WEF, 2001; 2002; 2003; 2004; 2005; 2006), the National Innovative Capacity Index (Porter and Stern, 2003 in WEF eds, 2003), the Rand Science and Technology Capacity Index 2002 (Wagner *et al*, 2002), the United Nations Development Program (UNDP) Technology Achievement Index (UNDP, 2001; Desai *et al*., 2002), the United Nations Industrial Development Organization (UNIDO) Industrial Scoreboard (UNIDO, 2003; UNIDO, 2004; Lall and Albaladejo, 2003), the UNIDO Industrial-cum-technological-advance (UNIDO, 2005), the New Indicator of Technological Capabilities for Developed and Developing Countries (ArCO) (Archibugi and Coco, 2004), the European Innovation

Scoreboard (European Commission, 2004), and the Georgia Tech High Technology Indicators (HTI). (Porter *et al*, 2002; Porter *et al*, 2005)

WEF Technology Index was the component of the WEF Growth Competitiveness Index. (WEF, 2001) It is constructed from three technological subindexes: a) innovation subindex (measured by patents grated at USPTO, gross tertiary enrollment rates, and survey data) b) technology transfer subindex (measured by technology-in-trade residual and survey data) and c) information and communication technology (ICT) subindex (measured by telephone, internet, personal computers, and survey data). WEF has two formulas to calculate the Technology Index for technological core economies and technological non-core economies. The core technology index is base on only innovation and ICT subindexes, while the non-core technology index is a combination of all three subindexes.

National Innovative Capacity Index (NICI) is developed by Michael Porter and Scott Stern and published in the WEF Global Competitiveness Report (WEF, 2003). They defined national innovative capacity as a country's potential, as both a political and economic entity, to produce a stream of commercial relevant innovations. They point out that national innovative capacity is distinct from the ordinary meaning of technological achievement as it focuses on the economic application of new technology. NICI is based on Porter's famous diamond model. Porter and Stern (2003) argue that this model represent the basic framework constituting national innovative capacity. NICI is a combination of five subindexes: a) the innovation policy subindex; b) the cluster innovation environment subindex; c) the scientific and engineering manpower subindex; d) the linkages subindex; and e) the company operation and subindex. Most of data are obtained from the WEF Executive Opinion Survey.

Table 2.2: Lists of Existing STI Composite Indicators and Their Subindexes.

Authors	STI composite indicators	Sub-indexes/ Systems Indexes/Grouped factors
WEF (2001)	Technology Index (for Core and Non-Core Economies)	• Innovation subindex • Technology transfer subindex • Information and communication technology subindex
Porter and Stern (2003); WEF (2003)	National Innovative Capacity Index	• Innovation policy subindex • Cluster innovation environment • Scientific and engineering manpower subindex • Linkages subindex • Company operation and subindex.
Wagner *et al* (2002)	Science and Technology Capacity Index 2002	• Enabling factors • Resources • Embedded knowledge
UNDP (2001) ; Desai *et al* (2002)	Technology Achievement Index	• Creation of new technology • Diffusion of recent innovations • Diffusion of old innovations • Human skills
UNIDO (2003); UNIDO (2004); Lall and Albaladejo (2003)	UNIDO Industrial Scoreboard	• technological activity • competitive industrial performance • technology imports • skills and ICT infrastructure
UNIDO (2005)	Industrial-cum-technological-advance	• Industrial advance • Technological advance

Table 2.2 (Cont.): Lists of Existing STI Composite Indicators and Their Subindexes.

Authors	**STI composite indicators**	**Sub-indexes/ Systems Indexes/Grouped factors**
Archibugi and Coco (2004)	The New Indicator of Technological Capabilities for Developed and Developing Countries (ArCO)	• Creation of technology • Technological infrastructures • The development of human skills
European Commission (2004)	European Innovation Scoreboard and The Summary Innovation Index (SSI)	-
Porter *et al* (2005)	Georgia Tech High Technology Indicators (HTI) – One composite Input Indicator (IN) / One output Indicator (TS)	*Input indicators* • National Orientation (NO) • Socio-economic Infrastructure (SE) • Technological Infrastructure (TI) • Productive Capacity (PC) *Output indicator* • Technological Standing (TS)

Source: Author's collection

Science and Technology Capacity Index-2002 (STCI-02) was advanced by Wagner *et al* (2002) for Rand Corporation and aims "to measure the extent to which a country can absorb and use scientific and technological knowledge" This index is based on the Rand Corporation's S&T Composite Index 2000 developed by Wagner *et al* (2001). STCI-02 covers 76 countries. To construct the index, eight quantitative indicators were selected, aggregated and then divided into three domains of S&T capacity: a) enabling factors (based on GDP per capita and tertiary enrollment in science); b) resources (based on number of scientists and engineers, number of institutions and R&D expenditures); c) embedded knowledge (based on patents, S&T journal articles and coauthorship publications). STCI-02 is created as the combination of these eight indicators. Furthermore, Wagner *et al* (2001) test different weighting schemes to increase the robustness of the index. Until now, there is no proposal to build this index on periodical basis.

Technology Achievement Index (TAI) was developed by Desai *et al* (2002) and introduced earlier by UNDP in its 2001 Human Development Report (UNDP, 2001). TAI focuses on assessing a country's technological performance based on its capacity in creating and using technology but not on measuring countries' technological development. In doing so, TAI first evaluate technological achievements of a country in four dimensions. Each dimension is based on two targeted indicators, namely a) creation of new technology (based on number of patents granted per capita and receipts of royalty and license fees from aboard per capita); b) diffusion of recent innovations (based on internet host per capita and high and medium technology exports as a share of total exports; c) diffusion of old innovations (based on telephones per capita and electricity consumption per capita) and d) human skills (based on mean years of schooling and tertiary enrollment in science, mathematics and engineering). With data limitations, TAI was only calculated for a set of 72 countries. Also, we should be noticed that the development of TAI is aimed to satisfy two particular concerns. Firstly, the design of TAI reflects “national policy concerns, regardless of technological development.” Secondly, the TAI attempts to “discriminate between countries at the lower end of the range to ensure that the indicator is useful for developing countries as well” (UNDP, 2001 cited in UN, 2003b) However, the later versions of the UNDP Human Development Report have discontinued to report TAI.

Industrial Development Scoreboard was developed by UNIDO and published in its Industrial Development Report (IDR). (UNIDO, 2003; UNIDO, 2004) UNIDO’s effort is strongly influenced by the work of Lall and Albaladejo (Archibugi and Coco, 2004) Lall and Albaladejo take into account four categories of the drivers of industrial performance: a) technological activity (based on R&D financed by productive enterprise and number of patents registered at USPTO) b); competitive industrial performance (based on manufactured value added (MVA) per capita, manufactured export per capita, and the share of medium and high technology (MHT) in manufactured exports); c) technology imports (based on FDI, foreign license payments and capital goods imports) and d) skills and ICT infrastructure (based on technical enrollment at the tertiary enrollment in science, engineering and mathematics and computing and telephone mainlines). Based on Lall and Albaladejo (2003), UNDP published IDR 2002/2003 and IDR 2004 with special effort given to competitive industrial performance (CIP) index[8]. (UNIDO, 2003; UNIDO, 2004) The 2002/2003 issue publishes CIP index for 87 countries and the 2004 issue extends to

---

[8] Results present in IDR 2002/2003 are based on Lall and Albaladejo (2003)

cover 93 countries. However, the IDR 2005 discontinued the report of CIP index, but it still reports six indicators of industrial performance, including MVA per capita, manufactured export per capita, share of manufactured export in total output (GDP), share of MHT production in MVA, and share of MHT in manufactured export. The 2005 report also develops a new index of industrial and technological advancement, called industrial-cum-technological advance (ITA), which represents another strong efforts to develop STI indicators for developing economies.

Industrial-cum-technological advance (ITA) was developed by UNIDO and published in its Industrial Development Report 2005 (UNIDO, 2005). ITA is a structural index aiming to capture core characteristics of an economy focusing on the role that industry and technology and their interactions and to provide alternative indicators for catching up economies. ITA is a product of four performance indicators for industrial development, which are firstly categorized into two dimensions. These include the share of manufacturing in GDP and the share of manufactures in total export, which jointly constitute the "industrial advance" dimension of countries, and the share of medium-or-high technology activities in manufacturing value added (MVA) and the share of medium-or-high technology activities in total export, which jointly constitute the "technological advance" of countries. The results of ITA are quite striking, with some of the developing countries are ranked as the "high performers" ahead of many industrialized nations. The plan to report this indicator on periodical basis is still not identified.

European Innovation Scoreboard (EIS) and its *Summary Innovation Index (SII)* are the product of the European Commission (European Commission, 2004). EIS is the instrument developed to evaluate and compare the innovative performance of European Union (EU) member states. Its current edition, EIS 2005*,* include innovation indicators, including Community Innovation Survey (CIS) indicators and non-CIS indicators, and trend analysis for 25 EU member countries and 8 non-EU countries. The Summary Innovation Index (SSI) is calculated by combing 19 non-CIS innovation indices. It is noteworthy that there is a technical adjustment for SSI in EIS 2005. The EIS 2006 is expected to publish in November 2006, with more reports on innovation indicators drawn from CIS 3.

High Technology Indicators (HTI) was developed by Alan Porter and David Roessner at the Georgia Institute of Technology and has been recently revised (Porter *et al*, 2005). Since the last adjustment, HTI now composes of 4 input indicators, a composite input indicator, and an output indicator. The input indicators include National Orientation (NO), Socio-economic Infrastructure (SE), Technological Infrastructure (TI) and Productive Capacity (PC). HTI 2005 introduces the new composite input indicator (IN), which combines four input indicators together and HTI 2005 keeps reporting an output indicator, Technological Standing (TS), which is an indicator of a country's recent overall success in exporting high technology products. HTI draws data both from hard statistics and an international survey of expert opinions from 33 countries to construct each indicator. Porter *et al* (2005) report both traditional HTI indicators, which combine statistical data with survey data to compute the indicators, and statistics-only HTI indicators, which use only statistical data to compute the indicators. According to Porter *et al* (2005), the current plan is to produce HTI every two years, in compliance with Science and Engineering Indicators series published by National Science Foundation (NSF).

The New Indicator of Technological Capabilities (ArCO) was developed by Archibugi and Coco (2004). It takes into account three dimensions of technology: a) creation of technology (based on patents registered at USPTO and scientific articles);

b) technological infrastructures (based on internet penetration, telephone penetration and electricity consumption); c) the development of human skills (based on tertiary science and engineering enrollment, mean years of schooling, and literacy rate). The main thrust of developing this indicator is to provide the measurement of technological capabilities that accounts for both developed and developing countries. As many as 162 countries are included in this indicator. Furthermore, Archibugi and Coco (2004) attempts to elaborate this indicator by including another influential component i.e. the technology import (based on FDI, technology licensing payments, and capital goods imports), as introduced by Lall and Albaladejo (2003). However, after this technology import variable was utilized, the number of countries included in the indicator fall to 86 countries, due to data limitations. In their later article (Archibugi and Coco, 2005), the authors state their interest to develop time series for this indicator, but the actual plan is yet to be considered.

Archibugi and Coco (2005) compare methodologies and country rankings from several studies, including WEF Technology Index, UNDP Technology Achievement Index, UNIDO Industrial Scoreboard, Rand Corporation Science and Technology Capacity Index, and their own ArCO index. They examine the correlation between rankings of each indicator and find that these rankings are broadly comparable, although they have a few significant differences. Among these composite indicators, WEF Technology Index has the lowest correlation with others, while ArCO index is found to have high correlations with UNDP Technology Achievement Index and Rand Corporation Science and Technology Capacity Index. It is noteworthy that they also found that most of components used in these composite indicators share many similarities, as they state that:

"The attempt reviewed here share many similarities, and this is certainly encouraging. These similarities reflect the certain consensus on the nature of technology, although some cases were kept implicit rather than explicit. We are also aware that in many cases the choices have been dictated by availability of the statistical sources rather than by theoretical preferences" (Archibugi and Coco, 2005)

We should notice that these similarities are the products of similar methodologies used in these studies. Individual indicators used in WEF Technology Index, UNDP Technology Achievement Index, RAND Science and Technology Capacity Index, and ArCO Index are largely overlapped. The calculating procedures are quite similar. Therefore, it is expectable to have high correlations among these rankings.

For all of composite indicators discussed in this chapter, even though many of them attempt to account for developing economies, only three of them, namely STCI-02, ITA and ArCO, that produce nearly completed set of indicators for developing countries. Furthermore, from all previous studies, there are several critical points that should be taken into account regarding these previous studies.

First of all, the two most important things for the construction of composite indicators are 'what components to include' and 'how to weight each component'. Most STI composite indicators are developed in early 2000s when data on many crucial factors, such as R&D expenditures, are not widely available for developing countries. Furthermore, most of STI composite indicators use simple arithmetic means to weight each component. As more statistics have become available, it is possible to include these statistics in composite indicators as well as to use a more rigorous weighting procedure to construct a STI composite indicator.

Second, most of the STI composite indicators measure technological capabilities by aggregating input with output indicators together. The mixing of input and output statistics into composite indicators produces only limited analytical information. I believe that composite indicators that are constructed with a more systematic framework, e.g. the Georgia Tech High Technology Index, are more useful in terms of public use. Porter and Stern (2000) develop one for OECD countries, but there is none in term of developing countries.

Last but not least, developing countries are different animals form developed ones. Most of the previous studies based their perception of technology advancement on the context of developed economies. For example, patent statistics are perceived as the most relevant innovation output indicator for the construction of most composite indicators. In fact, patents are not only major sources of innovation outputs in developing economies. Rather, productivity gains in developing countries are more subjected to minor or incremental technological changes. As suggested by Intarakumnerd and Viotti (2006), the measurement of technological capabilities such as "the diffusion of imported technologies" might not be as important to developed countries as to developing countries. Therefore, developing countries deserve to have their own STI composite indicators based on a set of components that are relevant to their context. Again, the availability of data is still a problematic issue here.

This paper aims to respond to the critical points above. The next chapter is devoted to the development of methodology that will be employed to construct a robust a STI composite indicator for developing countries. Chapter 4 will report the finding on factors that should be used to calculate the new STI composite indicator. Chapter 5 reveals the new STI composite indicator developed by this paper and compares it with previously-developed indicators.

CHAPTER 3

DETERMINANTS OF INNOVATIVENESS IN DEVELOPING COUNTRIES: A CONCEPTUAL FRAMEWORK

In the previous chapter, I have surveyed various attempts to develop science, technology and innovation indicators in recent years. This chapter will focus on the methodological concept that will be used to construct a STI composite indicator for developing countries, which I thereafter call it "the Innovativeness Index". More specifically, this chapter aims to develop "models of innovative capability of developing countries" based on two sets of theories, endogenous growth model on one hand, and systems of innovation on the other. In doing so, econometric models will be employed as tools for constructing the policy-relevant Innovativeness Index for developing countries.

3.1 Theories on the determinant of innovation

The two strands of economics theory have gained their prominences in policy researches during the last decades, including "national innovation systems theory" and "endogenous growth theory" as these theories treated national technological capability as a country's major source of international economic competitiveness. Systems of innovation school, based on the evolutionary theory of economics, provides a holistic approach to understand the creation of innovation and technological change as a result of the complex, sophisticated interactions among numbers of actors under a given institutional environment (Lundvall, 1992; Freeman, 1993; Nelson, 1993). Generally speaking, system of innovation is defined as composing of "all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations" (Edquist, 1997). Thus, the systems approach rejects the idea that innovation is an outcome of linear production process of "research in, technology out." Instead, the theory suggests a set of important factors that should be included in the analysis of determinants of innovation and technological change. As reviewed the previous chapter, the development of recent STI composite indicators have been influenced by and complimented to this theory.

Endogenous growth theory, initiated by Romer (1990), greatly challenges our view towards innovation and technological change (Ulku, 2004). In this model, innovation (defined as a new design used to produce new products) is created in the knowledge-based sectors utilizing skilled human capital and existing knowledge stock. Based on this theoretical framework, most of the empirical studies try to discover the influences of R&D variables on total factor productivity (TFP), the indicator of a country's production efficiency and its ability to compete in the world market. Only recently, several authors, including Porter and Stern (2000) and Ulku (2004), start to examine determinants of innovation, which is exclusively at the heart of the theory.

The Romer's model draws on critical premises that "economic growth is driven by technological change, technological change is market-driven actions, and innovation (new technological designs) used to produce new product are non-rival" (Ulku, 2004). In this model, the creation of innovation is evolved in R&D sectors, where innovation (Å) is a function of the human capital in R&D sectors (H) and the initial stock of knowledge in the economy (A). This relationship is illustrated by the following knowledge-based production function.

$$\dot{A} = \delta H_A^{\theta} A \qquad (3\text{-}1)$$

According to Romer, the production of innovation is linear in human capitals in the R&D sectors (Θ = 1) and the initial knowledge stock. This model, in turn, leads to sustainable economic growth for two reasons. Firstly, the more human capitals devoted to the R&D sectors, the more innovations will be created. Secondly, the larger initial stock of knowledge an economy posses, the higher the level of productivity the economy will achieve (Ulku, 2004).

Based on this model, Porter and Stern (2000) and Ulku (2004) test empirically whether innovation is created in the R&D sectors and whether it leads to sustainable economic growth. Porter and Stern (2000) find that innovation is positively related to R&D human capitals and initial stock of knowledge. They also find significant relationship between innovation and total factor productivity growth. In contrast, Ulku (2004) examines several determinants of innovation for 20 OECD countries and 10 Non-OECD countries and finds mixed results on the effect of R&D human capitals on innovation. Ulku (2004) finds that innovation is positively correlated to R&D human capitals only in the case of large-market OECD countries. However, he finds no evidence of constant returns to scale in terms of R&D human capitals, suggesting that innovation does not necessarily lead to sustainable economic growth.

Furman *et al* (2002) have developed a framework based on the concept of national innovative capacity. They integrate common and different features of theories, including endogenous technological change, national innovation systems, and Porter's famed cluster theory, into their novel framework. They differentiate the determinants of innovation into 3 sets of factors. The first set is "common innovation infrastructure", which includes two important determinants of innovation, namely stock of knowledge and R&D human capital, as suggested by endogenous growth theory. The other factors in this first set of variables are mostly suggested by innovation systems theory. The second set is "the cluster specific innovation environment" which includes microeconomic environment factors, as suggested by Porter's cluster framework. The last set is named "the quality of linkages", capturing the relationship between the common innovation infrastructure and cluster-specific environment. The results of their study are consistent with their background study, Porter and Stern (2000). They find the evidence that R&D variables are important determinants of innovation and productivity growth. They also find that the public policies shaping innovation incentive, cluster-specific environment, and quality of linkages are influential determinants of national innovative capacity. Gans and Hayes (2003; 2004; 2005; 2006) employ the national innovative capacity model and confirm the findings of Furman *et al* (2002). In the next section, I operationalize theories and literatures reviewed in this section and the previous chapter into my conceptual framework.

3.2 Conceptual framework

There are several methods for constructing composite indicators, from basic method like simple mean of qualified variables to more rigorous statistical techniques such as data envelopment analysis. One of the most problematic decisions confronting researchers on building a composite indicator is the issue of weighting. In the area of science and technology policy, several composite indicators, including ArCO and

---

[10] Ulku (2004) uses number of patent applications instead of patent grants in his study. However, the correlation between (lagged) patent application and patent grant are very high. The use of either statistics does not affect results.

UNIDO Industrial Scoreboard, assigned weight equally to the qualified variables in their construction of the indices, while some others distribute weights to each component of their composite indicators based on expert opinions. Porter and Stern (2001) is the very first attempt in the field to employ multivariate regression analysis to generate the appropriate weights for each component of their "national innovation capacity index". Gans and Hayes (2006) have argued for the advantage of using the Porter-Stern approach in at least two ways. First, the Porter-Stern approach provides a clear distinction between innovation output (USPTO-granted international patents) and its determinants (common innovation infrastructure, cluster environment, and linkages). Second, the approach entails a scrupulous analysis of weights attached to each determinants of innovation capacity. The Porter-Stern approach uses the actual relationship between innovation and innovative capacity factors to calculate the weights therefore "help avoid an 'ad hoc' weighting of potential determinants" (Gans and Hayes, 2006).

Porter and Stern (2000), Porter and Stern (2001), Furman *et al* (2002) Gans and Stern (2003) Gans and Hayes (2004), Gans and Hayes (2005) and Gans and Hayes (2006) all employ the similar approach to analyze the determinant of innovative capabilities of nations. However, these works based their studies chiefly on OECD samples. Ulku (2004) is the first attempt to discuss about the determination of innovation outside OECD countries. However, the study uses only 10 non-OECD countries that data are supplied through OECD Main Science and Technology database. Furthermore, due to the data limitation, Ulku (2004) does not include R&D variables in his non-OECD regressions. For the first time, this study will apply the endogenous growth-based innovation function to a sample set of developing countries.

As discussed before, the concept used in this study is powered by two sets of economic theories, endogenous growth models and national systems of innovation. The formal model is built on the endogenous growth theory, given the crucial role of R&D variables, while the selection of other factors is influenced by systems of innovation literature. This study, however, does not integrate the popular cluster theory into its analytical models for several reasons. First, developing countries lacks of statistics on microeconomic environment variables. Second, cluster development has been treated as the *ex ante* idea in developed countries but *ex post* in developing countries. Rather, this study recognizes other group of factors as more relevant to developing economies context. For example, since most of advanced technology used by developing countries are not developed locally but imported from developed countries, technology imports should be included in the models.

The main idea used in this study is presented in Figure 3.1 ‘the R&D economy diagram’. The diagram reads “the major source of a country’s international competitiveness is derived from innovation outputs, and innovation outputs are produced using R&D inputs and other enabling factors under a given institutional environment” According to Archibugi and Michie (1998), there are certain links between innovation and international competitiveness. They propose that, firstly, process innovations reduce production cost, hence increasing international competitiveness. Secondly, minor product innovations lead to higher demand for such products in both domestic and foreign markets, while major product innovations create monopolistic power, hence increasing international competitiveness. It should be noted that although the improvement in national innovativeness crucially raise the country’s international competitiveness, the competitiveness is also generated through several channels, such as the reduction in labor costs.

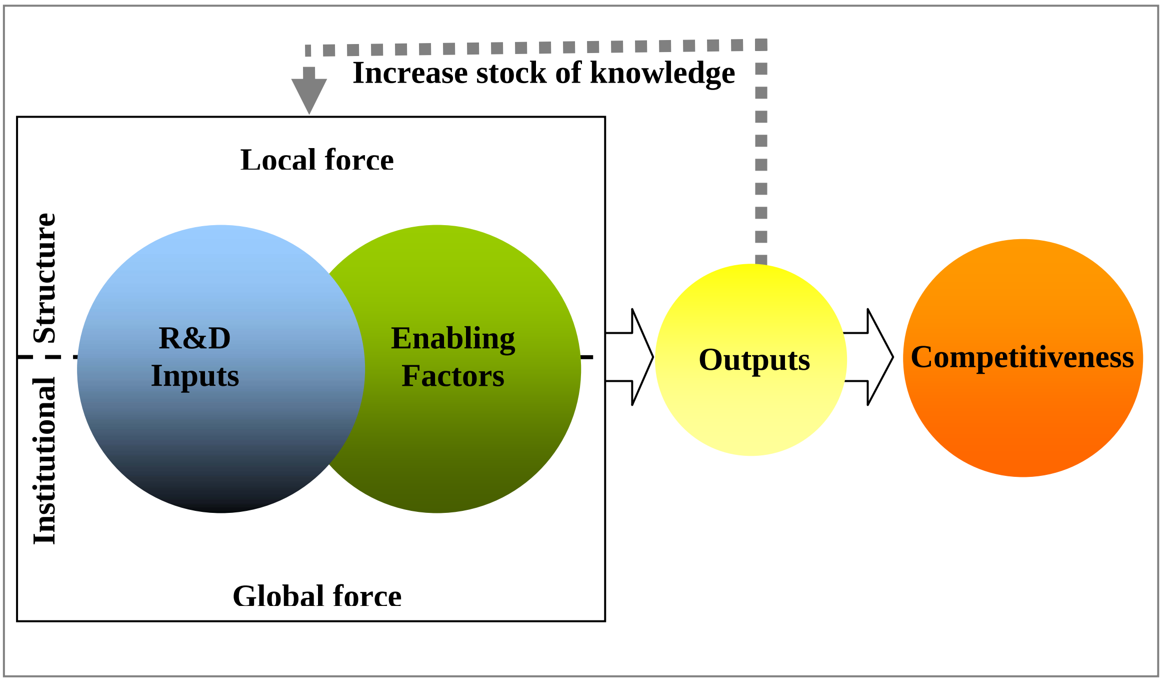

Figure 3.1: The R&D Economy Diagram

Several authors of STI composite indicators have already identified differences among R&D inputs, enabling factors, and innovation outputs. One common character of developing countries recognized by most authors is domestic technological capabilities in these countries are commonly low. Therefore, we have to take into account the role of 'global force' and especially 'technology imports'.

In sum, the model proposed here does not substantially deviate from models formerly used to study technological capabilities in OECD countries (Porter and Stern, 2000; Furman *et al*, 2002; Gans and Stern, 2003; Gans and Hayes, 2004; Ulku 2004;, Gans and Hayes 2005; Gans and Hayes, 2006). Variables used in this paper will be mostly similar to that used in OECD case and that used by other STI composite indicators. The important reason to keep all factors that determines innovativeness in OECD is that technology is dynamic by nature. The more developing countries are able to catch up with developed countries, the more their innovativeness can be measured by the same set of indicators as that of developed countries.

Nevertheless, some factors, e.g. those measuring technology imports, still need to be added since these factors seem to be relevant to developing country context. It is hypothesized that these factors will be significant determinants of innovativeness in developing countries. Furthermore, for the same variables used in OECD models, it is expected that different weights on innovativeness will be found. This is because the structure of science and technology sector in developing countries should be different from developed ones.

3.3 Econometric Model Specifications

Building on Romer's model of endogenous growth, a country's technological capability to innovate can be characterized by R&D production function as shown in equation (3-1), which can represent in log-linear form as fellows.

$$Log(\dot{A}) = Log(A) + \theta Log(H) \qquad (3\text{-}2)$$

As discussed before, this equation implies that a one percent increase in A and H increases innovation (Å) by one percent and Θ percent respectively. In Romer's model, Θ is expected to equal to one, a constant return to scale condition required for sustaining economic growth.

The following econometric model will be used to estimate the effect of R&D variables and other enabling factors on innovation and other output variables, using fixed-effects panel data estimates.

Outputs = f(R&D variables, enabling factors, control variables) (3-3)

Where *outputs* are innovation outputs or indicators, such as patent statistics and high technology exports. *R&D variables* are STI input factors, including stock of R&D expenditures and number of R&D human resources. *Enabling factors* and *control variables* include indicators described in Table 3.1. All variables are normalized by population series in order to account for the size of the economy. As suggested by most of the previous studies, the models take log-log functional form, in order to minimize outlier problems. Therefore, all variables are recalculated into log values for equation (3-3), except for those variables already taking percentage values. Details and definitions of each variable is discussed below and summarized in Table 3.1.

Output factors

Unlike previous study, this paper will utilize several innovation outputs as indicators for a country's innovativeness. I consider 'international patent statistics' and 'scientific and technical journal publication' as innovation outputs since the data are reliable and they have already been used extensively. But, as I argue in the previous chapter, patents and scientific publications might not be only major sources of innovation outputs in developing countries. Therefore, I also employ high technology export as another proxy of technological enhancement in developing countries. Furthermore, this paper, for the first time, uses 'STI composite output indices' developed by various authors to benchmark as output variables in innovation functions. The utilization of these indices follows a general consensus in previous studies on STI composite indicators that no individual indicator can be a perfect measurement of national innovativeness.

(a) Patent statistics

Most of the pioneer studies of the determination of innovativeness use USPTO international patent statistics as a proxy of innovation output (Porter and Stern, 2000; Furman *et al*, 2002; Ulku, 2004). Even though these authors recognize that patent statistics does not represent a perfect measurement of innovativeness of nations, they are all agree that USPTO patent statistics is the reliable and consistent source of innovation output measurement since all inventors face the same regulations on registering their innovation. Furman *et al* (2002) points out the advantage of using USPTO patents that "USPTO-granted international patenting constitutes a measure of technologically and economically significant innovations at the world's commercial technology frontier that should be consistent for all countries".

In this study, I use patents granted at USPTO in a given year as the measure of innovation output, following the work of Furman *et al* (2002) and Gans and Hayes (2005).[10] The use of patent grants need to be lagged to allow time delay between patent applications and patent grants. As suggested by USPTO, the average lag between patent applications and patent grants are approximately 2 years. (Gans and Hayes, 2005)

(b) Scientific and technical journal publications

Several STI composite indicators, including ArCO index and RAND Science and Technology Capacity Index, include number of scientific publications as another STI output indicator to construct their indices. However, there are several concerns of using number of scientific publication as the innovation output indicators, such as the potential bias of the statistics towards English-speaking countries. Nevertheless, since neither patents nor scientific publications are perfect measures of innovation outputs, one can be used to supplement each other. Another advantage of using scientific publication statistics is the reliability and consistency of data, as Yglesias (2003) points out this data has been collected efficiently and effectively by UNESCO.

Similar to patent statistics, scientific publications as innovation output indicators can only be measured with lag. Since there is no historical data on average lag of publications, I assume a one year lag between article submissions and article publications.

(c) High technology exports[11]

As discussed in Intarakumnerd and Viotti (2006), the abilities of developing countries to develop radical innovation or technological change are rather limited. Most of the recent studies on innovation in developing countries tend to focus more on "incremental innovation." Unfortunately, incremental innovation is quite hard to be measured, and we lacks of direct indicators for it, especially on the country aggregate level. One of the indirect measures that has been employed by several researchers is the value of high technology exports. It is argued that as a country lifts up its innovativeness, it will be able to export more high technology content products. Therefore, high technology export can be used as a proxy to capture technological change. For instance, Georgia Tech's High Technology Indicators (HTI) includes

[11] I use high technology exports from the Worldbank WDI database. It defines high technology exports as "products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery". (Worldbank, 2007)

high technology export in its composite output indicator, the Technological Standing (TS). For high technology exports, I again assume one year lag between the development of new high technology product and its realized commercial returns.

(d) Replicated composite output indicators

As discussed before, it is widely understood that no individual output indicator is a perfect measurement of innovativeness of the nation. There are several attempts to develop composite output indicators during the past decades. Two STI composite indicators have explicitly developed innovation output subindexes in the process of constructing their main indicators. These are ArCO index and UNDP Technology Achievement Indicators (TAI). Both call their innovation output subindexes as "technology creation indexes" but use different methodology to construct such indexes. While ArCO Technology Creation uses number of patents granted at USPTO per capita and scientific publications per capita to construct the index, TAI Technology Creation bases on the average of nationally granted patents per capita and royalty and license fees receipts per capita. In this paper, I will replicate their methodologies to construct composite output indicators and employ them as dependent variables in my models.

The Replicated ArCO Technology Creation Indicator (ArCO-TCI) is constructed using the following formula.

$$\textit{ArCO-TCI}_{j,t+2} = (\textit{USPTO Granted Patents Index}_{j,t+2} + \textit{Scientific Publication Index}_{j,t+1})/2$$

The Replicated TAI Technology Creation Indicator (TAI-TCI) is constructed using the following formula.[12]

$TAI\text{-}TCI_{j,t+2} = (USPTO\ Granted\ Patents\ Index_{j,t+2} + Royalty\ \ and\ License\ Fees\ Receipts_{j,\ t+1})/2$

The formulas for calculating ArCO-TCI and TAI-TCI are already reflected time lags between STI inputs and STI outputs.

(e) The Innovativeness Index for Developing Countries (INNODEX)

As already argued, developing countries are critical to incremental innovation as well as radical innovation. So far, only few scholars have responded to this observation. Georgia Tech's High Technology Indicator is one of the significant attempts to account for incremental innovation, as it integrates several factors that capture minor technology changes into its composite output indicator. Specifically, it includes the value of high technology exports, the value of electronics exports, and the value of export of computer, communications and other services into the calculation of Technological Standing index (Porter *et al*, 2005). However, Georgia Tech's Technological Standing Indicator does not include patent statistics and scientific publications into its formula.

To recognize for both effects of incremental and radical innovations, this paper proposes a new synthesized composite output indicator called the Realized

[12] Instead of using nationally granted patents per capita as suggested by the original TAI paper, I employ USPTO grated patents per capita because of the unreliability of nationally granted patent statistics in developing countries.

Innovativeness Index for Developing Countries (INNODEX), which is simply the average of number of USPTO granted patents per capita, number of scientific publications per capita and value of high technology export per capita[13]. I decide to exclude other suggested output factors, such as the value of export of computer and communications and royalty fees receipts in INNODEX because the data limitation. As usual, INNODEX is constructed in recognition of time lags between the transformations of inputs into outputs, using the following formula.

$INNODEX_{j,t+2} = (USPTO\ Granted\ Patents\ Index_{j,t+2} + Scientific\ Publications\ Index_{j,\ t+1} + High\ Technology\ Export\ Index_{j,\ t+1})/3$

R&D inputs and enabling factors

(a) R&D variables

As suggested by the endogenous growth theory, technological change and productivity gains are crucially driven by R&D inputs. In this study, there are two variables that I use to capture the effect of R&D human capitals, including R&D expenditure and R&D labor force. Specifically, I use "R&D expenditure per capita (RDCAP)" and "head counted R&D personnel (RDPERSON)" to represent R&D human capitals. I operationlize the initial stock of knowledge in the economy using USPTO patent stock (PATENTSTK) from 1963 to present year.

---

[13] All raw data on number of USPTO granted patents per capita, number of scientific publications and value of high technology exports are first calculated into individual indicators in order to make them comparable thus we can integrate them into single output indicators. This same methodology is used by ArCO and TAI Indexes. The formula to transform individual indicators is

$$\frac{(observed\ value_{present} - \min obsevred\ value_{past})}{(\max observed\ value_{present} - \min obsevred\ value_{past})}.$$

(b) Technology Infrastructure

The second group of variables is technology infrastructure. Most of STI composite indicators also include these variables to represent a country's technological capability. These variables include the basic science and technology infrastructures such as electricity consumption and number of telephone subscribers to a new information and communication technology infrastructures such as internet and mobile phone penetration rates. Some authors, such as Desai *et al* (2002), consider these variables as proxies for the diffusion of old and new technologies.

(c) Technology Imports

Technology imports refer to the acquisition of foreign technologies in various forms. These include capital goods imports, royalty and licensing fees payments, and technology transfer and technology spillover via foreign direct investment, as suggested by UNDP (2001) and Lall and Albaladejo (2003). Technology imports have been regarded as crucial source of innovativeness in developing countries, especially FDI, as Borensztein *et al* (1998) and Campos and Kinoshita (2002) argue that FDI can directly raise the level of technology and stimulate innovation in host economies. In other words, FDI generally embodies technological advancement from home economies and implant it to host economies. Especially, R&D performing FDI can lead to technology creation and create both product and process innovations in host countries.

(d) Other control variables

Other related variables included in the models are GDP per capita and degrees of openness. GDP per capita does not only control for the differences in countries' income but also does indirectly account for stock of knowledge in the economy, as argued by Furman *et al* (2002). Degrees of openness measures the size of countries' activities in international trade. It is generally accepted that the increasing volumes of international trade can benefit countries' technological capabilities.

Table 3.1: Variables and Definitions

Variables	**Full Names**	**Definitions**	**Data Sources**
Innovation Output			
PATENTS_CAP $_{j,t+2}$	International Patent Granted per Million populations	Number of patents granted by USPTO per million populations at year of grant (t+2)	USPTO Patent Database
JOURNAL_CAP $_{j,t+1}$	Scientific Publications per Million populations	Number of scientific and technical journal articles per million populations at the year of publication (t+1)	World Bank (WDI)
RECIEPT_CAP $_{j,t+1}$	Royalty and License Fees Receipts per Million populations	Royalty and license fees receipts per million populations at the year of receipts (t+1) (PPP)	World Bank (WDI)
HTEX_CAP $_{j,t+1}$	High Technology Export per Million populations	Value of high technology export per million populations at the year of export (t+1) (PPP)	World Bank (WDI)
ArCO_TCI $_{j,t+2}$	Replicated ArCO Technology Creation Index	The average index of USPTO granted patent index at year t+2 and scientific publication index at year t+1	Author's Calculation based on Argibuchi and Coco (2004)
TAI_TCI $_{j,t+2}$	Replicated TAI Technology Creation Index	The average index of USPTO granted patent index at year t+2 and royalty and license fees receipts at year t+1	Author's Calculation based on Desai *et al* (2002)
STIDEX $_{j,t+2}$	Synthesized STI Composite Indicators	The average index of USPTO granted patent index at year t+2, scientific publication index at year t+1 and high technology export index at year t+1	Author's Calculation

Table 3.1 (Cont.): Variables and Definitions

Variables	**Full Names**	**Definitions**	**Data Sources**
Independent Variables			
$PATENTSTK_{j,t}$	International Patents Stock per Million populations	Accumulated number of USPTO granted patent per million populations from 1970 to current year	USPTO Database
$RDGDP_{j,t}$	Gross R&D Expenditure as Percentage of GDP	Gross research and development expenditure (PPP) as percentage of gross domestic product (PPP)	UNESCO Institute for Statistics, RICYT, OECD Main Science and Technology Indicators, National Statistical Offices
$RDCAP_{j,t}$	Gross R&D Expenditure per Capita	Gross research and development expenditure per Capita (PPP)	UNESCO Institute for Statistics, RICYT, OECD Main Science and Technology Indicators, National Statistical Offices
$RDPERSON_{j,t}$	R&D Personnel per Million populations	Number of R&D personnel per million populations (Head counts)	UNESCO Institute for Statistics, RICYT, OECD Main Science and Technology Indicators, National Statistical Offices
$GDPCAP_{j,t}$	GDP per Capita	Gross domestic product per capita (PPP)	Penn World Table (PWT 6.2)
$INTERNET_{j,t}$	Internet Users per Thousand Population	Number of internet users per thousand population	World Bank (WDI)

Table 3.1 (Cont.): Variables and Definitions

Variables	Full Names	Definitions	Data Sources
Independent Variables			
$ELECTRIC_{j,t}$	Electric Consumption per Thousand Population	Electricity consumption per thousand population (Kwah)	World Bank (WDI)
$TEL_{j,t}$	Telephone Mainlines per Thousand Population	Number of telephone mainlines per thousand population	World Bank (WDI)
$MOBILE_{j,t}$	Mobile Phone Users per Thousand Population	Number of mobile phone user per thousand population	World Bank (WDI)
$FDICAP_{j,t}$	Foreign Direct Investment per Capita	Foreign direct investment per capita (PPP)	World Bank (WDI)
$PAYMENTCAP_{j,t}$	Royalty and Licensing Fees Payments per Capita	Value of royalty and licensing fees payments per capita (PPP)	World Bank
$KGOODSCAP_{j,t}$	Imports on Capital Goods per Capita	Value of capital goods import per capita (PPP)	UNCTAD, UN Comtrade, Global Trade Atlas
$OPENNESS_{j,t}$	Degrees of Openness	Exports plus Imports divided by Real Gross Domestic Product per Labor (Constant Price)	Penn World Table (PWT 6.2)

3.4 Scope of the study

In this study, I draw samples from the upper and lower middle income countries, according to World Bank's country classification. This paper does not include low income countries due to the lack of data. Furthermore, since I rely on number of patent grants as the innovation output, low income countries are generally the insignificant contributors. Of all 184 member countries of World Bank, 58 are categorized as lower middle income economies and 40 are upper middle income. From our full sample of 98 countries, only 38 countries produce quite complete statistics on R&D variables, for at least gross expenditure in research and development. Therefore, these 38 middle income economies will be used as samples throughout this study. Due to the limitation of international statistics on R&D, the UNESCO Institute of Statistics only supports such statistics from 1996. As a result, our dataset will cover from 1996 – 2003.[14] However, there are still some missing values for some series. For example, Malaysia only report R&D expenditure every other year. Thus, where appropriate, I substituted these missing values with their trend values. List of countries used in this study is provided in Table 3.2.

[14] The period of prediction for models that use USPTO-granted patents, ArCO-TCI, TAI-TCI and INNODEX as dependent variables is from 1998 – 2005, while the period of prediction for models that use scientific publications and high technology exports as dependent variables is from 1997 – 2004.

Table 3.2: Lists of Countries in the Sample by World Bank Income Classification

Upper Middle Income (21 Countries)		**Lower Middle Income (17 Countries)**	
Argentina	Mexico	Armenia	Kazakhstan
Chile	Panama	Azerbaijan	Macedonia, FYR
Costa Rica	Poland	Belarus	Peru
Croatia	Romania	Bolivia	Thailand
Czech Republic	Russia Federation	Brazil	Tunisia
Estonia	Slovak Republic	Bulgaria	Ukraine
Hungary	Trinidad and Tobacco	China	
Latvia	Turkey	Columbia	
Lithuania	Uruguay	Egypt	
Malaysia	Venezuela	Georgia	
Mauritius		Honduras	

CHAPTER 4

EMPIRICAL EVIDENCES ON THE DETERMINANT OF INNOVATIVENESS IN DEVELOPING COUNTRIES

This chapter provides empirical results based on empirical models proposed in the previous chapter. In the earlier chapters, I have reviewed previous studies and have been guided in the selection of dependent and explanatory variables. In this chapter, I will first examine statistical properties of each variable and propose baseline models that will be used to examine the impact of each determinant of innovativeness in developing countries.

4.1 Descriptive statistics

This section provides some background statistics of the dataset. Table 4.1 reports means and standard deviations of selected variables and Table 4.2 reports the same statistics but with decomposition into group of lower middle countries and group of upper middle income countries. On average, each country in the full samples produces only 29 patents per year or less than one patent per million populations per year, with an upper middle income country produces slightly more than one patent per million populations per year and a lower income country contributes to less than one patent per million populations per year. This is significantly lower than the average number of patents registered at USPTO by OECD countries. Furman *et al* (2002) reports that between 1973 and 1996 the average number of patents granted by USPTO to each of 17 selected OECD countries is about 3,986 patents per year or 3.73 patents per million populations per year.

In terms of R&D expenditures, countries in the samples finance their R&D activities about 0.5 percent of GDP annually (or about 39 US dollars per capita). This data again shows a significant difference from OECD countries, which invested about 2.3 percent of their GDP on R&D activities in 2002 (UNESCO, 2007). Table 4.2 also reveals the significant gaps between lower and upper middle countries, with the latter group doubles the amount of resources of the lower middle incomes in most categories.

Table 4.3 shows the correlation among selected variables, as suggested by the literature. Some interesting points should be mentioned here. First, the number of telephone lines and the electricity consumption are strongly correlated, with the correlation coefficient of 0.795. Both statistics are considered by UNDP (2001) as the proxies of "the diffusion of old technologies". Second, there is a high correlation (0.844) between mobile phone and internet penetration rates. Again, these two variables can be considered the proxies of "the diffusion of new technologies" (UNDP, 2001). Because high correlations lead to multicollinearity problems in fixed-effects regressions, I decide to exclude the telephone penetration rates and mobile phone penetration rates from the estimations. The exclusion of these two variables do not make the models less interpretable, since electricity consumption and internet penetration already capture the effect of diffusions of old and new technologies on innovativeness of countries. I also drop royalty and licensing fees payments variable because only 32 of the full sample (38 countries) supply such data. Furthermore, the inclusion of this variable lead to a multicollinearity problem, since there is a high correlation (0.73) between foreign direct investment and royalty and licensing fees payments.

For the correlation between R&D input variables, R&D expenditure per capita (GERD/Capita) and R&D human workforce (R&D Personnel/Million Pop) are highly correlated, with the correlation coefficient of 0.75. Since both variables are accounted for the same measurement, the R&D input, they will not be included in the same regression. Besides, it is expected that both variables will produce comparable effects on innovative performance of nations.

Table 4.1 Summary Statistics

Variables	**Observations**	**Mean**	**S.D.**
Patents	304	29.875	69.58812
Patents/Million Pop	304	.8868782	1.148346
Journal	232	2288.442	4445.797
Journal/Million Pop	232	70.02288	68.91464
High Tech Export	304	4.52e+09	1.46e+10
High Tech Export/Million Pop	304	122.3382	325.5263
GERD/GDP	304	.005101	.0032088
GERD/Capita	304	38.62566	35.06036
Patent Stock/Million Pop	304	12.85875	30.92797
R&D Personnel/Million Pop	232	2420.88	3192.26
Royalty Fees Payment/Capita	256	6.795243	7.413979
FDI Per Capita	304	135.8352	150.9918
Capital Goods Import/Capita	304	.4147292	.474347
GDP/Capita	304	6965.808	3141.967
Telephone/Thousand Pop	304	198.3212	94.32821
Internet/Thousand Pop	304	55.94959	74.88814
Electricity/Thousand Pop	288	2351.531	1359.097
Mobile/Thousand Pop	304	131.1676	166.1672

Source: Author’s calculation

Table 4.2: Summary Statistics by World Bank Country Classification

Variables	*Upper Middle Income*		*Lower Middle Income*	
	Means	**SD**	**Means**	**SD**
Patents	28.51786	44.95933	31.55147	91.45019
Patents/Million Pop	1.380698	1.335846	.276865	.2719041
Journal	2376.19	3884.639	2183.143	5055.023
Journal/Million Pop	102.3065	76.37815	31.28252	26.71297
High Tech Export	4.15e+09	1.03e+10	4.97e+09	1.87e+10
High Tech Export/Million Pop	200.1509	419.0998	26.21657	60.96058
GERD/GDP	.0056863	.0029337	.0043779	.0033926
GERD/Capita	53.05607	38.30685	20.79987	19.09025
Patent Stock/Million Pop	309.4702	490.1413	180.0368	363.2476
R&D Personnel/Million Pop	3116.779	4065.199	1557.698	1028.403
Royalty Fees Payment/Capita	9.044081	8.187234	3.215461	3.895688
FDI Per Capita	195.4585	175.2317	62.183	57.41591
Capital Goods Import/Capita	.6192634	.5158861	.154413	.2288093
GDP/Capita	9019.534	2465.919	4428.852	1703.618
Telephone/Thousand Pop	242.3321	78.75797	143.9549	83.12343
Internet/Thousand Pop	82.20299	88.593	23.51893	30.99924
Electricity/Thousand Pop	2917.899	1315.831	1643.572	1047.525
Mobile/Thousand Pop	188.5748	193.4215	60.25282	80.77979

Source: Author's calculation

Table 4.3 Correlation Matrix

	RDCAP	GDPCAP	ELECTRIC	TEL	INTERNET	MOBILE	FDICAP	PAYMENTCAP	KGOODCAP	OPENNESS	RDPERSONNEL
RDCAP	1.0000										
GDPCAP	0.5919	1.0000									
ELECTRIC	0.6522	0.6663	1.0000								
TEL	0.5958	0.6978	*0.7950*	1.0000							
INTERNET	0.4420	0.5054	0.3857	0.4653	1.0000						
MOBILE	0.6075	0.5861	0.4473	0.5058	*0.8444*	1.0000					
FDICAP	0.4555	0.1696	0.2088	0.1659	0.0940	0.1626	1.0000				
PAYMENTCAP	0.4917	0.6029	0.2784	0.3365	0.4942	0.5171	0.1051	1.0000			
KGOODCAP	0.6095	0.6065	0.4688	0.4523	0.5386	0.5883	0.2119	*0.7302*	1.0000		
OPENNESS	0.3150	0.2831	0.4507	0.4134	0.4259	0.3517	0.2736	0.3908	0.5963	1.0000	
RDPERSONNEL	0.7511	0.4285	0.5861	0.5575	0.4638	0.4396	0.3538	0.3156	0.3472	0.3971	1.0000

Source: Author's calculation

4.2 The determinant of innovativeness

Based on equation 3-3, the following econometric models are used to examine the determinant of innovativeness in developing countries. All models are in log-log specifications, allowing the interpretation of the estimation results in terms of elasticity. Therefore, all variables are calculated into log forms except those that are already expressed in percentage values.

$$LPANTENTS\_CAP_{j,t+2} = f(LRDCAP_{j,t}, LPATENTSTK_{j,t}, LGDPCAP_{j,t}, LOPENNESS_{j,t}, LKGOODSCAP_{j,t}, LINTERNETCAP_{j,t}, LELECTRIC_{j,t}, COUNTRY\_DUMMY_{j}) \quad (4-1)$$

$$LJOURNAL\_CAP_{j,t+1} = f(LRDCAP_{j,t}, LPATENTSTK_{j,t}, LGDPCAP_{j,t}, LOPENNESS_{j,t}, LKGOODSCAP_{j,t}, LINTERNETCAP_{j,t}, LELECTRIC_{j,t}, COUNTRY\_DUMMY_{j}) \quad (4-2)$$

$$LHTEX\_CAP_{j,t+1} = f(LRDCAP_{j,t}, LPATENTSTK_{j,t}, LGDPCAP_{j,t}, LOPENNESS_{j,t}, LKGOODSCAP_{j,t}, LINTERNETCAP_{j,t}, LELECTRIC_{j,t}, COUNTRY\_DUMMY_{j}) \quad (4-3)$$

$$ArCO\_TCI_{j,t+2} = f(LRDCAP_{j,t}, LPATENTSTK_{j,t}, LGDPCAP_{j,t}, LOPENNESS_{j,t}, LKGOODSCAP_{j,t}, LINTERNETCAP_{j,t}, LELECTRIC_{j,t}, COUNTRY\_DUMMY_{j}) \quad (4-4)$$

$$TAI\_TCI_{j,t+2} = f(LRDCAP_{j,t}, LPATENTSTK_{j,t}, LGDPCAP_{j,t}, LOPENNESS_{j,t}, LKGOODSCAP_{j,t}, LINTERNETCAP_{j,t}, LELECTRIC_{j,t}, COUNTRY\_DUMMY_{j}) \quad (4-5)$$

$$INNODEX_{j,t+2} = f(LRDCAP_{j,t}, LPATENTSTK_{j,t}, LGDPCAP_{j,t}, LOPENNESS_{j,t}, LKGOODSCAP_{j,t}, LINTERNETCAP_{j,t}, LELECTRIC_{j,t}, COUNTRY\_DUMMY_{j}) \quad (4-6)$$

The fixed-effects regression results are reported in Table 4.4. As seen from this Table, the coefficient of R&D expenditure per capita (RDCAP) is positive and significant in all models. According to the estimation, one percent increase in RDCAP leads to 0.59 percent increase in USPTO-granted patents, 0.25 percent increase in number of scientific journal publications (JOURNAL_CAP), and 0.31 percent increase in high technology exports (HTEX_CAP). Furthermore, changes in RDCAP lead to comparable changes in the innovation output indexes. One percent increase in RDCAP changes the Replicated ArCO Technology Creation Index (ArCO-TCI) by 0.06 percent, the Replicated TAI Technology Creation Index (TAI-TCI) by 0.07 percent, and the Realized Innovativeness Index (INNODEX) by 0.06 percent.

Surprisingly, variables that represent the stock of knowledge, including patent stock (PATENTSTK) and GDP per capita (GDPCAP) are mostly insignificant. PATENTSTK cannot explain variations in any innovation outputs. GDPCAP significantly determines changes in number of scientific publications. Foreign direct investment per capita (FDICAP) is the significant determination of number of USPTO granted patents, ArCO-TCI and INNODEX. Degrees of openness (OPENNESS) is significant in most models, except in the USPTO Patents and the TAI-TCI models. Internet penetration rates (INTERNET) also significantly influences changes in most output variables. These three indicators (FDICAP, OPENNESS, and INTERNET) imply the strong relationship between international market forces and science and technology sector in developing countries. For other variables, import of capital goods per capita (KGOODSCAP), not surprisingly, only affects the value of high technology exports. Many developing countries are export-oriented and the import of capital goods is usually accounted by export sectors.

In Table 4.5, I recalculate model 4-1 to 4-6 by substituting R&D expenditure variable with R&D human resource variable (R&D personnel per million populations). Due to data limitation on this latter variable, number of samples and observations drop down. The estimation results reveal that R&D personnel

(RDPERSON) can be used as the alternative to R&D expenditure and can significantly account for variations in most dependent variables. Although R&D personnel is insignificant in the USPTO Patents model (Model 4-7) and the High Technology Export model (Model 4-8), the t-statistics still relatively high so that the R&D personnel variable is significant at 20 percent level. For those significant at 10 percent level, one percent increase in number of R&D personnel associates with 0.39 percent increase in number of scientific publications, 0.07 percent increase in ArCO_TCI, 0.07 percent increase in TAI_TCI and 0.08 percent increase in INNODEX. GDPCAP, FDICAP, INTERNET and OPENNESS are four explanatory variables that are statistically significant in several models.

The findings in this study suggest several important points. First, despite the increasing focus on other factors, R&D expenditures are the most influential determinant of innovativeness in developing countries. With relatively low R&D expenditures in these countries, each additional investment in R&D activities leads to the increase in international patenting at the higher rate than the cases of OECD countries. According to OECD studies, one percent increase in aggregated R&D expenditure associates with only 0.07 to 0.1 percent increase in international patenting (Furman *et al*, 2002; Gans and Hayes, 2005)[15] In contrast, this study finds that one percent increase in R&D expenditure leads to about 0.6 percent increase in international patenting (Model 4-1). Second, either R&D expenditure or R&D personnel can be used as proxies for R&D input. The influences of these variables on innovation outputs are in comparable magnitudes. Therefore, the two variables can be substituted for one another. In this study, because the data on R&D expenditure is

[15] See also Table 4.7

more complete than those on R&D personnel, the models with R&D expenditure will be used for prediction purpose in the next chapter. Third, patent stock is insignificant in all models, contrary to what endogenous growth theory predicts. However, since patent stock is not the perfect measurement of a country's stock of knowledge, we cannot draw any clear-cut conclusion from the estimations. Forth, most of explanatory variables that significantly influence changes in innovation outputs share one common characteristic. Internet penetration rates, foreign direct investment and degrees of openness all imply the degree of connectedness of a country to the international community. Internet penetration rates do not only represent the diffusion of new technologies within national border but also represent the technology spillovers from aboard. Level of foreign direct investment is employed to capture the degree of commitment of a country to foreign capitals and technologies. Many authors, including Todo and Miyamoto (2004), suggest the use of R&D-performing FDI instead of aggregated FDI to account for productivity growth. However, with the lack of such data, we need to use aggregated FDI in this paper. Degrees of openness, a control variable used in the models, also identify the connection between a country and international market. The estimation results suggest that the more a country opens to international trade, the more a country effectively produces innovation outputs. In short, technology imports and international technology spillovers are proven to be crucial determinants of innovation outputs in developing countries.

Table 4.4 Fixed Effect OLS Panel Estimations of Innovation Output Indicators (With R&D Expenditure per Capita as R&D Input**)**

Dependent Variables	(4-1) LPATENTS_CAP $_{j,t+2}$	(4-2) LJOURNAL_CAP $_{j,t+1}$	(4-3) LHTEX_CAP $_{j,t+1}$	(4-4) ArCO_TCI $_{j,t+2}$	(4-5) TAI_TCI $_{j,t+2}$	(4-6) INNODEX $_{j,t+2}$
$RDCAP_{j,t}$	.5876661*** (.1995106)	.2458679*** (.0480349)	.3092694** (.19521)	.05527*** (.017706)	.0654464*** (.0243286)	.0557431*** (.014861)
$LPATENTSTK_{j,t}$	-.0893793 (.1012564)	-.0079048 (.0241952)	.0866906 (.1026222)	.0103168 (.0089185)	.0055555 (.0125404)	.0088107* (.0074855)
$LGDPCAP_{j,t}$	.1520132 (.6065809)	.6200825*** (.1358907)	.5884257 (.5480851)	.0023461 (.0500903)	.0888383 (.0939511)	.0453973 (.0406368)
$LOPENNESS_{j,t}$	.2209455 (.2951706)	.1785767* (.076448)	.8742168*** (.3078168)	.0809857*** .0281793	.063488 (.0420614)	.0733303*** (.0236499)
$LFDICAP_{j,t}$	.106397* (.0594892)	.0162995 (.0144097)	0464881 (.0594855)	.0062774* (.0053115)	.0110096 (.0087161)	.0051705* (.0044577)
$LKGOODSCAP_{j,t}$	.0387691 (.129084)	.0050382 (.020417)	.4349384*** (.0858117)	.0012631 (.0075258)	.0092163 (.0196192)	.0074878 (.0062817)
$LINTERNET_{j,t}$	.060648* (.0406954)	.0548933*** (.0100076)	.0884045** (.0421105)	.0003244 (.0036889)	-.002386 (.0056599)	.0006326* (.0030909)
$LELECTRIC_{j,t}$	-.5809053 (.5229709)	.2317581* (.1370687)	1.019663* (.5473692)	-.0128836 (.0505246)	-.0514588 (.0756046)	-.0010371 (.0422827)
CONSTANT	1.857292 (6.311514)	5.645855*** (1.510786)	-12.38681 (5.897465)	-.2963779 (.556887)	-.8199677 (.9173515)	.0310251 (.462211)
No. of Countries	38	34	38	33	25	34
R-Squared	0.7649	0.7822	0.8297	0.8108	0.8046	0.8485

Note: Standard error in the parentheses. L denotes natural logarithms.
* Statistically significant at the 10 % level
** Statistically significant at the 5 % level
*** Statistically significant at the 1 % level

Table 4.5 Fixed Effect Panel Estimations of Innovation Output Indicators (With R&D Workforce per 1,000 Populations as R&D Input)

Dependent Variables	(4-7) $LPATENTS\_CAP_{j,t+2}$	(4-8) $LJOURNAL\_CAP_{j,t+1}$	(4-9) $LHTEX\_CAP_{j,t+1}$	(4-10) $ArCO\_TCI_{j,t+2}$	(4-11) $TAI\_TCI_{j,t+2}$	(4-12) $INNODEX_{j,t+2}$
$LRDPERSON_{j,t}$	.4204413 (.267151)	.3908424*** .0730818	.4205543 .2757459	.072292** (.0297027)	.0691135* (.0377757)	.0783173*** (.0245733)
$LPATENTSTK_{j,t}$	-.0344138 (.1045881)	-.0161231 (.0248614)	.1505424 .1003653	.0086798 (.0101044)	.0059859 (.0140942)	.0074973 (.0083618)
$LGDPCAP_{j,t}$	1.20088* (.7388433)	.3089686** (.1432752)	.3705473 .5702008	.0642722 (.0582314)	.1908956* (.1092535)	.0192799 (.0462793)
$LOPENNESS_{j,t}$	.1803455 (.3445566)	.0407462 (.0895861)	.6812012** .3395578	.076347** (.0364105)	.070486 (.0528991)	.0662715** (.0301293)
$LFDICAP_{j,t}$	.0896367 (.0675948)	.0202669 (.0156229)	.0096304 (.0607521)	.0067569* (.0063496)	.0085546 (.0099165)	.0055921* (.0052542)
$LKGOODSCAP_{j,t}$	.197019 (.1745654)	.0315149 (.0211684)	.3538718*** (.0904628)	.0022328 (.0086035)	.0074084 (.0240775)	.0075461 (.0070816)
$LINTERNET_{j,t}$	.1246249*** (.0456754)	.0644789*** (.0110457)	.1116055** (.0447772)	.0017612* (.0044893)	-.0035007 (.006529)	.0026094* (.0037002)
$LELECTRIC_{j,t}$	-.5758913 (.6094924)	.090813 (.1605257)	1.181066* (.6208667)	-.0285224 (.0652425)	-.0403356 (.0888675)	-.019836 (.0539205)
CONSTANT	10.25673 (7.975868)	2.668865 (1.616561)	-2.633231 (6.229108)	-1.045177 (.6570191)	-2.11434* (1.065283)	-.7566976 (.5354302)
No. of Countries	29	27	29	27	21	27
R-Squared	0.7284	0.8224	0.8037	0.8441	0.7196	0.8294

Note: Standard error in the parentheses. L denotes natural logarithms.
* Statistically significant at the 10 % level
** Statistically significant at the 5 % level
*** Statistically significant at the 1 % level

So far, this chapter focuses on the empirical results of innovation functions. As illustrated in Figure 3.1, it is also important to determine the relationship between innovation (technological change) and national competitiveness and economic growth. In doing so, I evaluate the sensitivity of economic growth to R&D production. Specifically, Romer's endogenous growth-typed production functions are again employed to identify whether degrees of national innovativeness play an important role in supporting countries' economic growth. In Table 4.6, model 4-13 and 4-14 examine the influence of patent stock (PATENTSTK) to GDP per capita (GDPCAP) and total factor productivity (TFP), conditional on factors of production including labor (LABOR) and investment (INVESTMENT) series.

The fixed-effects regression results are shown in Table 4.6. As seen from the estimation results of model 4-13, the coefficient of patent stock is positive and significant as the determinant of countries' per capita income level, with one percent increase in patent stock leads to 0.14 percent increase in GDP per capita. INVESTMENT and LABOR are also highly significant and positive. Each additional percent increase in investment yields 0.18% increase in countries' income levels, and each additional percent increase in labor pool yields 0.47% increase in countries' income levels. Other control variables, including degrees of openness and foreign direct investment have expected signs with high t-values, implying that the country's trade and investment liberalizations are crucial determinant of the countries' income levels.

Model 4-14 examines further with the relationship between total factor productivity (TFP) and innovation. Again, the coefficient of patent stock is positive and significant, with one percent increase in patent stock is related with 0.01 percent increase in TFP. This result is on the same line with most studies of endogenous growth theory that innovation outputs (as a measurement of national innovativeness) drive economic growth partly through their influences on TFP. The results also suggest that while patent stock is a significant determinant of TFP and GDP growth, its effect is rather limited. The conclusion here is consistent with Furman *et al* (2002) that "the linkage between technological capability (measured through patent stock) and productivity growth maybe more subtle than commonly assumed (Furman *et al*, 2002)."

4.3 Discussion and conclusions

The objective of this chapter is to provide the empirical evidence on determinants of innovativeness in developing countries. Based on the integration of endogenous growth and system of innovations theories, the chapter evaluates the relationship between 'R&D efforts and other enabling factors' and 'innovation outputs'. The study also extends to evaluate the impact of innovation outputs on economic growth and productivity gains. The estimation results show that R&D investment can stimulate the creation of innovation in developing countries at significant rates. Using the USPTO granted patents as the benchmarking output indicators, this study shows that every dollar spent on R&D activities in developing countries yields higher returns on innovation than the previous studies of OECD countries indicate. However, consistent with most previous studies, the increase in R&D inputs does not lead to the constant return in innovation output, as endogenous growth theory predicts. (Furman *et al*, 2002; Ulku, 2004; Gans and Hayes, 2005) Table 4.7 provides the summary and comparison of important findings from this study and selected previous studies. Again, in contrast to the prediction of endogenous growth theory, the use of patent stock as initial stock of knowledge yields insignificant results. However, we cannot conclude that the theory is wrong since patent stock is not a perfect measurement of a country's stock of knowledge. Especially, most of the developing economies do not have highly developed patent system that encourages the use of patents. Besides, stock of knowledge might be accumulated in other forms, such as tacit knowledge. Therefore, it is important for developing countries to develop a relevant measurement for knowledge stock in their context.

Apart from R&D and patent stock variables, this study also identifies other important determinants of innovation in developing countries. Obviously, this study confirms dependencies of developing countries on imported technologies. Foreign direct investment (FDICAP) has proven to be beneficial to the enhancement of innovativeness in developing countries. This is consistent with many prior studies, including Borensztein *et al* (1998), Campos and Kinoshita (2002) and Cheng and Lin (2004). There are several reasons behind the positive impact of foreign direct investment on innovativeness. According to Cheng and Lin (2004), inward FDI can benefit local innovative capabilities in at least 3 ways. Firstly, domestic firms can learn about designs of the new products and processes and improve them to create new innovations. Secondly, inward FDI can spillovers to local firms through labor market turnover. Lastly, inward FDI may generate what they termed "a demonstration effect." The mere availability of foreign products in domestic markets can help general local firms' creativity to innovate. All in all, policymakers in developing countries could use FDI promotion as the strategy to enhance national innovativeness.

This study lends support to the positive relationships between innovation (patent stock) and economic growth (GDP per capita) and between innovation and total factor productivity. But, it should be noted that these effects are not quite strong as many may expect. These results imply that innovative capability is the important driver of economic growth in developing countries but it should not be overemphasized as the pure source of growth.

In this chapter, I propose the use of newly constructed Innovativeness Index (INNODEX) as the benchmarking output indicators, and it is found that this INNODEX is significantly explained by several determinants, including R&D expenditure, patent stock, degrees of openness, foreign direct investment, and internet penetration rates (Model 4-6). I will use the Model 4-6 as the preferred model to construct a STI composite indicator in the next chapter.

Table 4.6: Fixed Effect OLS Panel Estimations of GDP per Capita and

Total Factor Productivity

Dependent Variables	(4-13) $LGDPCAP_{j,t+2}$	(4-14) $TFP_{j,t+2}$
$LPATENTSTK_{j,t}$	.1467398*** .0105694	.0117784*** .0044281
$LINVESTMENT_{j,t}$	.1805081*** .0241318	-
$LLABOR_{j,t}$	.4735743*** .1765722	-
$LOPENNESS_{j,t}$	.1244072*** .0468279	.0460915** .0195628
$LFDICAP_{j,t}$	.0161772*** .0087389	.0087281** .0036316
Country Dummy	Significant	Significant
CONSTANT	6.44076*** .2460031	2.230728*** .079756
No. of Countries	38	38
R-Squared	0.978	0.960

Notes:
- Standard error in the parentheses. L denotes natural logarithms.
- Statistically significant at the 10 % level ** Statistically significant at the 5 % level *** Statistically significant at the 1 % level
- INVESTMENT is gross fixed capital formation per capita
- LABOR is total number of labor force as percentage of total population
- TFP is total factor productivity. TFP is calculated using the formula suggested by Ulku (2004).

Table 4.7: The Comparison of Findings on Determinant of International Patenting

	Furman (2002)	Ulku (2004)	Gans and Hayes (2005)	Recent study
Scope of Studies	17 OECD Countries	20 OECD Countries	29 OECD Countries	38 Developing Countries
Year	1973 - 1996	1981 - 1997	1997 - 2002	1996 – 2003
Effects of R&D variables on Innovation	- 1% increase in "aggregated R&D expenditure" is associated with 0.07% increase in international patenting - 1% increase in "patent stock" is associated with 0.48% increase in international patenting. - 1% increase in "full time equivalent science and engineering workforce" is associated with 0.54% increase in international patenting.	- 1% increase in "R&D stock" is associated with 0.2% increase in international patent applications in large-market OECD countries and 0.3% increase in international patent applications in low-income OECD countries.	- 1% increase in "aggregated R&D expenditure" is associated with 0.1% increase in international patenting - 1% increase in "full time equivalent science and engineering workforce" is associated with 1.06% increase in international patenting.	- 1% increase in "R&D expenditure per capita" associated with 0.59% increase in international patenting. (Model 4-6) - 1% increase in "R&D personnel per 1,000 populations" associated with 0.42% increase in international patenting. (Model 4-12) - "Patent stock" is insignificant determination of international patenting (Model 4-6 and 4-12)
Effects of R&D variables on Economic Growth	- 1% increase in patent stock associated with 0.11% increase in GDP	- 1% increase in patent stock is associated with 0.06% increase in GDP per labor and 0.88% increase in TFP.	- Not Studied	- 1% increase in patent stock is associated with 0.15% increase in GDP per capita and 0.01% increase in TFP.

CHAPTER 5

THE INNOVATIVENESS INDEX FOR DEVELOPING COUNTRIES

The main objective of this study is to propose the alternative way to construct a rigorous science, technology and innovation composite indicator for developing countries. Instead of producing an indicator by integrating all kinds of individual indicators, regardless whether it is input, output, or enabling factors, this study shares the same ideas with Porter and Stern (2000), Porter and Stern (2001), Furman et al (2002) and Gans and Hayes (2005) to construct 'a composite output indicator' that represents national innovativeness. This approach clearly identifies a distinction between a country's innovation output (as a measure of national innovativeness) and its determinants (R&D inputs and other enabling factors). Based on regression analysis, I examine appropriate weights for each determinant. Then, I assign these weights to each determinant to construct a composite output indicator.

5.1 The Predicted Innovativeness Index for Developing Countries

From the previous chapter, this paper argues for using the newly constructed Realized Innovativeness Index (INNODEX) as the innovation output indicator for developing countries. This chapter uses the estimation result of the INNODEX regression (Model 4-6) to construct the Predicted Innovativeness Index for

Developing Countries (*INNÔDEX*).[16] Due to the data limitation (the inclusion of scientific publications into INNODEX), *INNÔDEX* can be calculated for only 34 countries[17]. The full rankings of *INNÔDEX* are presented in Table 5.1.

Based on the *INNÔDEX* rankings, Central and Eastern European (CEE) countries finish as top performers, with Hungary ranked first during the period of study. Other CEE countries also received high ranks including Czech Republic, Croatia, Estonia, Bulgaria and Slovak Republic. Surprisingly, Russia ranks relatively low in the index from the start but it is gaining positions overtime. It is notably that *INNÔDEX* is calculated without the inclusion of R&D human resources, the area that Russia is noted for its strength. Overall, CEE countries are eye-catching. However, as Archibugi and Coco (2004) argued, the economic and social conditions in these countries are quite unstable, due to the transition from central planned economy to market economy. Therefore, we need to monitor the development in these countries very cautiously. After all, at least the index reflects that the solid innovative capabilities have been grounded in this group of countries.

Most Northern American, Central American and Caribbean countries are sparsely rank in the middle of *INNÔDEX*, with Panama receives the highest ranking at 11th in 2005. Only exception is Honduras, which finishes almost at the bottom of the ranking. Mexico, though it locates in close proximity to the United States, only ranks 20 out of 34 countries in 2005.

In the Latin American region, Chile consistently shows its lead in *INNÔDEX*. Besides, most of the countries in this continent finish at the bottom half of the

---

[16] I do not employ the INNODEX regression with R&D human resources variable (Model 4-12) since once include such variable, the number of countries drop down to 27.
[17] Kazakhstan, Latvia, Macedonia and Mauritius are excluded from the calculation.

ranking. Bolivia, Brazil, Argentina, Uruguay, Venezuela, Columbia and Peru all rank below 20th in 2005. For East and Southeast Asian countries, Malaysia shows its stregth in national innovativeness, by moving from 6th place in 1998 to as high as 2nd place in 2005. Other 2 high performing East Asian economies, including Thailand and China, also show their considerably advancement in science and technology. Thailand has moved up from 24th in 1998 to 18th in 2005. China has terrifically jumped from 27th in 1998 to 17th in 2005, the highest gain in *INNÔDEX* during the period of study. For Northern African countries, Tunisia ranks relatively high while Egypt ends up finishing almost at the bottom of the ranking.

Figure 5.1 to Figure 5.5 shows *INNÔDEX* scores for each regional group. From Figure 5.1, in the case of Central and Eastern European countries, although Hungary and Czech Republic have consistently led the group, we can witness the slow improvement in *INNÔDEX* scores in recent years. In contrast, the two followers, Estonia and Croatia, have enjoyed considerable growths in *INNÔDEX* scores. Therefore, it is possible that Estonia and Croatia will catch up with Hungary and Czech Republic in the near future. Russia also shows the high improvement in innovativeness scores, resulting in the jump of its *INNÔDEX* rank as discussed before.

While most of the CEE countries have improved their innovativeness overtime, North American, Central America and the Caribbean countries have little or no improvement in their innovativeness (Figure 5.2). Their *INNÔDEX* scores have been stable overtime. As a result, these countries should take a serious warning. While developing countries in other regions enjoying growths in their innovativeness, North America, Central America and the Caribbean countries are risky to lose their competitiveness in the international market.

Three East and Southeast Asian economies are still on the growth trend on *INNÔDEX* scores (Figure 5.3). Malaysia already takes lead, not only among Asian countries, but also among other developing countries. In the period of study, China is able to catch up with Thailand. As of 2005, China's *INNÔDEX* scores already surpasses its Southeast Asian counterpart. It is widely recognized that China has successfully revitalized its science and technology sector in the last decade. On the other hand, Thailand is still in the process of recovery from the 1997 Asian Crisis. *INNÔDEX* points out that the country has slowly improved its innovativeness.

Latin American countries show a mixed trend in the development of innovative capabilities (Figure 5.4). *INNÔDEX* reveals persistent gaps among countries in the region in term of innovative capabilities. Chile stays clear as the regional leader. Brazil, Bolivia, Argentina, Uruguay and Venezuela produce comparable *INNÔDEX* scores, with Colombia follows a little bit behind. Peru crumbles at the bottom with very low *INNÔDEX* scores. Generally, most Latin American countries illustrate only slow growth in the innovativeness index.

The last figure shows *INNÔDEX* scores for African countries (Figure 5.5). There are only two countries from North Africa presented in this study. Surprisingly, there is a significant gap in *INNÔDEX* scores between Tunisia, the leader, and Egypt, the follower. Similar to the case of Latin American countries, Tunisia and Egypt show only slow improvements in the innovativeness index during the period of study.

Table 5.1: Full $\hat{INNODEX}$ Rankings, 1998 - 2005

Ranking	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
1	Hungary	Hungary	Hungary	Hungary	Hungary	Hungary	Hungary	Hungary
2	Estonia	Czech	Czech	Czech	Czech	Czech	Czech	Malaysia
3	Croatia	Estonia	Malaysia	Malaysia	Malaysia	Malaysia	Malaysia	Czech
4	Czech	Croatia	Croatia	Estonia	Estonia	Estonia	Estonia	Estonia
5	Slovak	Slovak	Estonia	Croatia	Croatia	Croatia	Croatia	Croatia
6	Malaysia	Malaysia	Slovak	Slovak	Slovak	Slovak	Slovak	Slovak
7	Panama	Panama	Panama	Belarus	Bulgaria	Bulgaria	Lithuania	Bulgaria
8	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Ukraine	Lithuania	Bulgaria	Lithuania
9	Ukraine	Belarus	Lithuania	Ukraine	Belarus	Ukraine	Ukraine	Ukraine
10	Belarus	Lithuania	Belarus	Costa Rica	Panama	Belarus	Belarus	Belarus
11	Lithuania	Ukraine	Ukraine	Panama	Lithuania	Panama	Russia	Russia
12	Chile	Poland	Poland	Russia	Costa Rica	Russia	Chile	Panama
13	Costa Rica	Chile	Costa Rica	Poland	Poland	Poland	Panama	Chile
14	Poland	Costa Rica	Chile	Lithuania	Russia	Chile	Tunisia	Costa Rica
15	Romania	Russia	Russia	Chile	Chile	Costa Rica	Costa Rica	Poland
16	Venezuela	Romania	Mexico	Mexico	Tunisia	Tunisia	Poland	Tunisia
17	Russia	Tunisia	Tunisia	Tunisia	Thailand	Thailand	Thailand	China
18	Mexico	Trinidad	Trinidad	Thailand	Mexico	Mexico	Mexico	Thailand

Table 5.1: (Cont.): Full $\hat{INNODEX}$ Rankings, 1998 - 2005

Ranking	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
19	Tunisia	Mexico	Romania	Trinidad	Trinidad	Turkey	China	Romania
20	Trinidad	Venezuela	Thailand	Romania	Romania	Romania	Trinidad	Mexico
21	Uruguay	Uruguay	Venezuela	Turkey	Turkey	Trinidad	Romania	Turkey
22	Turkey	Turkey	Azerbaijan	Venezuela	China	China	Turkey	Trinidad
23	Armenia	Azerbaijan	Turkey	Brazil	Venezuela	Brazil	Brazil	Azerbaijan
24	Thailand	Argentina	Uruguay	China	Brazil	Venezuela	Venezuela	Bolivia
25	Argentina	Brazil	Brazil	Uruguay	Uruguay	Azerbaijan	Azerbaijan	Brazil
26	Bolivia	China	Argentina	Argentina	Argentina	Uruguay	Argentina	Georgia
27	China	Thailand	Bolivia	Azerbaijan	Azerbaijan	Armenia	Georgia	Argentina
28	Azerbaijan	Bolivia	China	Bolivia	Bolivia	Argentina	Uruguay	Uruguay
29	Colombia	Georgia	Georgia	Armenia	Armenia	Georgia	Armenia	Venezuela
30	Brazil	Colombia	Armenia	Georgia	Georgia	Bolivia	Bolivia	Armenia
31	Georgia	Armenia	Colombia	Colombia	Colombia	Colombia	Colombia	Colombia
32	Egypt	Honduras	Honduras	Honduras	Honduras	Egypt	Egypt	Egypt
33	Honduras	Egypt	Egypt	Egypt	Egypt	Honduras	Honduras	Honduras
34	Peru	Peru	Peru	Peru	Peru	Peru	Peru	Peru

Source: Author's calculation

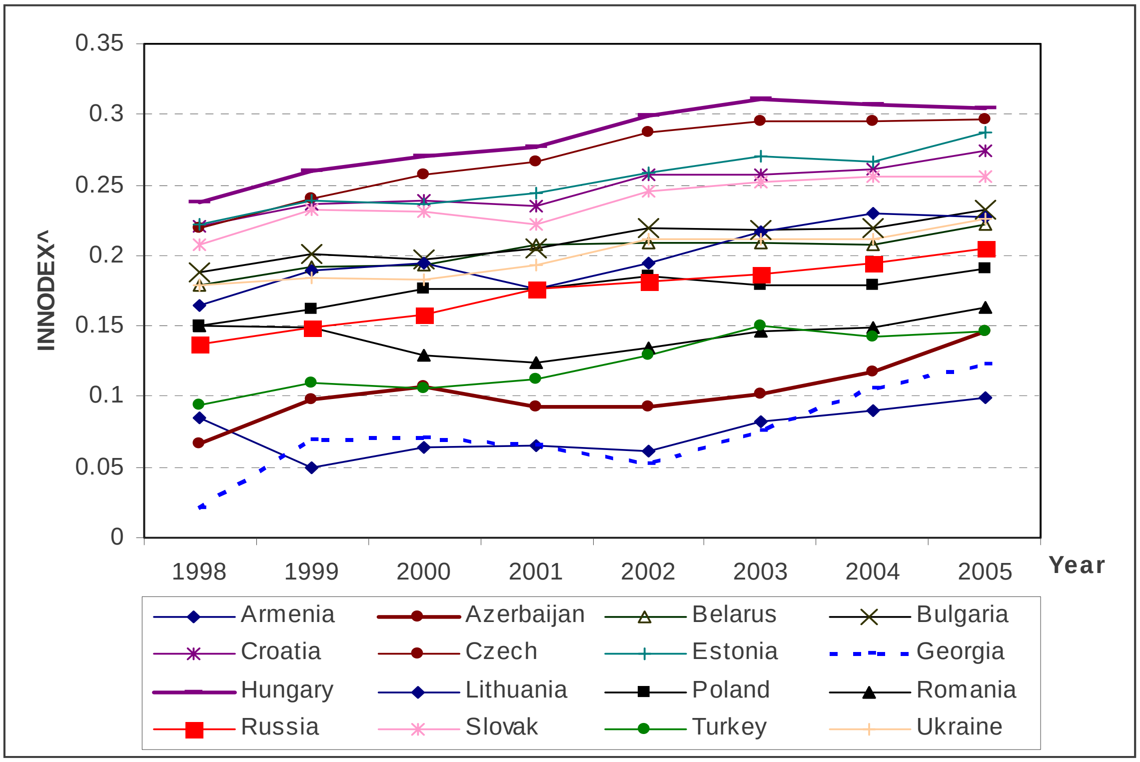

Figure 5.1: *INNÔDEX* scores for Central and Eastern European countries

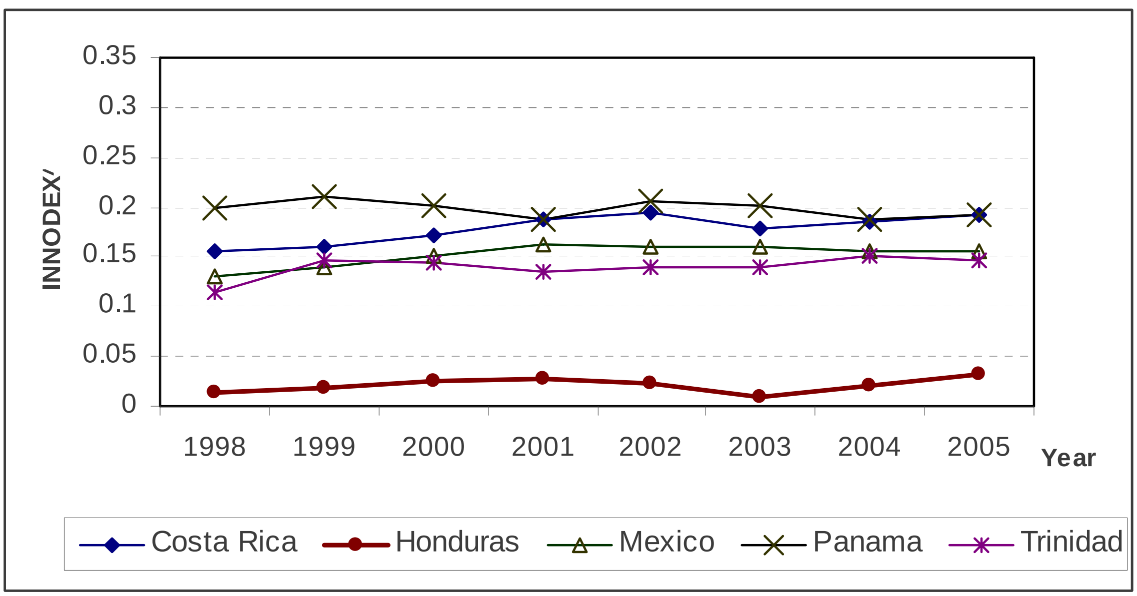

Figure 5.2: *INNÔDEX* scores for North America, Central America and the Caribbean countries

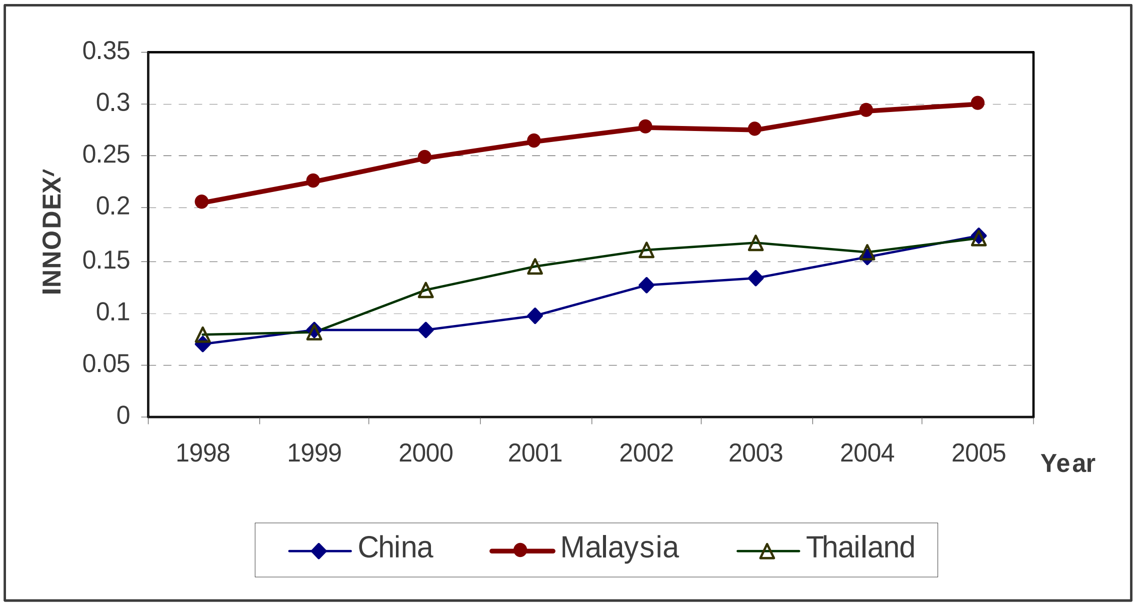

Figure 5.3: *INNÔDEX* scores for East and Southeast Asian countries

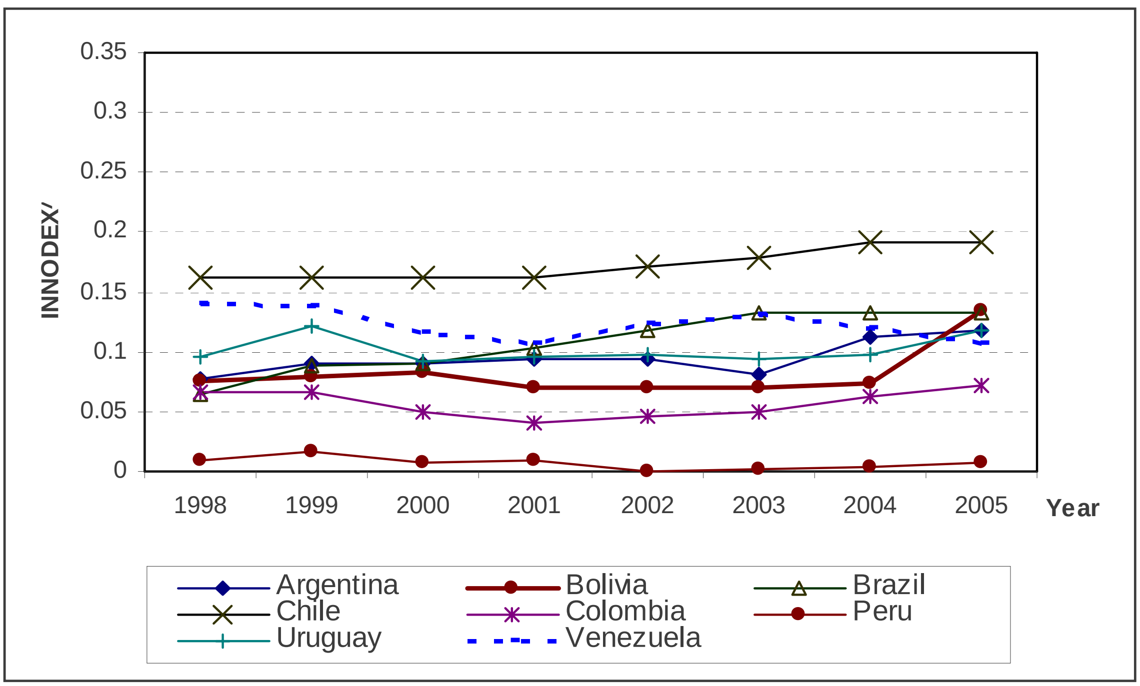

Figure 5.4: *INNÔDEX* scores for Latin American countries

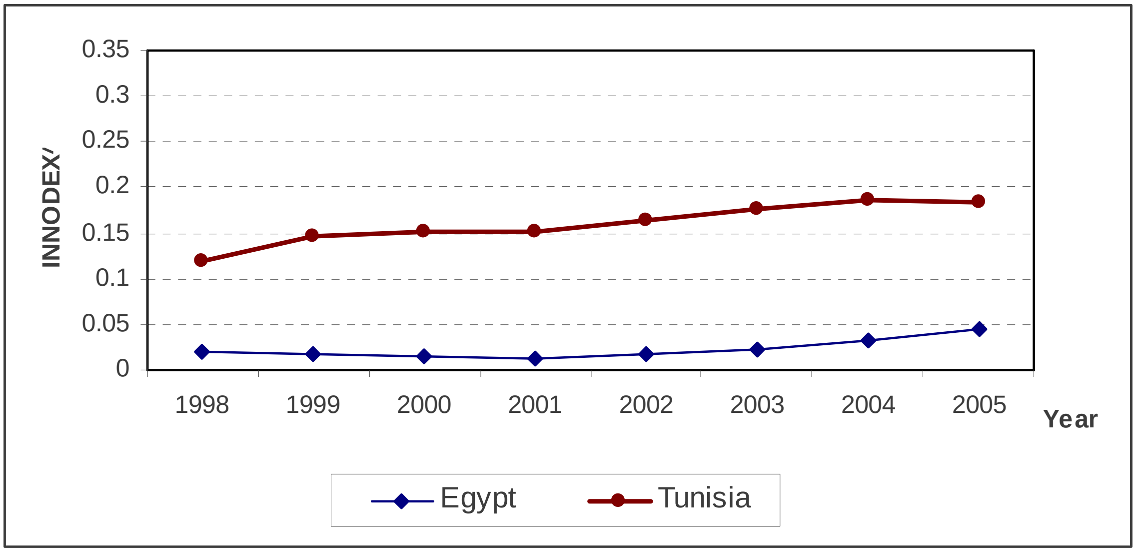

Figure 5.5 : *INNÔDEX* scores for African countries

5.2 Ranking Comparison

This section provides the comparison of rankings between *INNÔDEX* and several other STI composite indicators, including ArCO index and ArCO Technology Creation Subindex (Archibugi and Coco, 2004), Technology Achievement Index (TAI) (UNDP, 2001), Science and Technology Capacity Index (STCI) (Wagner *et al*, 2003) and National Innovative Capacity Index (NICI) (Porter and Stern, 2001). The method used here for comparison is similar to Archibugi and Coco (2005), focusing on the rank correlations. Only 18 countries are presented in all 6 indexes thus can be used for the comparison. Table 5.2 shows the rankings provided by 6 indexes. Since most of the rankings are reported between 1999 and 2002, I use 2002 *INNÔDEX* for comparing.

According to Table 5.2, the positions for the top two performers in *INNÔDEX* are comparable to other rankings. Hungary, ranked first in *INNÔDEX*, finishes at 2nd or 3rd place in other ranking, except in NICI which ranks Hungary at no. 6. Czech Republic ranks first to second in *INNÔDEX* and other rankings. In contrast, among the top performers, Malaysia shows great divergence in rankings. While *INNÔDEX* and NICI rank Malaysia as one of the most innovative countries, Two ArCO indexes and Rand STCI ranks Malaysia quite at the middle of the table. Other countries that get diverse rankings include Romania, Argentina, Brazil and China. . Romania ranks between 9th to 16th, Brazil ranks between 9th to 14th and Argentina ranks between 6th to 15th. In the case of China, NICI has it at 7th place while other indexes place China at 10th place or below. (However, it should be noticed that China has significantly gained its position in *INNÔDEX* ranking overtime.) From Table 5.2, we are also able to draw conclusion about the bottom 3. Bolivia, Egypt and Peru are ranked relatively low in all indexes.

Table 5.3 shows the rank correlations among six indexes. The highest correlation coefficient is between ArCO Technology Creation and RAND STCI (0.932). In general, ArCO Index, ArCO Technology Creation, UNDP TAI and RAND STCI have high correlations with each other (at least 0.85). It is explicit that Porter and Stern NICI has the lowest correlation with other indexes. One explanation to this deviation of Porter and Stern NICI is their model includes variables that are not considered by other rankings, such as cluster-specific environment. *INNÔDEX* sets another departure from other rankings, with the correlation coefficients approximately equaling to 0.7 (except in case of correlation coefficient with UNDP TAI with the correlation coefficient of 0.83). This is quite predictable since *INNÔDEX* employ different methodology from other studies to construct the index, with the focus on developing countries and the use of regression analysis to determine weights to each variable.

It is also useful to compare between the Realized Innovativeness Index (INNODEX) and the Predicted Innovativeness Index (*INNÔDEX*). While the former represent the actual innovation output index, the latter provides insight into innovative capabilities of nations, based on historical relationship between components of national innovativeness and innovation outputs.

Table 5.4 shows that ranking comparison between the Realized Innovativeness Index (INNODEX) and Predicted Innovativeness Index (*INNÔDEX*) for 2002. The top 6 performers in the two indexes are the same group of countries, with few different orders in rankings. This result implies that these countries can utilize their innovative capabilities to generate innovation outputs. However, there are several countries that the ranking differences between the two indexes exist. Russia, Argentina, Uruguay and

Mexico are ranked relatively high in INNODEX but low in *INNÔDEX.* This divergence implies that although this group of countries can develop certain level of innovation output, they may still have structural weaknesses in their innovativeness. Therefore, it is important for policymakers in these countries to evaluate their innovative capabilities very carefully.

Another group of countries, including Panama, Ukraine, Panama, Trinidad and Tobacco, Romania and China, has relatively high *INNÔDEX* but low INNODEX ranks. This phenomenon implies that even though this group of countries has accomplished certain level of innovative capabilities, they may not fully utilize their innovative capabilities to generate innovation outputs. However, it should be noticed that INNODEX is not a perfect measurement of innovation outputs; therefore, it is possible that these countries may use their innovative capabilities to produce other types of innovation that have not been yet measured.

5.3 Discussion and conclusions

In the knowledge-based world, economic success requires high degree of country's innovativeness. A country needs to be able to measure its technological and innovative capabilities. Since there is no theory nor historical evidence to suggest the appropriate level of innovativeness that countries should accomplish, STI composite indicators have gained their popularities in recent years, as countries use these indicators to benchmark against other countries and define their desired level of technological achievements.

Several authors have developed STI composite indicators on behalf of developed countries context, and the potential of their indicators are mostly limited by the lack of data. It is reasonable after all that developing countries rank low in those composite indicators. But, what we need to address is the composition of the composite indicators. Are these composite indicators the blends of crucial determinants of innovativeness in developing countries and in good proportionate? This study is just about that. I believe that developing countries are different animals from developed ones. They do not necessarily deserve higher ranks in any composite indicators but they do need indicators that reflect their true stages of technological capabilities, allowing them to make good policy decisions and develop relevant and effective public policies on science, technology and innovation. With a novel dataset, this study examines the significant determinants of innovativeness in developing countries and uses these determinants to construct the policy-relevant STI composite indicators for developing countries.

The Predicted Innovativeness Index for Developing Countries (*INNÔDEX*) is developed accordingly. There are some striking features of this indicator. The two sets of frequently-omitted components are proven to be crucial determinants of innovativeness in developing countries thus are used to compute *INNÔDEX*. These include R&D variables and technology imports. Most of the existing STI composite indicators do not use these variables not because they do not recognize the importance of such variables but because there are the data limitation problems (Archibugi and Coco, 2005). But, as the previous chapter presented, these factors are crucial sources of technological development in developing economies. With the increasing availability of data, this study is able to examine empirically the influences of R&D resources and technology imports on developing world's innovativeness.

What is also needed to address here is the limitations of *INNÔDEX*. I believe that no STI composite indicator is a perfect measurement of technological capabilities of countries. Thus, none of STI composite indicators can claim for its superiority in country rankings. Besides, it is always useful to have various STI composite indicators. It is also important to investigate deep into components and methodologies used to construct such indicators. The comparison among several STI indicators would give policymakers a true understanding of their countries' technological capabilities. For *INNÔDEX*, it is for very first time that international statistics are available to conduct an in-depth study of the determination of innovativeness in developing countries, although data limitation and reliability are still major problems confronting this study. Specifically, there are several factors that are critical to technological capabilities of developing economies that cannot be yet considered. For example, education level of population is the very relevant factor. But, with the lack of reliability on such data, I cannot include education level in this study. Therefore, there is high probability that the omitted variable problem still exits. Another limitation lines within the foundation of *INNÔDEX.* The index is only capable of identifying innovative capabilities in manufacturing sectors. On the other hand, a country also needs to measure innovativeness in its service sector, as service sector innovations are also important to a country's competitiveness. However, with data limitation, there is no reliable source of service sector statistics for developing countries that can be introduced in the study. Thus, with several limitations discusses lately, it is recommended to use *INNÔDEX* as the supplement to other STI indicators, either composite or individual ones, for the more complete understanding of national innovative capabilities.

Table 5.2: Partial $\widehat{INNODEX}$ Rankings in Comparison with Other STI Composite Indicators (18 Countries)

Country	$\widehat{INNODEX}$	ArCO Index	ArCO Tech Creation	UNDP TAI	RAND STCI	Porter & Stern NICI
Hungary	1	3	2	2	3	6
Czech	2	2	1	1	1	1
Malaysia	3	10	14	6	14	3
Croatia	4	8	4	7	4	10
Slovak	5	1	3	3	2	4
Bulgaria	6	5	6	4	6	13
Costa Rica	7	11	11	11	11	11
Poland	8	4	5	5	5	2
Chile	9	7	8	12	8	8
Tunisia	10	17	13	17	16	5
Mexico	11	12	12	8	13	12
Romania	12	9	9	10	9	16
China	13	15	16	14	10	7
Brazil	14	14	10	13	12	9
Argentina	15	6	7	9	7	15
Bolivia	16	16	17	15	15	18
Egypt	17	18	15	18	18	14
Peru	18	13	18	16	17	17

Source: UNDP (2001), Archibugi and Coco (2004), Wagner *et al* (2004), Porter and Stern (2001) and Author's

Table 5.3: Correlation Matrix among $\hat{INNODEX}$ and Other STI Composite Indicators

	$\hat{INNODEX}$	ArCO Index	ArCO Tech Creation	UNDP TAI	RAND STCI	Porter & Stern
$\hat{INNODEX}$	1.000					
ArCO Index	0.699	1.000				
ArCO Tech Creation	0.725	0.886	1.000			
UNDP TAI	0.827	0.909	0.835	1.000		
RAND STCI	0.701	0.911	0.932	0.851	1.000	
Porter & Stern	0.709	0.443	0.490	0.521	0.478	1.000

Source: Author's calculation based on Table 5.2

Table 5.4: The Ranking Comparison for the Realized Innovativeness Index ($INNODEX$) and the Predicted Innovativeness Index ($\hat{INNODEX}$)

Rank	$INNODEX$	$\hat{INNODEX}$
1	HUNGARY	HUNGARY
2	ESTONIA	CZECH
3	CZECH REPUBLIC	MALAYSIA
4	MALAYSIA	ESTONIA
5	CROATIA	CROATIA
6	SLOVAK	SLOVAK REPUBLIC
7	RUSSIA	BULGARIA
8	POLAND	UKRAINE
9	ARGENTINA	BELARUS
10	COSTA RICA	PANAMA
11	LITHUANIA	LITHUANIA
12	MEXICO	COSTA RICA
13	BULGARIA	POLAND
14	CHILE	RUSSIA
15	THAILAND	CHILE
16	URUGUAY	TUNISIA
17	VENEZUELA	THAILAND
18	TURKEY	MEXICO
19	BRAZIL	TRINIDAD & TOBACCO
20	UKRAINE	ROMANIA
21	PANAMA	TURKEY
22	GEORGIA	CHINA
23	BELARUS	VENEZUELA
24	ARMENIA	BRAZIL
25	ROMANIA	URUGUAY
26	TUNISIA	ARGENTINA
27	BOLIVIA	AZERBAIJAN
28	CHINA	BOLIVIA
29	EGYPT	ARMENIA
30	COLOMBIA	GEORGIA
31	TRINIDAD & TOBACCO	COLOMBIA
32	AZERBAIJAN	HONDURAS
33	PERU	EGYPT
34	HONDURUS	PERU
Ranking Correlation Coefficient = 0.770		

REFERENCES

Archibugi, D; Coco, A. 2004. A New Indicator of Technological Capabilities for Developed and Developing Countries (ArCO).WORLD DEVELOPMENT 32 (4): 629 – 654.

Archibugi, D; Coco, A. 2005. Measuring Technological Capabilities at the Country Level: A Survey and A Menu for Choice. RESEARCH POLICY 34: 175 – 194.

Archibiugi D; Iammarino, S. The Policy Implications of the Globalisation of Innovation, in Innovation Policy in a Global Economy (Eds.). United Kingdom: Cambridge University Press.

Archibugi, D; Michie, J. 1998. Technical Change, Growth and Trade: New Departures in Institutional Economics. JOURNAL OF ECONOMIC SURVEYS 12(3): 1 – 20.

Archibugi, D; Pianta, M. 1996. Measuring Technological Change through Patents and Innovation Surveys. Technovation 16(9): 451 – 468.

Argenti, G; Filgueira, C; Sutz, J. 1990. From Standardization to Relevance and Back Again: Science and Technology Indicators in Small, Periperhal Countries. WORLD DEVELOPMENT 18 (11): 1555-1567.

Borensztein, E; Gregorio, J; Lee, J. 1998. How Does Foreign Direct Investment Affect Economic Growth? JOURNAL OF INTERNATIONAL ECONOMICS 45: 115 – 135.

Campos, N; Kinoshita, Y. Foreign Direct Investment as Technology Transferred: Some Panel Evidence from Transition Economies. THE MANCHESTER SCHOOL 70: 389 – 419.

Cherchye, L; Moesen, W; Rogge, N; Puyenbroeck, T. 2006. Creating Composite Indicators with DEA and Robustness Analysis: The Case of the Technology Achievement Index. Italy: Joint Research Centre, European Commission..

Cheung, K; Lin, P. 2004. Spillover effects of FDI on innovation in China: Evidence from the Provincial Data. CHINA ECONOMIC REVIEW 15: 25 – 44.

Coe, D; Helpman, E; Hofmaister, A. 1997. North-South R&D Spillovers. THE ECONOMIC JOURNAL 107(440): 134 – 149.

Collecchia, A. 2006. What Indicators for Science, Technology and Innovation Policies in the 21st Century. OECD Blue Sky II Forum Background Paper. OECD.

Desai, M; Fukuda-Parr, S; Johansson, C; Sagasti, F. 2002. Measuring Technology Achivement of Nations and the Capacity to Participate in the Network Age. JOUNRNAL OF HUMAN DEVELOPMENT 3(1): 95 - 122.

Dosi, G. 1998. Sources, Procedures and Microeconomic Effects of Innovation. JOURNAL OF ECONOMIC LITERATURE 36: 1126 – 1171.

Edquist, C. 2005. Systems of Innovation: Perspectives and Challenges, in the Oxford Handbook of Innovation (Eds). London: Oxford University Press.

European Commission. 2004. European Innovation Scoreboard 2004: Comparative Analysis of Innovation Performance. Brussels: European Commission.

Freeman, C. 1993. The 'National System of Innovation' in Historical Perspective. CAMBRIDGE JOURNAL OF ECONOMICS 19(1): 5 – 24.

Freeman, C. 1994. The Economics of Technical Change: A Critical Survey. CAMBRIDGE JOURNAL OF ECONOMICS 18.

Furman, J; Hayes, R. 2004. Catching Up or Stand Still? National Innovative Productivity among 'Follower' Countries, 1978 – 1999. RESEARCH POLICY 33: 1329 – 1354.

Furman, J; Porter, M; Stern, S. 2002. The Determinants of National Innovative Capacity. RESEARCH POLICY 31: 899 – 933.

Gans, J; Hayes, R. 2003. Assessing Australia's Innovative Capacity: 2003 Update. Australia: Melbourne Business School and Intellectual Property Research Institute of Australia, the University of Melbourne.

Gans, J; Hayes, R. 2004. Assessing Australia's Innovative Capacity: 2004 Update. Australia: Melbourne Business School and Intellectual Property Research Institute of Australia, the University of Melbourne.

Gans, J; Hayes, R. 2005. Assessing Australia's Innovative Capacity: 2005 Update. Australia: Melbourne Business School and Intellectual Property Research Institute of Australia, the University of Melbourne.

Gans, J; Hayes, R. 2006. Assessing Australia's Innovative Capacity: 2006 Update. Australia: Melbourne Business School and Intellectual Property Research Institute of Australia, the University of Melbourne.

Gans, J; Stern, S. 2003. Assessing Australia's Innovative Capacity in the 21st Century. Australia: Intellectual Property Research Institute of Australia, the University of Melbourne.

Godin, B. 2001a. The Number Makers: A Short History of International Science and Technology Statistics. Working Paper No. 9, Project on the History and Sociology of S&T Statistics.

Godin, B. 2001b. What's So Difficult About International Statistics? UNESCO and the Measurement of Scientific and Technological Activities. Working Paper No. 13, Project on the History and Sociology of S&T Statistics.

Godin, B. 2002. Are Statistical Really Useful? Myths and Politics of Science and Technology Indicators. Working Paper No. 20, Project on the History and Sociology of S&T Statistics.

Godin, B. 2003. The Most Cherished Indicator: Gross Domestic Expenditures on R&D (GERD). Working Paper No. 22, Project on the History and Sociology of S&T Statistics.

Godin, B. 2004. The Obsession for Competitiveness and Its Impact on Statistics: The Construction of High-Technology Indicators. RESEARCH POLICY 33: 1217-1229.

Godin, B. 2005. The Linear Model of Innovation: The Historical Construction of an Analytical Framework. Working Paper No. 30, Project on the History and Sociology of S&T Statistics.

Griliches, Z. 1990. Patent Statistics as Economic Indicators: A Survey Part I. NBER Working Paper No. 3301. Massachusetts: National Bureau of Economic Research.

Grupp, H; Mogee M. 2004. Indicators for National Science and Technology Policy: How Robust Are Composite Indicators? RESEARCH POLICY 33: 1373 – 1384.

Hagedoorn, J; Cloodt, M. 2003. Measuring Innovative Performance: Is There an Advantage in Using Multiple Indicators? RESEARCH POLICY 32: 1365 – 1379.

Hollenstein, H. 1996. A Composite Indicator of a Firm's Innovativeness: An Empirical Analysis Based on Survey Data for Swiss Manufacturing. RESEARCH POLICY 25: 633 - 645.

Intarakumnerd, P; Viotti, E. 2006. ST&I Indicator for Developing Economies: A Preliminary Mapping of Initiatives and Proposal for the Catch-up Project.

IMD. 2006. World Competitiveness Yearbook. Switzerland: International Institute for Management and Development.

Jones, C. 1995. R&D Based Models of Economic Growth. JOURNAL OF POLITICAL ECONOMY 103: 739 – 784.

Jones, C. 1995. Time Series Tests of Endogenous Growth Models. THE QUATERLY JOURNAL OF ECONOMICS 110(2): 495 – 525.

Katz, J. 2006. Indicators for Complex Innovation Systems. RESEARCH POLICY 35: 893 – 909.

Lall, S. 2001. Competitiveness Indices and Developing Countries: An Economic Evaluation of the Global Competitiveness Report. WORLD DEVELOPMENT 29(9): 1501 – 1525.

Lall, S; Albaladejo, M. 2003. Indicators of the Relative Importance of IPRs in Developing Countries. International Center for Trade and Sustainable Development (ICTSD) and United Nations Conference on Trade and Development (UNCTAD).

Leydesdorff, L. 2006. The Knowledge-Based Economy: Modeled, Measured, Simulated. Florida: Universal Publishers.

Lugones, G; Peirano, F. 2004. Proposal for an Annex to the Oslo Manual as a Guide for Innovation Surveys in Less Developed Countries Non-Member of OECD. RICYT.

Lundvall, B. 1992. National Systems of Innovation - Towards a Theory of Innovation and Interactive Learning. London: Pinter Publishers.

Mani, S. 2000. Exports of High Technology Products from Developing Countries: Is It Real or a Statistical Artifact. Maastricht: The United Nations University Institute for New Technologies (UNU-INTECH)

Moon, H; Lee, J. 2005. A Fuzzy Set Theory Approach to National Composite S&T Indices. SCIENTOMETRICS 64(1): 67 – 83.

Morck, R; Yeung, B. 1999. The Economic Determinants of Innovation. University of Alberta and New York University.

Munda, G; Nardo, M. 2005. Constructing Consistent Composite Indicators: the Issue of Weights. Italy: European Commissions.

Nardo, M; Saisana, M; Saltelli, A; Tarantola, S. 2005. Tools for Composite Indicators Building. Italy: Joint Research Centre, European Commission.

Nardo, M; Saisana, M; Saltelli, A; Tarantola, S; Hoffman, A; Giovannini, E. 2005. Handbook on Constructing Composite Indicators: Methodology and User Guide. OECD.

Nelson, R. 1993. National Innovation Systems: A Comparative Analysis. New York: Oxford University Press.

NEPAD Science and Technology. 2005. African Science, Technology and Innovation Indicators (ASTII): Towards African Indicator Manuals. South Africa.

OECD. 2005. Main Science and Technology Indicators. OECD Publishing.

Patel, P; Pavitt, K. 1994. National Innovation Systems: Why They Are Important, and How They Might Be Measured and Compared. ECONOMICS OF INNOVATION AND NEW TECHNOLOGY 3(1): 77 – 95.

Porter, A.; Roessner, D; Jin, X; Newman, N. 2002. Measuring National 'Emerging Technolgy' capabilities. SCIENCE AND PUBLIC POLICY 29(3): 1 – 12.

Porter, A.; Roessner, D; Newman, N; Jin, X; Johnson, D. 2005. High Tech Indicators: Technology-Based Competitiveness of 33 Nations 2005 Final Report. Atlanta: Technology Policy and Assessment Center, Georgia Institute of Technology.

Porter, M. 1998. On Competition. Boston: Harvard Business School Press.

Porter, M; Stern, S. 1999. The New Challenge to America's Prosperity: Findings from the Innovation Index. Washington, D.C.: Council on Competitiveness.

Porter, M; Stern, S. 2000. Measuring the 'Ideas' Production Function: Evidence from International Patent Output. NBER Working Paper No. 7891. Massachusetts: National Bureau of Economic Research.

Porter, M; Stern, S. 2001. National Innovative Capacity, in the Global Competitiveness Report 2001 – 2002 (Eds.). New York: Oxford University Press.

Porter, M; Stern, S. 2003. Ranking National Innovative Capacity: Findings from the National Innovative Capacity Index, in the Global Competitiveness Report 2003 – 2004 (Eds.). New York: Oxford University Press.

Roessner, D; Porter, A; Newman, N; Jin, X. 2002.A Comparison of Recent Assessments of the High-Tech Competitiveness of Nations. Atlanta, Technology Policy and Assessment Center, Georgia Institute of Technology.

Romer, P. 1990. Endogenous Technological Change. JOURNAL OF POLITICAL ECONOMY 98: S71 - S102.

Romer, P. 1994. The Origins of Endogenous Growth. JOURNAL OF ECONOMIC PERSPECTIVES 8: 3 – 22.

Intarakumnerd, P; Viotti, E. 2006. ST&I Indicators for Developing Economies: A Preliminary Mapping of Initiatives and Proposal for the Catch-up Project.

Saisana, M. 2004. Composite Indicators: A Review. Second Workshop on Composite Indicators of Country Performance. OECD, Paris.

Sala-i-Martin, X; Artadi, E. 2004. The Global Competitiveness Index, in Global Competitiveness Report 2004 – 2005 (Eds). Palgrave Macmillan

Sutz, J. 2006. On Surveys for Studying Innovations as Learning and Designing Policies in Underdevelopment. Uruguay: Universidad de la Republica.

Todo, Y; Miyamoto, K. 2004. Knowledge Spillovers from Foreign Direct Investment and the Role of Local R&D Activities: Evidence from Indonesia. Indonesia.

Yglesias, E. 2003. Porter vs. Porter: Modeling the Technological Competitiveness of Nations. SCIENTOMETRICS 57(2): 281 – 293.

Ulku, H. 2004. R&D, Innovation, and Economic Growth: an Empirical Analysis. IMF Working Paper. International Monetary Fund.

UNESCO. 2003. Immediate, Medium and Longer-term Strategy in Science and Technology Statistics. Montreal: UNESCO Institute of Statistics

UNESCO. 2007. UNESCO Institute of Statistics. Date Accessed in April, 2007 at: http://www.uis.unesco.org/

UN. 2003a. Knowledge Management Methodology: An Empirical Approach in Core Sectors in ESCWA Member Countries. New York: Economic and Social Commission for Western Asia (ESCWA), United Nations.

UN. 2003b. New Indicators for Science, Technology, and Innovation in the Knowledge-Based Society. New York: Economic and Social Commission for Western Asia (ESCWA), United Nations.

UNDP (2001) Human Development Report 2001. Oxford University Press.

UNIDO. 2003. Industrial Development Report 2002/2003: Competing through Innovation and Learning. Vienna: United Nations Industrial Development Organization (UNIDO).

UNIDO. 2004. Industrial Development Report 2004:Industrialization, Environment and the Millennium Development Goals in Sub-Saharan Africa. Vienna: United Nations Industrial Development Organization (UNIDO).

UNIDO. 2005. Industrial Development Report 2005: Capability Building for Catching-Up. Vienna: United Nations Industrial Development Organization (UNIDO).

UNU-INTECH. 2004. Designing a Policy-Relevant Innovation Survey for NEPAD. Maastricht: UNU-INTECH.

USPTO. 2007. United States Patent and Trademark Office. Date Accessed in April , 2007 at: http://www.uspto.gov.

Wagner, C; Brahmakulam, I; Jackson, B; Wong, A; Yoda, T. 2001. Science and Technology Collaboration: Building Capacity in Developing Countries? California: Rand Corporation.

Wagner, C; Horlings, E; Dutta, A. 2002. Can Science and Technology Capacity be Measured? California: Rand Corporation.

WEF. 2001. The Global Competitiveness Report 2001 - 2002. New York: Oxford University Press.

WEF. 2002. The Global Competitiveness Report 2002 - 2003. New York: Oxford University Press.

WEF. 2003. The Global Competitiveness Report 2003 - 2004. New York: Oxford University Press.

WEF. 2004. The Global Competitiveness Report 2004 - 2005. Palgrave Macmillan.

WEF. 2005. The Global Competitiveness Report 2005 - 2006. Palgrave Macmillan.

WEF. 2006. The Global Competitiveness Report 2006 - 2007. Palgrave Macmillan..

World Bank. 2007. World Development Indicators. Date Accessed in April, 2007 at: http://www.worldbank.org/data/wdi

Yglesias, E. 2003. Porter vs. Porter: Modeling the Technological Competitiveness of Nations. SCIENTOMETRICS 57(2): 281 – 293.