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How Innovative Is Your Agriculture? Using Innovation Indicators and Benchmarks to Strengthen National Agricultural Innovation Systems

David J. Spielman
Regina Birner

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Abstract

Agricultural science, technology, and innovation are vital to promoting rural development and poverty reduction. To this end, many studies on agricultural research, extension, and education have highlighted the importance of public investment and policies in these areas. However, as agricultural innovation becomes increasingly viewed as a complex process that defies simple solutions, it has become more and more difficult to identify the types of investment and policy interventions needed to make developing-country agriculture more responsive, dynamic, and competitive.

The "national system of innovation" framework offers an interesting perspective for guiding investment and policy interventions in this area. The framework draws attention to the wide range of actors and organizations from the public, private, and civil society sectors that are involved in bringing new products, processes, and forms of organization into economic use. The framework also emphasizes the role of the institutional and policy environment that affects their performance and behavior. Applying this innovation systems framework is particularly promising for agricultural development because it can help identify where the most binding constraints to agricultural innovation are located and how better to target interventions to remove such constraints.

This paper explores the application of the innovation systems framework to the design and construction of national agricultural innovation indicators. Optimally, these indicators could be used to gauge and benchmark national performance in developing more responsive, dynamic, and innovative agricultural sectors in developing countries. The paper develops a conceptual framework that ties the innovation systems framework to the agricultural sector; reviews how the framework has been used to develop innovation indicators in other fields; discusses a set of potential innovation indicators for developing-country agriculture; and identifies potential data sources and methods for constructing different types of indicators.

Ultimately, the paper aims to inform national and regional stakeholders, policymakers, development partners and researchers who are interested in developing or using indicators as a tool for designing evidence-based agricultural innovation policies.

Acknowledgments

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1. Introduction

Technological change in agriculture is essential to reducing poverty, fostering development, and stimulating economic growth in many developing countries. Hence, the identification of how investments in and policies for improving agricultural education, research, and extension can efficiently promote technological change is an important issue for both researchers and policymakers (Alston, Pardey, and Taylor 2001; Alston, Norton, and Pardey 1998). However, identifying the most promising investments and policy interventions in this field has become a more difficult task as the objectives have shifted from increasing outputs and yields to transforming agriculture into a more responsive, dynamic, and competitive sector.

This shift has become increasingly relevant with the emergence of major structural changes in the global food and agricultural system, including the integration of agriculture into global markets, the emergence of consumers as key drivers of technological change, the growth of private investment in new agricultural technologies, and the revolution in information and communication technologies (World Bank 2006). These factors—combined with the growing recognition that agricultural innovation is far more complex and less linear than once believed—imply a need to refine the conceptual and analytical tools used to identify how policies and investments can best promote innovative behavior and practices in the agricultural sector, thereby promoting poverty reduction and sustainable livelihood improvements among the rural poor.

An increasingly popular mode of analysis to this end is the study of agricultural innovation from a systems perspective—that is, the study of sets of interrelated actors who interact in the generation, exchange, and use of agriculture-related knowledge in processes of social or economic relevance, and the institutional context that conditions their actions and interactions. The approach captures many of the changing realities of developing-country agriculture by going beyond earlier studies that were based on the national agricultural research systems (NARS) and agricultural knowledge and information systems (AKIS) frameworks. Whereas previous studies based on these frameworks focused primarily on the role of education, research, and extension in supplying new knowledge and technology to the farmer, the agricultural innovation system (AIS) approach includes the farmer as part of a complex network of heterogeneous actors engaged in innovation processes, along with the formal and informal institutions and policies environments that influence these processes.

In effect, the AIS framework represents a move away from a more linear interpretation of innovation as a sequence of research, development, and dissemination, to an interpretation that recognizes innovation as a complex web of related individuals and organizations—notably private industry and collective action organizations—all of whom contribute something to the application of new or existing information and knowledge. The framework addresses novel issues such as the capacity of individuals and organizations to learn, change and innovate, the nature of iterative and interactive learning processes among innovation agents, and the types of interventions that enhance such capacities and processes.

To date, however, most AIS studies of developing-country agriculture have focused on the relational aspects of the approach—that is, on an analysis of the ties between public research agencies, private industry, and farmers engaged in specific technological-cum-organizational innovation processes. These studies have mostly dealt with specific commodities or specific technologies but not the wider issues of policy reform or poverty reduction (Spielman 2006).

In other geographic regions and economic sectors, system-based indicators have been used with considerable effect to guide innovation policy, improve innovation performance, and inform national and global discourse on science and technology for innovation. This paper explores how these approaches can be used to similar ends for developing-country agriculture, and what the potential limitations might be. Emphasis is placed on what types of indicators might best measure agricultural innovation performance as well as the inputs, processes, and outcomes that contribute to such performance.

Several recent initiatives of global or regional relevance suggest an acute demand for this type of information and analysis. Initiatives include the African Science, Technology and Innovation Indicators project under the New Partnership for Africa's Development (NEPAD), which is being developed as a tool for African countries to monitor and benchmark the state of their agricultural innovation systems and their contribution to economic and social change and sustainable development (NEPAD 2005). Ideally, such indicator initiatives can be used as focal points for dialogues and consultations into the state of science and technology for innovation in a given country, the causes of relative degrees of success in innovation, and the interventions that might be needed to strengthen a country's innovation system. Thus, this paper contributes to these goals by generating dialogue among policymakers, development practitioners, and researchers on the potential value of indicators to inform national agricultural innovation policymaking.

This paper proceeds as follows. Section 2 provides a conceptual framework describing the AIS approach. Section 3 presents an overview of existing indicators, indices, typologies, and benchmarks developed for the study of innovation. Section 4 discusses the data, data sources, and methods that might be used to design innovation indicators for developing-country agriculture. Section 5 discusses a set of prototype indicators, followed by concluding remarks in Section 6.

2. Conceptual Framework

2.1. The Evolution of the Agricultural Innovation Systems Concept

While the conceptual frameworks used to guide policy analysis on agricultural science, technology, and innovation have changed over time, all have made relevant contributions to the study of agricultural development, economic growth, and poverty reduction (see, e.g., Chema, Gilbert, and Roseboom 2003; Rivera et al. 2006; World Bank 2006). The following provides a brief review of the three most widely used frameworks—the national agricultural research system, agricultural knowledge and information system, and agricultural innovation system approaches—as a departure point for discussion of innovation indicators. Table 1 presents a comparison of these frameworks.

The national agricultural research system (NARS) framework, developed during the 1970s, was informed by neoclassical economics and the inherent failures in the market for agricultural research in developing countries. Although numerous studies had empirically demonstrated that agricultural research generates a high social rate of return in developing countries (Alston et al. 2000), the private benefits of such research were often limited by poor market infrastructure in rural areas and weak purchasing power among farmers, thus requiring public investment to address a chronic undersupply (see Echeverría 1990; Huffman and Evenson 1993; Anderson, Pardey, and Roseboom 1994; Alston, Norton, and Pardey 1998; and Alston, Pardey, and Smith 1999; among others). The NARS framework focused on ways of optimizing the investment in public research organizations—and later, public universities and extension services—as a means of developing technologies to foster agricultural transformation and development.

A broader approach to the study of technological change, economic growth, and poverty reduction was introduced with the agricultural knowledge and information systems (AKIS) framework in the 1980s. Originally, AKIS was defined as

> "a set of agricultural organizations and/or persons, and the links and interactions between them, engaged in such processes as the generation, transformation, transmission, storage, retrieval, integration, diffusion and utilization of knowledge and information, with the purpose of working synergetically to support decision-making, problem solving and innovation in a given country's agriculture or domain thereof" (Röling 1990, 1).

In spite of this wide definition, the AKIS framework was mainly applied in a narrower sense, recasting agricultural research as one point of a "knowledge

Table 1 Frameworks to Support Agricultural Research

Defining feature	NARS: National Agricultural Research Systems	AKIS: Agricultural Knowledge and Information System	AIS: Agricultural Innovation System
Purpose	Planning capacity for agricultural research, technology development, and technology transfer	Strengthening communication and knowledge delivery services to people in the rural sector	Strengthening the capacity to innovate throughout the agricultural production and marketing system
Actors	National agricultural research organizations, agricultural universities or faculties of agriculture, extension services, and farmers	National agricultural research organizations, agricultural universities or faculties, extension services, farmers, NGOs, and entrepreneurs in rural areas	Potentially all actors in the public and private sectors involved in the creation, diffusion, adaptation, and use of all types of knowledge relevant to agricultural production and marketing
Outcome	Technology invention and technology transfer	Technology adoption and innovation in agricultural production	Combinations of technical and institutional innovations throughout the production, marketing, policy research, and enterprise domains
Organizing principle	Using science to create new technologies	Accessing agricultural knowledge	New uses of knowledge for social and economic change
Mechanism for innovation	Technology transfers	Knowledge and information exchanges	Interactive learning
Role of policy	Resource allocation, priority setting	Enabling framework	Integrated component and enabling framework
Nature of capacity strengthening	Strengthening infrastructure and human resources for scientific research	Strengthening communication between actors in rural areas	Strengthening interactions between actors; creating an enabling environment

Source: Adapted from World Bank 2006.

triangle" that also includes agricultural extension and education, and placed the farmer in the middle of this triangle. Still, the AKIS framework succeeded in refocusing the study of technological change on the dissemination and diffusion of knowledge and information, emphasizing specifically the importance of knowledge and information flows between researchers, extension agents, educators, and farmers.

At the end of the 1990s, researchers began to promote another approach: the agricultural innovation systems (AIS) framework. A recent application of this approach by the World Bank (2006) defines an innovation system as

> "a network of organizations, enterprises, and individuals focused on bringing new products, new processes, and new forms of organization into economic use, together with the institutions and policies that affect their behavior and performance. The innovation systems concept embraces not only the science suppliers but the totality and interaction of actors involved in innovation. It extends beyond the creation of knowledge to encompass the factors affecting demand for and use of knowledge in novel and useful ways" (World Bank 2006, vi–vii).

This approach draws on the concept of a "national system of innovation," which emerged in evolutionary economics in the 1980s (see Lundvall 1985, 1988; Freeman 1987, 1988; Nelson 1988; Dosi et al. 1988; and Edquist 1997). The approach was introduced to the analysis of developing-country agriculture mainly as a critique of the "linear" or "pipeline" model of agricultural research that was prominent in the NARS framework (Clark 2002). Thus, it shares important features with the original AKIS concept as the rather similar definitions of AKIS and AIS quoted above imply.

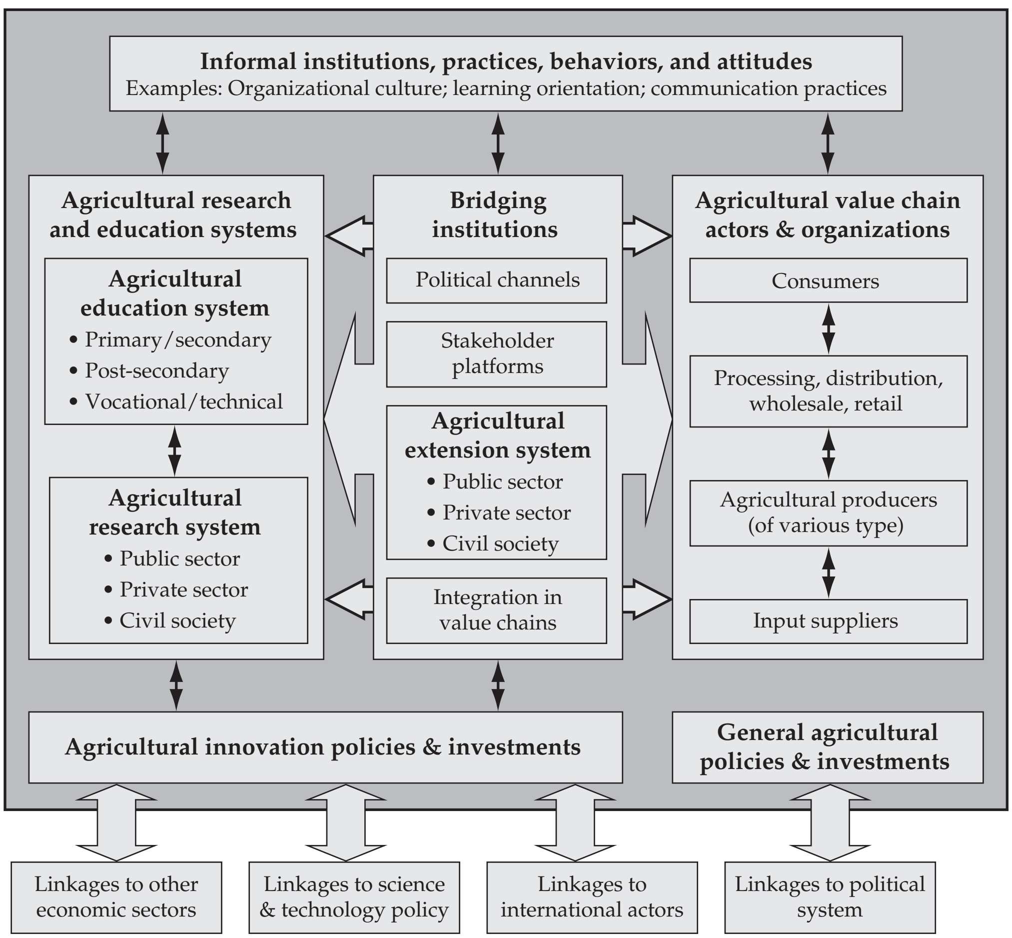
Empirical studies based on the AIS framework highlight the ways in which heterogeneous actors interact in the generation, exchange, and use of information and knowledge; how individuals and organizations learn and change; and how social and economic institutions condition these interactions and processes. Such studies provide new insights into ways of increasing both the efficiency and effectiveness of innovation processes by identifying and exploiting comparative advantages of different actors and organizations; reducing transaction costs in the exchange of knowledge and technology; and achieving economies of scale and scope, exploiting complementarities, and realizing synergies in innovation (Davis et al. 2007). As indicated above, this is particularly important given the changing nature of developing-country agriculture, including the growth of demand-side market forces and consumer preferences, the increasing knowledge intensity of agricultural production, and expanding private investment in new information, communications, and agricultural technology (World Bank 2006).

However, applications of the AIS framework to date have been primarily used to describe innovation processes that underlie the introduction of a given technology (for example, zero tillage cultivation (Ekboir and Parellada 2002); postharvest technologies and value chain development (Clark et al. 2003); and organizational learning and change in research institutes (Hall et al. 1998). Efforts to describe and assess entire national agricultural innovation systems have been scarce in the literature to date. An exception is the study by Temel, Janssen, and Karimov (2002) on Azerbaijan's agricultural innovation system. Moreover, efforts to combine quantitative and qualitative research methods to study innovation systems have been similarly scarce in the literature, despite an extensive parallel literature on innovation in industrialized countries that uses such a combination (see Balzat and Hanusch 2004; OECD 1999, 1997). Thus, the potential offered by the innovation systems approach has yet to be fully utilized in the study of developing-country agriculture.

2.2. The Agricultural Innovation System: A Conceptual Framework

To identify what types of indicators can be used to measure innovation inputs, processes, and outcomes, it is necessary to first develop a conceptual framework that captures the essential elements of a national agricultural innovation system, the linkages between its components, and the institutions and policies that constitute the enabling environment for innovation. Figure 1

Figure 1 A Conceptual Diagram of a National Agricultural Innovation System



Source: Authors; adapted from Arnold and Bell 2001.

presents such a framework, following on a logic that is widely used in the national system of innovation literature.

The essential elements of an innovation system include (a) a knowledge and education domain, (b) a business and enterprise domain, and (c) bridging institutions that link the two domains. The knowledge and education domain is represented at the left-hand side of Figure 1 and is composed of the agricultural research and education systems. The business and enterprise domain is shown on the right-hand side of Figure 1 and comprises the set of value chain actors and activities that both use outputs from the knowledge and education domain, and innovate independently. Between these domains are the bridging institutions—extension services, political channels, and stakeholder platforms—that facilitate the transfer of knowledge and information between the domains.

The framework also includes reference to the frame conditions that foster or impede innovation, including public policies on innovation and agriculture; informal institutions that establish the rules, norms, and cultural attributes of a society; and the behaviors, practices, and attitudes that condition the ways in which individuals and organizations within each domain act and interact.

Implicit throughout the system are farmers—both as consumers and producers of knowledge and information, as producers and consumers of agricultural goods and services, as bridging institutions between various components, and as value chain actors. Beyond the borders of the system, though nonetheless important, are influencing factors such as linkages to other sectors of the economy (manufacturing and services); general science and technology policy; international actors, sources of knowledge, and markets; and the political system.

3. Prior Studies of Innovation Indicators and Benchmarks

The purpose of presenting the framework above is to identify key components of an innovation system that can in turn be measured in terms of inputs, outputs, and processes. This section reviews prior initiatives designed to identify and measure these components or the wider innovation systems at the country level and with respect to the agricultural sector.[1] For a comparison of data from these initiatives, see Table 2.

3.1. General Science, Technology, and Innovation Indicators

The Organisation for Economic Co-operation and Development (OECD) pioneered international efforts to develop innovation indicators in 1963. The publication of the *Proposed Standard Practice for Surveys of Research and Experimental Development* (better known as the *Frascati Manual*) set down a common methodology for collecting and analyzing indicators on science, technology, and innovation in OECD member countries (OECD 2002). The *Frascati Manual* contributed to the design of the *Science, Technology and Industry Scoreboard*, a compilation of OECD country data on innovation in beginning from 1981 (OECD 2005a). The scoreboard provides country-level measures in the areas of research and development, human resources in science and technology, intellectual property rights performance, information and communications technology infrastructure, knowledge flows embedded in trade and investment, and global enterprise and the impact of knowledge on productive activities. New indicators are introduced on a regular basis to capture emerging trends in the region (see Annex A).

OECD efforts to promote data collection and analysis more in line with the innovation systems approach are described in the *Oslo Manual* (OECD 2005b) and, specifically regarding developing Latin American countries, in the *Bogota Manual* (Jaramillo, Lugones, and Salazar 2001). These studies attempt to systematize criteria and procedures for the construction of technological innovation indicators and provide a common methodology for measuring and analyzing innovative procedures.

These manuals also inform the design of an online database on innovation in the Latin America and Caribbean region managed by the Network on Science and Technology Indicators—Ibero-American and Inter-American (known by its Spanish acronym, RICYT). The RICYT database provides country-specific data on science and technology (S&T) inputs (financial and human resources), outputs (patents and publications), and contextual factors (demographic and economic characteristics). The RICYT indicators are compiled based on firm-level surveys, and include such topics as the firm's economic performance, the

Table 2 Innovation Indicators, Various Sources 2000–06

Type	Overall innovation climate	Innovation performance	Competitiveness	Investment in knowledge creation	Investment in knowledge creation
Sector	General	General	General	General	Agriculture
Source	World Bank/K4D	CEC	WEF	OECD	CGIAR/ASTI
Measure	Knowledge Economy Index score[a]	Global Summary Innovation Index score[b]	Global Competitiveness Index score[c]	R&D Intensity[d]	Public sector agricultural R&D intensity[e]
Year	**2006**	**2006**	**2006**	**2003[f]**	**2000[g]**
Europe (EU 25)	—	0.50	—	1.85	—
United Kingdom	8.67	0.57	5.54	1.89	—
Germany	8.48	0.63	5.58	2.55	—
France	8.21	0.56	5.31	2.19	—
Italy	7.66	0.36	4.46	1.16	—
Spain	7.93	0.36	4.34	1.10	—
Asia					
India	2.71	0.17	4.44	—	0.48
China	4.26	0.27	4.24	—	0.37
Vietnam	2.69	—	3.89	—	0.67
Thailand	4.88	—	4.58	—	--
Malaysia	5.69	—	5.11	—	3.64
Indonesia	2.96	—	4.26	—	—
Africa					
Nigeria	1.57	—	3.45	—	0.38
Kenya	2.62	—	3.57	—	2.68
Ethiopia	0.72	—	2.99	—	0.38
Ghana	1.97	—	—	—	0.47
Senegal	2.08	—	—	—	—
South Africa	5.19	0.24		—	3.04

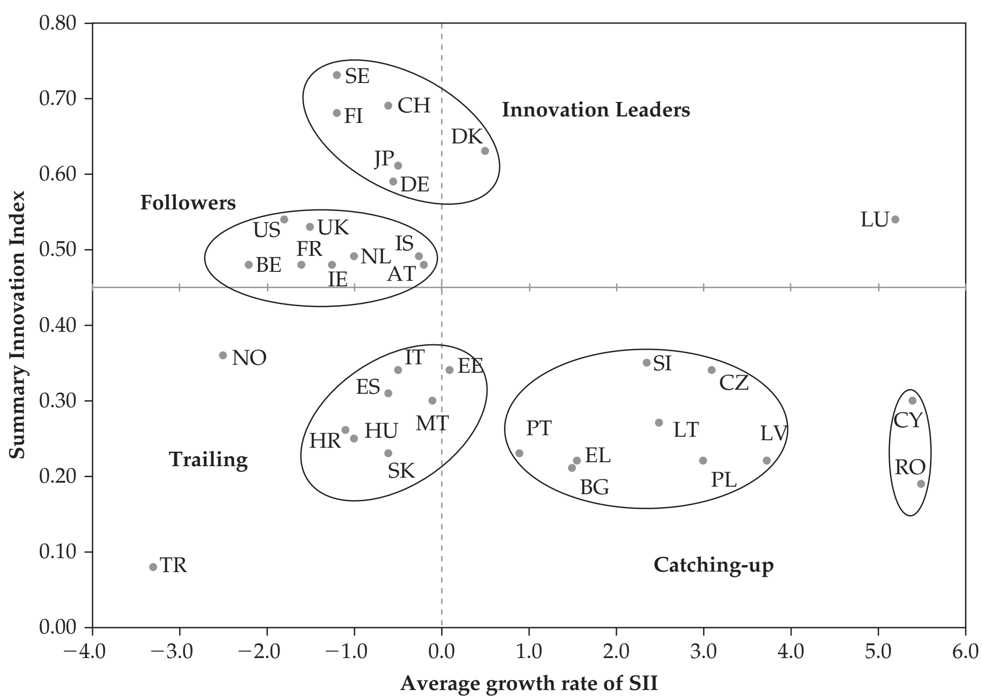
Notes: a. Scores range from 1 to 10. *Source:* KAM 2006.
b. Scores range from 0 to 1. *Source:* CEC 2006.
c. Scores range from 1 to 7. *Source:* WEF 2006.
d. Gross domestic expenditure on R&D as a percentage of GDP. *Source:* OECD 2005a.
e. Gross domestic expenditure on R&D as a percentage of agricultural GDP. *Source:* ASTI 2006.
f. Italy: 2002 instead of 2003.
g. India: 1999 instead of 2000; China 1990 instead of 2000.

size and scope of its innovative activities and investments, its innovation outputs in terms of products and processes, its relationship with the national innovation system, and its assessment of national innovation policies.

The European Innovation Scoreboard (EIS) provides similar analyses by focusing on technical innovation and economy-wide indicators to benchmark the innovative capabilities of European Union (EU) member states, and to provide indicators that complement on-going policy developments within the region (CEC 2006; Hollanders and Arundel 2004). The EIS compiles indicators (ranging from 12 to 20 indicators, depending on data availability) for four main thematic groups: human resources; creation of new knowledge; transmission and application of knowledge; and innovation finance, output, and markets. Unlike the OECD scoreboard, these indicators are normalized and combined into a composite indicator, the Summary Innovation Index (SII), to provide an overview of relative national innovation performance (Annex B). Figure 2 shows how the Summary Innovation Index is mapped to compare trends in innovative performance across countries. Another composite index developed under the same initiative is the Global Summary Innovation Index, which uses 12 of the SII's underlying indicators to compare European innovative performance against other industrialized and developing countries (Figure 3).

The World Bank's Knowledge for Development (K4D) database is a benchmarking tool designed to support the efforts of developing countries to

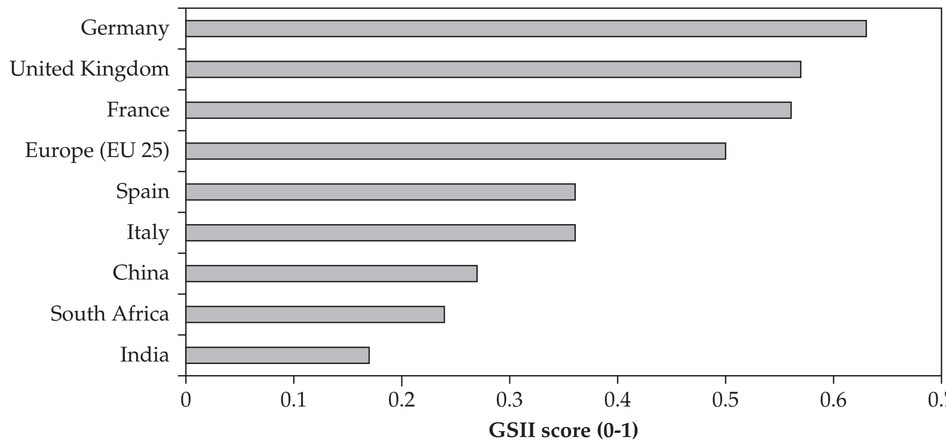
Figure 2 Summary Innovation Index (SII) Scores and Trends



Dotted lines show EU25 mean performance. Summary Innovation Index ranges from 0 to 1.

Sources: CEC 2006; Hollanders 2007, personal communication.

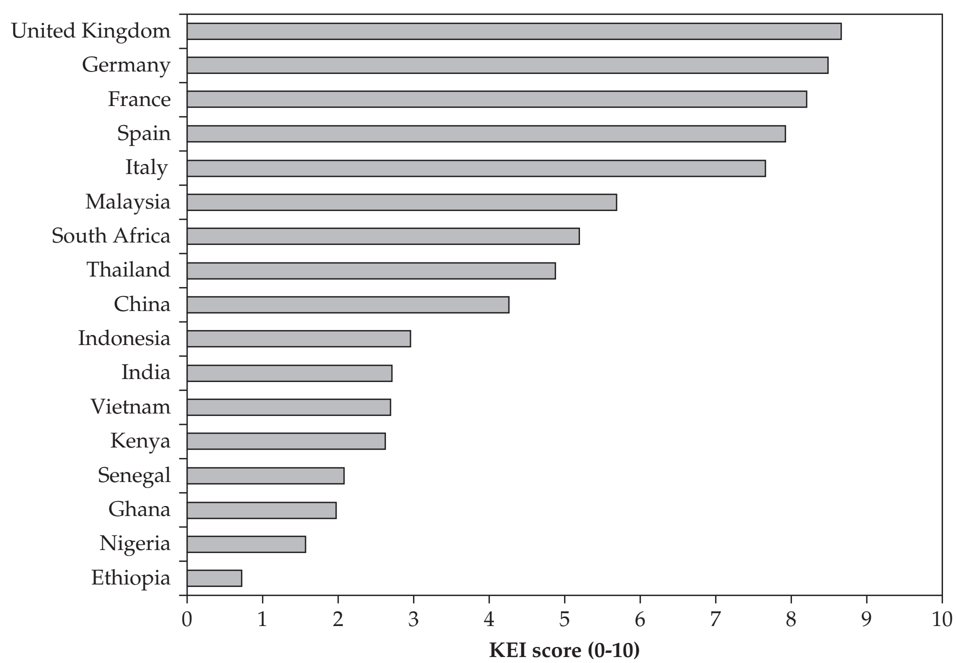
Figure 3 2006 Global Summary Innovation Index (GSII) Score



Source: CEC 2006.

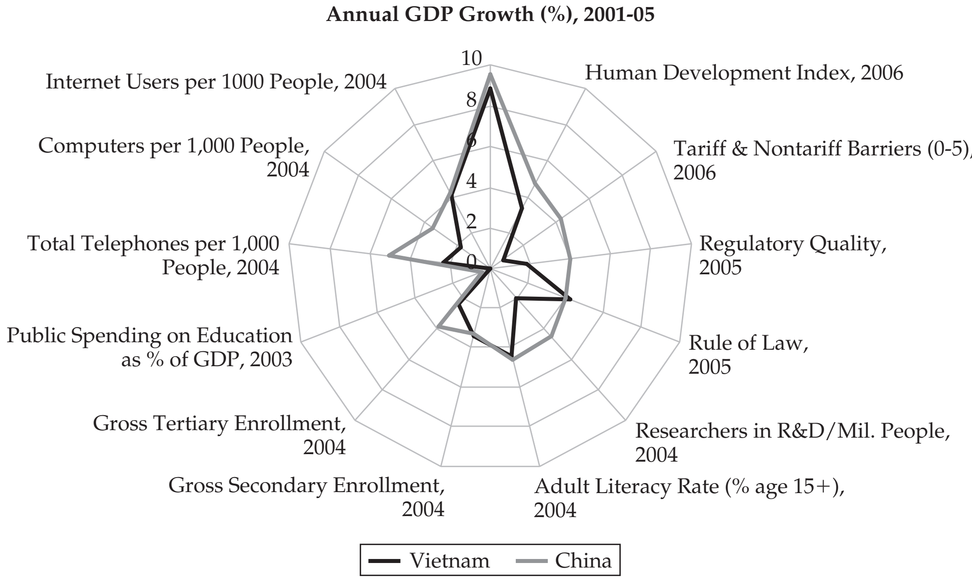
transition into knowledge-based economies (Annex C). The database's conceptual framework describes the knowledge economy in terms of four pillars: (1) economic incentives and institutional regimes, (2) education, (3) innovation, and (4) information and communications technologies (KAM 2006). Approximately 80 indicators across 132 countries are categorized within these four pillars and normalized on a scale of 0 to 10 relative to other countries in a given comparison group. These figures are used to create composite indices such as the Knowledge Economy Index (KEI) (Figure 4), and country or cross-country measures of individual indicators (Figure 5).

Figure 4 Selected Knowledge Economy Index (KEI) Scores, 2006



Source: KAM 2006.

Figure 5 Selected Knowledge Economy Index (KEI) Scores for Vietnam and China, 2006

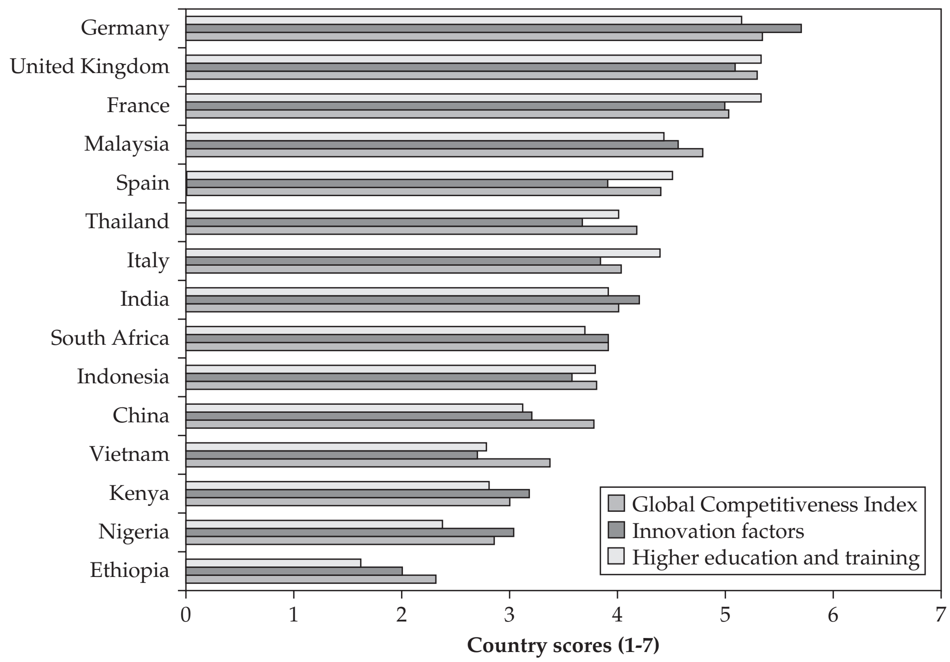


Source: KAM 2006.

The World Economic Forum's Global Competitiveness Index (GCI) combines a range of indicators in a similar manner to measure a country's potential for productivity growth and, ultimately, international competitiveness (WEF 2006). Some 89 indicators are taken into consideration by the GCI and are drawn from both secondary data sources as well as the WEF Executive Opinion Survey. Indicators are categorized under the pillars of institutions, infrastructure, macroeconomy, health and primary education, higher education and training, market efficiency, technological readiness, business sophistication, and innovation; and normalized and weighted for computation of the GCI. Figure 6 gives the GCI scores for selected countries along with their innovation scores (an average of the scores under the business sophistication and innovation categories), and scores for higher education and training (a combination of seven indicators on quality and quality of education and on-the-job training).

The initiatives discussed above highlight several important points for the design of innovation indicators for developing-country agriculture. First, these initiatives generally demonstrate the contribution of innovation, however measured, to economic growth and development and thus the importance of measuring and tracking innovation-related indicators. Second, these initiatives illustrate how different types of data from different data sources—ranging from nationally-reported statistics to expert assessments—can be combined to measure innovation inputs, outputs, and processes. Third, these initiatives demonstrate a certain degree of consistency and commonality in terms of tools and methods used to compile and analyze innovation indicators that can inform the design of agriculture-specific innovation indicators discussed throughout this paper.

Figure 6 Selected Global Competitiveness Index (GCI) Scores, 2006



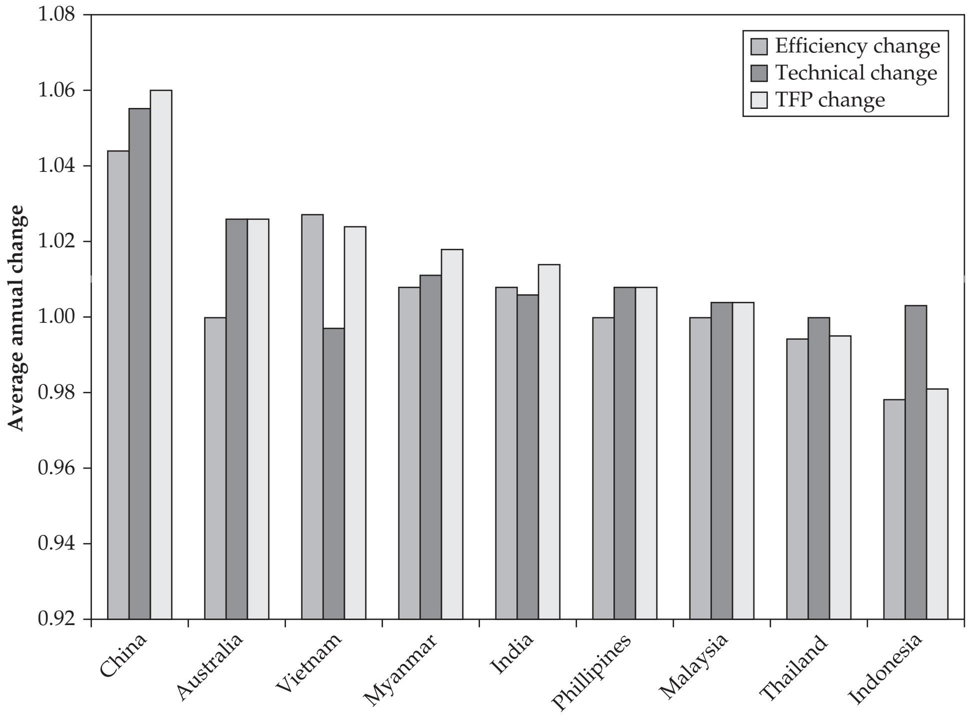
Source: WEF 2006.

3.2. Agricultural Science, Technology, and Innovation Indicators

In the realm of developing-country agriculture, Pardey and Roseboom (1989) and Pardey, Roseboom, and Anderson (1991) provide early attempts to develop systematic indicators on agricultural research.[2] Specifically, their works develop the conceptual foundation for the measurement of NARS investment in research and address issues relating to data availability, reliability, and comparability over time and space. The Agricultural Science and Technology Indicators (ASTI) initiative[3] follows on these works by regularly compiling and analyzing internationally comparable data on institutional developments and investments in agricultural research worldwide (ASTI 2005).

Several other agriculture-related initiatives are also worth noting. Evenson (2003) measures innovative performance with indicators designed to measure country stocks of "innovation capital" and "imitation capital" that rely on indicators for (1) adult male literacy, (2) agricultural research investment/agricultural value added, (3) agricultural extension/agricultural value added, (4) foreign direct investment/GDP, (5) R&D in manufacturing firms/value added, and (6) strength of the intellectual property rights regime. Coelli and Rao (2003) measure innovative performance with a Malmquist Index Analysis of total factor productivity (TFP) growth in agriculture for 93 countries covering the time period 1980 to 2000, providing data on both technical efficiency and technical change (Figure 7). Other studies attempt to compile

Figure 7 Mean Technical Efficiency Change, Technical Change and Total Factor Productivity (TFP) Change in Agriculture, 1980–2000



Source: Coelli and Rao 2003.

and analyze hard-to-get innovation-related indicators such as agricultural research organization performance (Peterson and Perrault 1998); biotechnology research capacity in developing country NARS (Byerlee and Fischer 2000, 2002); private investment in agricultural research in Asia (Pray and Fuglie 2001); and biosafety regulatory regimes (FAO 2003; AGBIOS 2003).

Looking beyond the research and education domains, several other studies identify useful indicators for other AIS components. Rivera and Alex (2004a–e) compile an extensive collection of case studies that offer measures ranging from extension inputs (farmer to extension agent ratios) to processes (methods of consultation between extension agents and farmers), to performance (returns on investment in extension). Kaplinsky and Morris (2001) provide instruction on how to identify and collect data on key indicators of agricultural value chain performance and their contribution to agricultural development. Segnestam (2002) reviews the myriad international efforts to design indicators for environment and sustainable development, and offers insights into several technical aspects of indicator work—concepts, definitions, and selection criteria—as well as the more practical aspects—data availability, quality and collection, and tools for analysis and dissemination. However, very few of these studies have extended their reach to consider the wider innovation systems that underlie developing-country agriculture.

Efforts to develop agricultural innovation indicators also need to be seen in the broader context of recent efforts to develop monitoring and evaluation data for the agricultural sector. The shift from project-based lending to general budget support has motivated donor agencies and international financial institutions to place more emphasis on collecting on agricultural performance indicators and to coordinate their efforts in this regard. In 2006, the Global Donor Platform for Rural Development commissioned a study on "Core Indicators for Agriculture and Rural Development," which will, according to current drafts, include indicators that refer to agricultural research and extension.[4] These efforts build upon earlier compilations of agricultural and rural development indicators (World Bank 1999, 2000; Okidegbe 2000) as well as compilations of project-specific monitoring and evaluation indicators in the agricultural sector (AKIS 2000; Rajalahti, Woelcke, and Pehu 2005; Marchant 2006).

3.3. Epistemological and Methodological Issues

There are several explanations for the current lack of progress in developing comprehensive innovation indicators for developing-country agriculture. A key reason is because the construction of innovation indicators is subject to a range of methodological and epistemological debates, described here.

The epistemological debate relates to the question of whether quantitative measures are able to adequately explain a system that is highly complex, context-specific, and endogenous. Related to this issue is the concern that the use of indicators can even cause damage to the study of innovation as they may focus policy attention narrowly on improving certain indicators that may not have a clearly causal relationship with the innovation process.

At the other end of the spectrum of this epistemological debate is the view that measuring the attributes of an innovation system is key to understanding how policies and investments can improve the outcomes of the system such as national competitiveness, economic growth, and poverty reduction. Necessarily, more work is needed.

The methodological debate refers to how indicators are selected, constructed, and interpreted. Balzat and Hanusch (2004) offer some perspective on the use of quantitative indicators for the study of innovation systems. They argue that while studies in this vein were originally limited to descriptive analyses of country-specific structures and their historical, cultural, and political contexts, recent policy-driven efforts to improve innovative capacity in the European Union and other industrialized countries have led to the increased use of quantitative methods, namely, innovation indicators, indices, benchmarking, and rankings. They conclude that both approaches contribute to an improved understanding of innovation, but that more can be done to strengthen analytical tools and applications to developing countries.

With that said, this paper argues that the collection of data on innovation system inputs, processes, and outcomes is a necessary precondition for cross-country analyses that examine how different components of an innovation system and their relationships affect innovative performance in the agricultural sector. However, several issues arise in the construction of innovation indicators. First is the idea that innovativeness can be reduced to a single index value (much like gross domestic product) for comparison across countries and over time. Second is the hypothesis that the relationship between innovation and the various inputs and processes identified as key determinants is not endogenous. Third is the fundamental issue of availability, both of the data in question and the resources needed to obtain data.

Several other limitations are also worth noting. Tunny (2007), for example, raises issue with the selection and interpretation of indicators. In a critique of recent OECD studies on innovation, he argues that many of the indicators used in these studies are weakly correlated with innovation. He points out that while the OECD interprets R&D intensity or patents per capita as positively correlated to innovation, it could also be argued that such measures may be offset by other innovative activities not captured in the measurements (for example, learning-by-doing or the reorganization of production). Indeed, this criticism is also made with respect to the agricultural sector, where the empirical evidence correlating innovation to plant variety protections and other forms of intellectual property rights is largely inconclusive (Naseem, Omamo, and Spielman 2006).

Grupp and Mogee (2004) take issue with the methods used to construct composite innovation indicators, focusing their critique on the European Innovation Scoreboard. They argue that innovation indicators expressed as multidimensional measures necessarily defy aggregation by some common unit of measure (e.g., monetary value), thus introducing the possibility of improper selection and weighting in the resulting composite indices. They demonstrate the problem by using alternative aggregation procedures to 2001 EIS data to produce a scoreboard with significantly different results.

Katz (2006) raises additional methodological concerns by arguing that scaling correlations that exist between primary measures of an innovation system must be normalized to account for different group sizes. He illustrates the problem by showing how R&D intensity and national wealth scale with the sizes of European countries and Canadian provinces, thus arguing the need for normalization by scale. Tunny (2007) adds the argument that variation in geographical contexts, factor endowments, and industry structure result in similar scaling problems when measuring the relationship between R&D and innovation.

Studies such as these suggest that innovation indicators must meet several criteria to be valid and robust. First, indicators must be selected with a strong theoretical grounding that explains their expected relationship to the performance on the agricultural sector in terms of enhancing agricultural productivity, poverty reduction, and environmental sustainability. Second, indicators must be measurable across both time and space. Third, indices that combine a range of multidimensional indicators (for example, cross-country data on patents per capita, publications per scientist, R&D expenditure per scientist, and R&D intensity) must convert indicators to some common unit and scale that take into account their relative contribution to innovative outcomes and the frame conditions of a given country's innovation system.

Related to the epistemological and methodological debate is the ongoing discussion about the types of analysis required to make innovation indicators relevant for concrete policy advice.[5] From an economic perspective, it can be argued that the relation between input and output indicators needs to be analyzed—not merely indexed—to assess the efficiency of agricultural innovation systems before being able to derive policy recommendations on investment priorities. Fan et al. (2005) and Pardey et al. (2004) apply this approach by using experimental yield data to quantify the role of investments in agricultural research relative to other factors in explaining agricultural sector productivity and its impact on poverty reduction.

In summary, the epistemological and methodological issues discussed here suggest that researchers need to be explicit about the potential and limitations of the indicators they construct. Moreover, researchers must be cognizant of the fact that policymakers and other stakeholders will make their own judgment on how useful innovation indicators are to informing policy choices.

4. Agricultural Innovation Indicators: Methods and Data

4.1. Criteria for Selecting Indicators

The innovation indicators proposed here are selected in accordance with the domains set forth in the conceptual framework above: (a) the knowledge and education domain; (b) the business and enterprise domain; (c) the bridging institutions that link the two domains; and (d) policies, institutions, and frame conditions. Several key criteria are considered as follows.

First, indicators must refer to some measurable phenomenon. However, this does not imply that indicators should be limited strictly to commonly-measured input or output indicators such as public expenditure on agricultural research or the growth rate of agricultural GDP. Process or throughput indicators also play an important part in understanding how innovation occurs within a system, and how processes of learning and change contribute to innovation system performance. Thus, measures such as the number of technological innovations tried or adopted by a farmer, or the number of product or process innovations tried or adopted by a firm, are important to capturing individual and organizational efforts to absorb and apply knowledge and information.

Second, indicators must be relevant to the analysis of innovation in developing-country agriculture. Thus, indicators that may be commonly accepted in the measurement of innovation in industrialized-country manufacturing may not always be relevant. For example, the role of patents, trademarks, and venture capital may not play a significant role in measuring innovation in systems that rely on imitation and adaptation, or are supported almost exclusively by public financing of science, technology, and innovation.

Third, indicators must rely on more than a recombination of existing data. To be sure, few data available from reliable sources address the specificities of developing-country agriculture. Thus, any attempt to develop innovation indicators will likely have to combine hard data from existing accessible sources—published statistics that are compiled based on commonly accepted methods of collection and analysis—with data drawn from expert assessments, such as qualitative assessments carried out with actors who possess some specific knowledge of the indicator in question. Hard data might include such measurements as the number of telephone lines per capita or the number of agricultural patents issued per year. Data drawn from expert assessments might include measures such as the quality of agricultural research institutes and are translated into measurable units using such tools as a Likert scale.

Fourth, indicators must be measured using some type of common unit across all categories. Measurements may thus be classified into three areas:

benchmark, simple, and binary indicators. *Benchmark indicators* capture figures where clearly preferred outcomes exist and where direct or indirect interventions can be employed to generate such outcomes. For example, the clearly preferred outcome for agricultural GDP growth is a positive and high rate, rather than a negative or low rate, against which a given country can employ any number of policy, investment, or other interventions. Benchmarks can be calculated based on the mean value of the given indicator for a subset of several top-performing countries, with appropriate controls for exogenous shocks (for example, natural disasters), volatility from year to year (for example, by using five-year averages rather than single-year observations), and policy distortions (for example, subsidies on agricultural inputs). Benchmark indicators can then be expressed as the percentage difference from a benchmark and scaled to a range between 0 and 100 in the dataset in order to account for the differences in the magnitude and the range of each indicator. *Simple indicators* capture figures not directly linked to clearly preferred outcomes and can be similarly scaled. For example, the proportion of a given country's population residing in rural areas is a simple indicator because direct policy interventions are rarely employed to change this figure. Simple indicators are scaled to a range between 0 and 100 in the dataset. *Binary indicators* reflect figures that are dichotomous in nature and can be scaled accordingly. For example, a country may or may not be a member of the Union for the Protection of Plant Varieties or the World Trade Organization.

4.2. Data and Data Sources

Given these criteria, indicators must be drawn from reliable sources that rely on rigorous data collection methods. Several types of data sources can be identified as follows:

- International sources (data gathered from multicountry databases)
  - Databases focused on economic growth and social development such as the World Bank's World Development Indicators and Aggregate Governance Indicators, or the Food and Agricultural Organization of the United Nation's FAOSTAT
  - Specialized databases such as the CGIAR's ASTI Initiative (ASTI 2005), the Johnson and Evenson Patent Set (JEPS 2004), or various science publications indices
- Government sources (data gathered directly from government documents and statistics)
  - Censuses, statistical compilations, national databases, and official reports on national, sectoral, and industry performance
  - Data on government expenditures and allocations
- Industry sources (data gathered directly from industry or corporate documents)
  - Industry- and firm-level surveys on research and development investment, product and process innovation, and innovation management practices
  - Market- and firm-level analysis reports

- Survey sources
  - Survey data from surveys on household income and expenditure, rural production technology practices, etc.
- Expert sources
  - Data derived from expert opinion polls on agricultural policy, agricultural investment trends, rural household behavior, and other relevant topics
- Other sources
  - Data extracted from research studies on agricultural policy, agricultural investment trends, rural household behavior, and other relevant topics
  - Agricultural development project documents including project descriptions, monitoring and evaluation reports, and impact assessments.

4.3. Empirical Strategies

There are several alternative strategies that could be employed—individually or in combination—to develop cross-country innovation indicators. This applies to both one-time innovation indicators initiatives and long-term, regular exercises designed to collect and analyze indicators across time.

A first strategy might use data from international sources like those mentioned above to create a cross-country index of innovation indicators. Subject to testing for validity and robustness with statistical tools such as factor analysis, such indicators can be used to form a basic benchmarking system.

A second strategy might focus on the collection and analysis of more specific but harder-to-get indicators on AIS inputs, processes, and performance from alternative sources including the government, industry, and other sources noted above.

A third strategy entails the development and deployment of in-depth survey instruments and key informant questionnaires to obtain detailed data on inputs, outputs, and processes from relevant experts. Ideally, these tools could be employed on a regular basis by national-level agencies or organizations so that time series can be compiled. Such tools could build on prior questionnaires developed for the study of agricultural research, extension, and education systems (e.g., Peterson, Gijsbers, and Wilks 2003), and could also include questionnaires that target other components of the pilot countries' innovation systems (e.g., value chains for food staples, high value crops, and livestock). The value of expert surveys as a method to collect data should not be underestimated: Many widely-used international governance data sources, for example, rely on expert assessments, as does the World Economic Forum's Global Competitiveness Index, discussed earlier.

A fourth strategy might employ participatory tools of data collection and analysis to better identify and understand complex system-level processes and their impact on innovation performance. For example, given the emphasis that the innovation systems approach places on system linkages and interactions, the strategy might make use of new analytical tools developed for the collection and analysis of relational data. Influence network mapping might be useful in this context given its ability to provide insight into complex innovation processes by analyzing the networks linking actors involved in such processes, and by assessing the influence these actors have on such processes. Influence network mapping merges characteristics of two existing methods, namely social network analysis and power mapping tools to map the actors involved in a given policy arena, characterize the different kinds of links between actors, assign indicative values to each actor as a means of transferring the abstract concepts of power and influence into more tangible or visible representations, and stimulate structured but in-depth discussions on crucial issues and ways forward for stakeholders (see Schiffer 2007).

Alternatively, the strategy might make use of scenario planning, or structured participatory exercises in which experts provide insights into the future conditions in which a system may operate based on hypotheses about key variables that affect the system, along with the possible outcomes that may result (Rajalahti et al. 2006). When used to anticipate unknown future situations, scenario planning can be used to analyze possible developments that could impact individuals, organizations, or societies, and suggest policy and investment scenarios to address such impacts.

5. A Prototype Set of Agricultural Innovation Indicators

Using the conceptual framework presented above as its foundation, this section discusses a set of potential innovation indicators and their data sources. The list of indicators presented here is not meant to be inclusive or exhaustive; rather, it is offered to illustrate what types of data can be collected and from where in order to map the conceptual framework to potentially measurable indicators. Moreover, many indicators can be disaggregated or recast to provide greater detail or relevance, for example, through breakdowns that isolate gender-based allocations of resources, public versus private sector levels of investment, or national versus per capita levels of performance. Finally, it should be noted that these indicators combine a range of measures, including inputs (materials, information, and tools used in an innovation process), outputs (the goods, services, or knowledge resulting from an innovation process), and the outcomes (the performance that results from an innovation process), all of which are potentially useful to the characterization of an agricultural innovation system.

5.1. Agricultural Innovation Outcomes and Sectoral Performance

Since the performance of an agricultural innovation system influences the overall performance of the agricultural sector, measuring sectoral performance is vital to assessing an innovation system. As discussed earlier, it is a researchable task to identify the relative contribution of the different components of the innovation to overall sector performance. Table 3 lists several agricultural sector performance indicators that are influenced by the performance of the innovation system, dividing them between those that are commonly accepted and used widely in the literature ("classical indicators") and those that are more oriented toward capturing aspects of innovation that are highlighted in the innovation systems literature, such as the demand-orientation, learning processes, interactions and relationships, and informal institutions ("AIS-oriented indicators").

Classical indicators of agricultural sector performance include measures such as agricultural sector growth rates and total factor productivity. The growth rate of the agricultural sector is an important indicator of the sector's potential to contribute to poverty reduction if distributional aspects are taken into account. Increases in agricultural productivity are a major driver of agricultural growth and are an important measure of the sector's competitiveness. Yields for a range of crops—food staple crops, high-value crops, and livestock—are also common indicators of agricultural sector performance. While they capture only outputs rather than inherent input-output relationships, they still reflect both the

Table 3 Indicators of Innovative Outcomes in the Agricultural Sector ("Innovation Outcomes")

Classical indicators	Data sources	AIS-oriented indicators	Data sources
Agricultural GDP and GDP growth rate	International or government sources	Share of farmers who have tried/adopted some new agricultural production practice (e.g., new crop variety or livestock breed)[p, g]	Government or survey sources
Total agricultural factor productivity	International, government, or other sources	Share of farmers who have tried/adopted some new agricultural marketing practice (e.g., pre-production contracts, collective marketing)[p, g]	Government or survey sources
Yields per hectare of major food staple and high value crops/livestock	International, government, or survey sources	Share of farmers who have tried/adopted some new natural resource management technique (e.g., conservation tillage, soil erosion controls, water harvesting)[p, g]	Government or survey sources
Share of cultivable land under modern varieties	Government or survey sources	Share of agricultural firms who have tried/introduced some new product or process innovation	Industry source

Source: Authors.
Notes: p. Disaggregated by income group (poverty).
g. Disaggregated by gender.

availability of yield-increasing technologies and the incentives of farmers to adopt those technologies. Measuring gaps between on-farm yields and yields in countries with comparative agroecological conditions provide additional information on the performance of the innovation system. Measures of cropping area under modern varieties and fertilizer use intensity also point to the ability of the innovation system to make these technologies.

While these indicators are no doubt useful, an AIS-oriented approach argues that more understanding is needed of the *processes* that underlie sectoral performance and the contribution of innovation to performance. Thus, AIS-oriented indicators might measure smallholder innovation processes such as farmer experimentation with new plant varieties or other knowledge and technology generated from foreign or local sources. India's National Sample Survey, for instance, asked farmers whether they had tried some new agricultural practice during the past year, implicitly measuring their efforts to innovate, i.e., to introduce new or existing knowledge into their social or economic practices. Similarly, process-oriented indicators might measure the number of process or product innovations tried or adopted by agroindustrial firms, as measured in the OECD scoreboard described above.

5.2. The Agricultural Research and Education System

Increasingly, agricultural research and education systems in developing countries are expected to do more than maintaining and enhancing agricultural yields and outputs. While these goals remain important to allow agriculture to keep pace with population growth, research and education organizations are also being called upon to generate knowledge and technology that add value to processes ranging from on-farm production to processing, distribution, packaging, marketing, and, ultimately, consumption. This suggests the need to strengthen the ways in which research and education contribute to enhancing the innovative capabilities of both individuals and organizations, or their ability to identify and use novel or existing information to create new products and processes.

Table 4 lists several indicators that refer to the agricultural research and education component of the agricultural innovation system, again divided between commonly used and systems-oriented indicators. Common input indicators include public agricultural research and education spending (measured as a percentage of agricultural GDP) and full-time equivalent (FTE) staffing in public organizations (by degree, gender, area of specialization; and measured in terms of per-FTE spending). Common output indicators include the number of international journal publications published per year by researchers and the number of new plant varieties or livestock breeds released per year. While these indicators are typically measured in terms of public sector research and education—representing the lion's share of expenditure on science and technology in developing countries—consideration should also be given to the private sector, particularly in those countries where private investment in research and education is rising rapidly.

Table 4 Research and Education in the Agricultural Sector

Classical indicators	Data sources	AIS-oriented indicators	Data sources
Expenditure on agricultural research and education[s]	International or government sources	Share and quality of research that are based on collaborations among innovation system actors[s]	Government, expert, or other sources
Number of agricultural researchers and educators by degree and area of specialization[s,g]	International or government sources	Share of research and education expenditures that involve multiple stakeholders in (a) priority setting and strategic planning or (b) decision making and resource allocation[s]	Government, expert, or other sources
Number of new plant varieties, livestock breeds, natural resource management techniques, or other technologies released[s]	International or government sources	Frequency of priority setting, strategic planning, and reform exercises in research and education institutions[s]	Government, expert, or other sources
Number of international journal publications per agricultural researcher	International or government sources	Extent of individual or organizational membership in regional and international research and education networks[s]	International or government sources
Enrollment rates in primary, secondary, or tertiary levels of agricultural education[s,g]	International or government sources	Quality of information and communications technology available to the research and education system[s]	International or government sources
Number of plant variety protection certificates, agricultural patents, approvals for field testing, or approvals for commercialization issued	International, government, or industry sources	Share of agricultural students sent abroad for advanced training; share of agricultural graduates that leave the sector or country for other opportunities[g]	International, government, or other sources

Source: Authors.
Notes: s. Disaggregated by public, private, and civil society sectors where applicable.
g. Disaggregated by gender.

Other commonly used indicators capture research and education system outcomes in terms of scientific outputs such as the number of plant variety protection certificates, patents, or other forms of intellectual property rights granted for specific agricultural crops and technologies; approvals granted for field testing or commercialization of new crop technologies in areas such as advanced biotechnology. Still other indicators include comparisons of the gaps between on-farm yields and research station yields or comparator country yields.

More system-oriented indicators might include measures of the research and education system's degree of integration or connectedness, and thus its relevance to the wider innovation system. For example, a key indicator might be the quality of information and communications technology (ICT) available to research and education institutions. Another indicator might measure the number and size of research collaborations among key system actors, primarily public research organizations, public universities, international agricultural research organizations, private companies, nongovernmental organizations, and rural producer or community-based organizations (see for example Giuliani and Bell 2005).

Indicators on the particular type of collaborative arrangements also provide insight into the relative maturity of these innovation systems to leverage and manage diverse relationships as a means of promoting innovation. Arrangements—categorized along a continuum of, say, increasing complexity or cost—include technology transfers, humanitarian donations of intellectual property, research subcontracting arrangements, research directly financed by producer organizations, competitive research grant schemes, public-private partnerships, and research prize schemes. A related measure is the extent to which these same actors participate in research priority setting and strategic planning, or decision making and resource allocations for research and education; and the number of years that lapse between priority setting or strategic planning exercises that result in necessary reforms to the structure, agenda, or activities of different organizations and the system as a whole.

Other measures in this vein include the degree to which researchers and research organizations are connected to regional and international research networks, whether through professional associations, network-based research programs, or global and regional research forums. Additional measures include the level of student sponsorships for advanced studies abroad less losses attributable to brain drain from the agricultural research and education domain.

5.3. Agricultural Value Chains

As noted above, the agricultural value chains represent the business domain in the agricultural innovation system. An agricultural value chain describes the full range of activities required to bring agricultural goods or services through different phases of production, delivery to final consumers, and final disposal after use, and it incorporates a range of activities within each phase, including both input supply and output marketing systems (Kaplinsky and

Morris 2001). Importantly, the value chain functions not only as an end user of research and education system outputs, but also as a driver of their outputs and a source of its own product and process innovation.

Table 5 lists several indicators that can be used to characterize the structure, function, and performance of a given value chain, implicitly capturing the contribution of technological, organizational, or institutional innovation. Classical indicators focus on the level and growth of value chains as a share of the agricultural sector, the returns to value addition at each point along the chain, and the distribution of value among different actors in the chain.

From a system-oriented perspective, indicators might focus more on measuring how different value chain arrangements integrate actors within a given point along the chain, coordinate between different points along the chain, govern key relationships throughout the chain, and foster competitiveness. Indicators in this vein shed light on the processes that determine an actor's ability to overcome barriers to entry and other market failures to ensure their ability to capture economic rents generated by the value addition process.

Integration, for example, includes indicators on the extent to which farmers rely on collective marketing of commodities via rural producer associations to secure higher prices. Coordination indicators measure how different types of contracting arrangements minimize transaction costs within a value chain—for example, whether market exchanges, formal contracts, or vertical integration of a value chain improves the delivery of goods and services of desired quantity, quality, and timeliness. Governance indicators focus on measuring the existence and effectiveness of weights, standards, quality assurance, or environmental safety systems. Competition indicators measure the size or sophistication of the supplier networks and business operation strategies of firms and other organizations throughout the value chain.

5.4. Bridging Institutions

Among the bridging institutions, agricultural extension systems represent one of the most critical institutions with respect to the small-scale, resource-poor farmer and other agricultural producers. As defined here, agricultural extension includes all agricultural advisory services that support and facilitate people engaged in agricultural production to solve problems and to obtain information, skills and technologies to improve their livelihoods and well-being (Birner et al. 2006). This includes advisory services provided by the public sector, the private sector, and nongovernmental organizations and rural producer organizations.

Past approaches to agricultural extension have often relied on technology transfers based on the dissemination of modern input packages, typically improved seed and chemical fertilizer, through public extension services. The growing participation of other sources of information and advice for farmers suggests the need for a better understanding of alternative approaches to address different country-specific conditions. In particular, this calls for: closer analysis of alternative approaches to (a) governance, (b) organization,

Table 5 Value Chains in the Agricultural Sector

Classical indicators	Data sources	AIS-oriented indicators	Data sources
Share and growth rate of agricultural value chains in overall agricultural sector value added	Government or industry sources	Share of farmers who say that they have access to/are satisfied with agricultural inputs, financial services, transportation services, and marketing services[p,g]	Government, industry, survey, or other sources
Share of farm output that is marketed commercially; share of farmers engaged specifically in value chain activities[p,g]	Government, industry, survey, or other sources	Quality of interactions among actors in a specific value chain in terms of product and process innovation	Government, industry, survey, or other sources
Value of private firms operating in the production, processing, distribution, or marketing of agricultural inputs or outputs	Government, industry, survey, or other sources	Share of farmers participating in different types of value chain arrangements, e.g., membership in a producer organization, preproduction contracts with agricultural firms, or market-based sales of output[p,g]	Government, industry, survey, or other sources
Share of value added domestically to a commodity within a specific value chain; Share of free on board (FOB) price retained by farmers for specific value chains	Government or industry sources	Quality of standardization systems or their implementing agencies	Government, industry, survey, or other sources
Share of value added at each point along a specific value chain (production, processing, distribution, certification, marketing, branding)	Government, industry, survey, or other sources	Share of actors adhering to certain product or process standards within a specific value chain	Government, industry, survey, or other sources
Return on net assets for households and firms operating at all points along a specific value chain[p]	Government, industry, survey, or other sources		
Degree of market or price volatility for a specific commodity; share of value chain actors with access to risk management arrangements	Government, industry, survey, or other sources		

Source: Authors.
Notes: p. Disaggregated by income group (poverty).
g. Disaggregated by gender.

management, and financing, and (c) educational and advisory methods; as well as better analysis of the wider context in terms of (a) policy environment, (b) capacity of potential service providers, (c) type of farming systems and degree of market access, and (d) the nature of local communities, including their ability to cooperate (Birner et al. 2006).

Beyond extension, there is also a range of other institutions that link value chain actors with the agricultural research and education systems. Such institutions may include political bodies through which actors may exercise voice and demand accountability or stakeholder platforms and advisory councils that operate to similar ends. Agricultural value chains may also integrate research, education, and extension directly. For example, input supply or commodity marketing companies may operate their own research programs that link directly with farmers on a contract basis.

It is important to recognize that innovation often relies on a diversity of bridging institutions. The full range of institutional forms might be described as a set of "networks" that address the fundamental economic constraint underlying innovation—the scarcity of resources with which to innovate (Davis et al. 2007).

Different actors integrate into innovation networks to achieve economies of scale and scope, reallocate labor and human capital more efficiently, reduce transactions costs, exploit complementarities, and realize synergies in the innovation process. These networks can vary from informal interactions between extension agents and farmers to promote a new plant variety to very complex contracts between public researchers and private firms to conduct research in advanced biotechnology. Thus, the innovation process resembles a complex web of related but diverse individuals and organizations, all of whom contribute something to the application of new or existing information and knowledge (Davis et al. 2007).

Table 6 presents a set of indicators that refer to the bridging institutions in an agricultural innovation system. The role of bridging institutions in tying the distinct domains of an innovation system can be measured by several proxies. Given the importance of agricultural extension as a bridging institution, public expenditure on extension (as a percentage of agricultural GDP) and the number of full-time equivalent extension agents (by degree, gender, area of specialization; and per capita) are appropriate input measures.

Complementary indicators include measurements of the gap between research station yields and on-farm yields have typically been interpreted as indicators of the performance of the agricultural extension system and the factors that influence farmers' incentives to adopt new technologies. From an innovation systems perspective, gaps between research station and on-farm yields may also indicate a lacking demand-orientation of the agricultural research system, pointing to deficits in bridging institutions that go beyond the performance of agricultural extension.

More system-oriented indicators include measures such as the share of public expenditure on extension that involves other innovation system actors in

Table 6 Bridging Institutions in the Agricultural Sector

Classical indicators	Data sources	AIS-oriented indicators	Data sources
Public expenditure on agricultural extension	Government sources	Share and quality of extension services that are based on collaborations among innovation system actors[s]	Government, survey, expert, or other sources
Number of agricultural extension agents by degree and area of specialization[g,s]	Government or survey sources	Share of extension expenditures that involve multiple stakeholders in (a) priority setting and strategic planning or (b) decision making and resource allocation[s]	Government, survey, expert, or other sources
Share of farmers with regular access to extension services; ratio of farmers to extension agents[p,g]	Government or survey sources	Frequency of priority setting, strategic planning, and reform exercises in extension services[s]	Government, survey, expert, or other sources
Percentage of farmers reporting satisfaction with the quality and timeliness of extension services[p,g,s]	Government or survey sources	Number of different consultation methods used by extension services[s]	Government, survey, expert, or other sources
Share of state subsidy and farmer copayment in extension services	Government or survey sources	Frequency of training and skills upgrading for extension agents[s,g]	Government, survey, expert, or other sources
		Quality of extension services with respect to enhancing agricultural production, managing natural resources, and facilitating market linkages for farmers[s]	Government, survey, expert, or other sources

Source: Authors.
Notes: s. Disaggregated by public, private and civil society sectors where applicable.
p. Disaggregated by income group (poverty).
g. Disaggregated by gender.

decision making; or a quantitative assessment of the quality of linkages between extension services and other system actors. Output measures include estimates of the proportion of farmers with regular access to extension services and the proportion of farmers reporting satisfaction with the quality of extension services.

5.5. Policies, Institutions, and Frame Conditions

Agricultural policies, formal and informal institutions, and general conditions in the agricultural sector describe the enabling environment for agricultural innovation. Table 7 lists a set of broad indicators that refer to the enabling environment. Necessarily, measurements of these indicators would require measurement of a range of related sub-indicators.

Agricultural innovation policies are those policies designed to enhance a country's capacity to innovate in the agricultural sector. Innovation policies operate on both the formal and informal sources of innovation. Thus, while innovation policies may target the development of formal national agricultural research and extension organizations, other policies may emphasize efforts to promote local innovation by extending credit to small-scale entrepreneurs and artisans.

Based on the innovation systems framework developed here, innovation policies can be classified into three categories: (a) policies designed to create and strengthen the formal organizations and institutions needed to generate and apply new or existing information; (b) policies that support and facilitate innovation among system actors, including farmers; and (c) policies that integrate and intermediate among public, private, and civil society actors engaged in innovation processes. Potential indicators on agricultural innovation policy include expert assessments of policies on agricultural research, education, and extension/advisory services, or membership in international regimes such as the International Union for the Protection of New Varieties of Plants (UPOV), or the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA).

In many countries, there are considerable gaps between the policies that exist in the form of written laws, statutes, or regulations; and their actual implementation and enforcement. Hence, consideration of both legislation *and* implementation—specifically, the allocation of public resources n support of articulated policies and strategies—requires special attention.

General agricultural policies influence the agricultural innovation system in a more indirect way than agricultural innovation policies. They include policies that create economic incentives and regimes that are fundamental to growth and development, including policies on market efficiency and infrastructure, international trade, physical infrastructure, banking and financial services, property rights, and so on. Potential indicators on general agricultural policy include measures of agricultural sector protection or taxation, the ratio of agricultural investment to agricultural subsidies, and general indicators of the investment climate, including membership in the World Trade Organization and related treaties, conventions, and regimes.

Table 7 The Enabling Environment for Agricultural Innovation

Classical indicators	Data sources	AIS-oriented indicators	Data sources
Agricultural innovation policies and investments			
Membership in the international treaties, conventions, and regimes including UPOV, ITPGRFA, and the Cartegena Protocol	International or government sources	Quality of policies on agricultural research, education, and extension/advisory services	Expert and other sources
		Quality of legislation and enforcement of intellectual property rights	International, expert, and other sources
		Quality of legislation and enforcement of biosafety and food safety regulations	Expert and other sources
General agricultural policies and investments			
Ratio of agricultural investment to agricultural subsidies	International or government sources	Quality of government effectiveness and quality of agricultural regulation	International, expert, and other sources
Rate of agricultural protection or taxation	International or government sources	Quality of invest-ment climate or competitiveness of agricultural sector	International, expert, and other sources
Rural infrastructure			
Road density, average distance of farm households to markets	International or government sources		
Share of rural households with access to fixed or mobile telephone lines and Internet services	International or government sources		
Informal institutions and frame conditions			
Share of rural population in total population	International or government sources	Level of entrepreneurial activity or behavior in the rural economy	Expert and other sources
Rural labor force with primary, secondary, or tertiary education or rural enrollment rates[p,g]	International or government sources	Quality of rural innovation system and local innovation networks and partnerships	Expert and other sources
Rate of rural infant mortality, access to safe drinking water, and related health and nutrition indicators[p,g]	International or government sources	Level of openness to indigenous or foreign knowledge sources[s]	Expert and other sources

Source: Authors.
Notes: s. Disaggregated by public, private, and civil society sectors where applicable.
p. Disaggregated by income group (poverty).
g. Disaggregated by gender.

Informal institutions and frame conditions. An agricultural innovation system is also influenced by informal institutions—the shared beliefs, cultures, practices, behaviors, and attitudes that are specific to a given country, group, or organization in a system. These institutions include the "propensity" to innovate; the cultural tendency to promote entrepreneurship; the extent of trust and respect among actors (for example, between public sector and private sector organizations); the attitudes of different actors toward risk and their orientation toward individual and social learning; or the prevailing political and bureaucratic cultures. These informal factors are often the consequence of the incentives that different actors face. Though difficult to measure, these factors nonetheless require special attention when studying a country's innovation potential and performance. Potential measures might be derived from expert assessments of an innovation system and its constituent components.

5.6. Beyond the System's Borders: The External Environment

An agricultural innovation system is also influenced by the actors, organizations, institutions, and policies that are outside the boundaries of the innovation system. What is to be considered "inside" and "outside" is obviously a matter of definition and conceptualization. The linkages between the agricultural innovation system and other economic sectors are important because other sectors (such as the manufacturing or service sectors) create demand for agricultural products, thus creating incentives for process and product innovation. These same sectors also supply new knowledge and information applicable or adaptable to the agricultural sector in the form of technological or organizational innovation.

The influence of general policies on science and technology for innovation are similarly important because they often drive the formulation and implementation of both agricultural and agricultural innovation policies, as do general economic policies such as investment, trade, money and banking, and infrastructure development. Related to this is the quality of governance, the structure of the political system, the openness of the economy, and the nature of linkages to international or regional organizations, conventions, and treaties. While many of these factors may not be described as directly influencing a country's agricultural innovation system, they are nonetheless indicators that are important to fully understanding a given country's agricultural innovation system.

6. Concluding Remarks

This paper has applied the national innovation systems framework to the agricultural sector with the aim of identifying potential indicators that can inform agricultural innovation policy and policymakers. The paper has also attempted to provide the methodological basis for constructing innovation indicators based on this framework. Ultimately, such indicators can be used as static measures of innovativeness within the agricultural sector of a given country; as comparative measures of agricultural innovativeness across several countries; and—if data collection can be organized as an ongoing process—as dynamic measures that track changes over time. Importantly, the collection of innovation indicators is an important precondition to improving our understanding of how to promote more responsive, dynamic, and innovative change in developing-country agriculture.

Indicator exercises such as this can play a potentially important role in facilitating dialogues and consultations into the state of science and technology for innovation in a given country, the causes of relative degrees of success in innovation, and the interventions that might be needed to strengthen a country's innovation system. This paper can be viewed as a starting point in the process of developing agricultural innovation indicators and a platform from which to obtain feedback from stakeholders, policy-makers, and the research community. Ultimately, the goal of this approach is to inform policy dialogues on agricultural innovation policy and to help identify priority areas for investments, policies, and other interventions that aim at improving the innovative performance of agriculture with a view to poverty reduction and environmental sustainability.

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Annex A: OECD Science, Technology, and Industry Indicators

Source: OECD 2005a

A. R&D and innovation: creating and diffusing knowledge

A.1. Investment in knowledge
A.2. Trends in domestic R&D expenditure
A.3. R&D financing and performance
A.4. R&D in non-OECD economies
A.5. Business R&D
A.6. Business R&D by size classes of firms
A.7. Business R&D by industry
A.8. Health-related R&D
A.9. R&D linkages
A.10. Internationalization of manufacturing R&D
A.11. Government R&D budgets
A.12. Tax treatment of R&D
A.13. Innovation in small and medium-sized firms
A.14. Scientific articles
A.15. Venture capital

B. Human resources in science and technology: knowledge and skills

B.1. Flows of university graduates
B.2. International mobility of doctoral students
B.3. S&E doctorates and postdoctorates to foreign citizens in the United States
B.4. Employment of tertiary-level graduates
B.5. Human resources in science and technology
B.6. International mobility of the highly skilled
B.7. R&D personnel
B.8. Researchers
B.9. Foreign scholars in the United States
B.10. Human resources in S&T in non-OECD economies

C. Patents: protecting and commercializing knowledge

C.1. Triadic patent families
C.2. Patent intensity
C.3. Patent applications to the European Patent Office
C.4. ICT-related patents

C.5. Biotechnology patents
C.6. Foreign ownership of domestic inventions
C.7. Domestic ownership of inventions made abroad
C.8. International cooperation in patenting activity
C.9. Internationalization of ICT-related inventions
C.10. Internationalization of biotechnology inventions
C.11. Geographic concentration of patents

D. ICT: an enabler for the knowledge society

D.1. Investment in ICT equipment and software
D.2. ICT occupations and skills
D.3. Telecommunications networks
D.4. Internet hosts and domain names
D.5. Internet subscribers and secure servers
D.6. Broadband and security
D.7. ICT access by households
D.8. Use of the Internet by individuals
D.9. Internet use by businesses
D.10. Electronic commerce volume
D.11. Internet commerce activity
D.12. Telecommunication pricing
D.13. ICT in non-OECD economies
D.14. Size and growth of the ICT sector
D.15. Contribution of the ICT sector to employment
D.16. International trade in ICT goods
D.17. R&D in selected ICT industries

E. Knowledge flows and the global enterprise

E.1. Trends in international trade and investment flows
E.2. International trade
E.3. Exposure to international trade competition by industry
E.4. Intrafirm trade
E.5. Foreign direct investment flows
E.6. Activity of affiliates under foreign control in manufacturing
E.7. Activity of affiliates under foreign control in services
E.8. Trends in the employment of foreign affiliates
E.9. Share of turnover under foreign control in selected manufacturing and services sectors
E.10. The contribution of multinationals to value added and labor productivity
E.11. The contribution of multinationals to productivity growth
E.12. Technological balance of payments

F. The impact of knowledge on productive activities

F.1. Income and productivity levels
F.2. Labor productivity growth
F.3. Growth accounts for OECD countries

F.4. Labor productivity growth by industry
F.5. Technology- and knowledge-intensive industries
F.6. The structure of OECD economies
F.7. International trade by technology intensity
F.8. Exports from high- and medium-high-technology industries
F.9. Contributions to the manufacturing trade balance
F.10. The interdependence of services and manufacturing
F.11. The changing nature of manufacturing

Annex B: European Innovation Scorecard (EIS) Indicators

Source: CEC 2006

1. Human resources

1.1 S&E graduates (% of 20–29 years age class)
1.2 Population with tertiary education (% of 25–64 years age class)
1.3 Participation in lifelong learning (% of 25–64 years age class)
1.4 Employment in medium-high and high-tech manufacturing (% of total workforce)
1.5 Employment in high-tech services (% of total workforce)

2. Knowledge creation

2.1 Public R&D expenditures (% of GDP)
2.2 Business expenditures on R&D (% of GDP)
2.3.1 EPO high-tech patent applications (per million population)
2.3.2 USPTO high-tech patents granted (per million population)
2.4.1 EPO patent applications (per million population)
2.4.2 USPTO patents granted (per million population)

3. Transmission and application of knowledge

3.1 SMEs innovating in-house (% of all SMEs)
3.2 SMEs involved in innovation cooperation (% of all SMEs)
3.3 Innovation expenditures (% of total turnover)
3.4 SMEs using nontechnological change (% of all SMEs)

4. Innovation finance, output and markets

4.1 Share of high-tech venture capital investment
4.2 Share of early stage venture capital in GDP
4.3.1 Sales of “new to market” products (% of total turnover)
4.3.2 Sales of “new to the firm but not new to the market” products (% of total turnover)
4.4 Internet access
4.5 ICT expenditures (% of GDP)
4.6 Share of manufacturing value-added in high-tech sectors

Annex C: Knowledge For Development (K4D) Indicators

Source: KAM 2006

1. Overall performance of the economy

1.1 Average annual gross domestic product (GDP) growth (%)
1.2 Gross domestic product (GDP) per capita, 2005
1.3 Gross domestic product (GDP)
1.4 Human development index (HDI)
1.5 Poverty index (UNDP)
1.6 Composite risk rating
1.7 Unemployment rate (% of total labor force)
1.8 Employment in industry (% of total employment)
1.9 Employment in services (% of total employment)

2. The economic regime

2.1 Gross capital formation as % of GDP (Average)
2.2 Trade as % of GDP
2.3 Tariff & nontariff barriers, 2006 (Heritage Foundation)
2.4 Intellectual property protection, 2006 (2006/7 WEF Global Competitiveness Report)
2.5 Soundness of banks, 2006 (2006/7 WEF Global Competitiveness Report)
2.6 Exports of goods and services as % of GDP, 2004
2.7 Interest rate spread (lending rate minus deposit rate)
2.8 Intensity of local competition, 2006 (2006/7 WEF Global Competitiveness Report)
2.9 Domestic credit to private sector (% of GDP)
2.10 Cost to register a business (% of GNI per capita) (doing business)
2.11 Days required to start a business (doing business)
2.12 Cost to enforce a contract (% of debt) (doing business)

3. Governance

3.1 Regulatory quality (Governance Indicators, World Bank)
3.2 Rule of law, 2005 (Governance Indicators, World Bank)
3.3 Government effectiveness (Governance Indicators, World Bank)
3.4 Voice and accountability (Governance Indicators, World Bank)
3.5 Political stability (Governance Indicators, World Bank)
3.6 Control of corruption (Governance Indicators, World Bank)
3.7 Press freedom (Freedom House)

4. The innovation system

4.1 FDI outflows as % of GDP (UNCTAD)
4.2 FDI inflows as % of GDP (UNCTAD)
4.3 Royalty and license fees payments, US$ millions
4.4 Royalty and license fees payments (US$ millions) per million population
4.5 Science and engineering enrollment ratio (UNESCO)
4.6 Researchers in R&D, 2004 (UNESCO)
4.7 Researchers in R&D per million population
4.8 Total expenditure for R&D as % of GDP (UNESCO)
4.9 Manufacturing trade as percentage of GDP
4.10 University-company research collaboration (WEF Global Competitiveness Report)
4.11 Scientific and technical journal articles, 2003
4.12 Scientific and technical journal articles per million population
4.13 Availability of venture capital (WEF Global Competitiveness Report)
4.14 Patent applications granted by the USPTO (USPTO)
4.15 Patent applications granted by the USPTO per million people
4.16 High-technology exports as % of manufactured exports
4.17 Private sector spending on R&D (WEF Global Competitiveness Report)
4.18 Firm-level technology absorption (WEF Global Competitiveness Report)
4.19 Value chain presence (WEF Global Competitiveness Report)

5. Education

5.1 Adult literacy rate (% age 15 and above) (UNESCO)
5.2 Average years of schooling (15 years old and above) (WDI)
5.3 Secondary enrollment (% gross) (UNESCO)
5.4 Tertiary enrollment (% gross) (UNESCO)
5.5 Life expectancy at birth
5.6 Internet access in schools (WEF Global Competitiveness Report)
5.7 Public spending on education as % of GDP
5.8 Professional and technical workers as % of the labor force (ILO)
5.9 8th-grade achievement in mathematics, (Trends in International Mathematics and Science Study, TIMSS)
5.10 8th-grade achievement in science (Trends in International Mathematics and Science Study, TIMSS)
5.11 Quality of science and math education (WEF Global Competitiveness Report)
5.12 Extent of staff training (WEF Global Competitiveness Report)
5.13 Quality of management education (WEF Global Competitiveness Report)
5.14 Brain drain (WEF Global Competitiveness Report)

6. Gender

6.1 Gender development index (UNDP Human Development Report)
6.2 Females in labor force (% of total labor force)
6.3 Seats in parliament held by women (as % of total) (UNDP Human Development Report 2006)
6.4 School enrollment, secondary, female (% gross) (UNESCO)
6.5 School enrollment, tertiary, female (% gross) (UNESCO)

7. Information and communication technology

7.1 Telephones per 1,000 people (telephone mainlines + mobile phones) (ITU)
7.2 Telephone mainlines per 1,000 people (ITU)
7.3 Mobile phones per 1,000 people (ITU)
7.4 Computers per 1,000 persons (ITU)
7.5 TV households with television
7.6 Daily newspapers per 1,000 people
7.7 International Internet bandwidth
7.8 Internet users per 1,000 people (ITU)
7.9 Price basket for Internet, US$ per month
7.10 Availability of e-government services (WEF Global Information Technology Report)
7.11 Extent of business Internet use (WEF Global Competitiveness Report)
7.12 ICT expenditure as % of GDP 2005

Endnotes

[1] See NSF (2006) for a more comprehensive overview of recent initiatives to measure innovation.

[2] For a general history of science and technology indicators and their use in national policymaking, see Grupp and Mogee (2004).

[3] ASTI is a program of the Consultative Group for International Agricultural Research (CGIAR) and the International Food Policy Research Institute (IFPRI).

[4] See http://www.donorplatform.org/index.php?option=com_docman&task=doc_details&gid=399.

[5] For example, the World Bank's Agriculture and Rural Development Department has expressed concern about the "laundry list" nature of some the existing suggestions for using agriculture and rural development indicators in the context of project monitoring and evaluation, and accordingly decided not to proceed with a revised and expanded version of the World Bank (1999) publication on rural development performance indicators (Anderson, pers. comm., 2007).