Measuring Agricultural Innovation System Properties and Performance: Illustrations from Ethiopia and Vietnam

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Abstract

Rapid changes in the global food and agricultural system suggest that developing-country agriculture must become more dynamic, responsive, and competitive to survive. However, without adequate measurements of the properties and performance of innovativeness in the agricultural sector, it is difficult for decision-makers to make policies and investments that promote innovation in agriculture. This paper attempts to demonstrate how innovativeness in developing-country agriculture can be measured. It does so first by identifying a set of indicators from secondary data sources that capture key elements of an agricultural innovation system, and aggregates these indicators into a unique Agriculture, Development, and Innovation Index (ADII) covering 35 developing countries. It then provides a toolkit for collecting and analyzing "systems-oriented" indicators that add more process-related nuances to ADII with both attributional and relational data. This is illustrated with data collected in Ethiopia and Vietnam in 2007-08.

Keywords: Agriculture; developing countries; innovation; Ethiopia; Vietnam

JEL Codes: O13, O32, Q16

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1 Introduction

Food and agricultural systems are changing rapidly in many developing countries. More than ever before, growing consumer demand and shifting consumer preferences are driving changes in agricultural price trends, technology options, and trade patterns. Global integration of agricultural markets, supply chains, and communications networks have created new opportunities for sharing goods, services, and information, while new scientific achievements in microbiology, genomics, bioinformatics, and other fields are changing the quantity and quality of food and agriculture produced and consumed globally (World Bank 2006).

The implication of these stylized facts is that developing-country agriculture must become more responsive, dynamic, and competitive to survive in a changing world. Unfortunately, there are few tools with which to measure these key characteristics. In an effort to fill this knowledge gap, this paper discusses how innovativeness can be measured with respect to developing-country agriculture, and illustrates this with data compiled from both primary and secondary sources.

The design of the innovation measurement system discussed here is grounded in the increasingly popular "innovation systems" conceptual framework (Edquist 1997; Nelson 1993; Lundvall 1992; Dosi et al. 1988; Freeman 1987). This framework models social, economic and technological change as a process that involves a range of factors, including: heterogeneous agents engaged in the generation, exchange, and use of knowledge and information; the actions and interactions that link these agents to each other; and the socioeconomic institutions—the formal regulations, informal rules, organizational cultures, and learning processes—that influence their practices and behaviors.

In applying this framework to developing-country agriculture, this paper aims to demonstrate "proof of concept" of how innovation system properties and performance can be measured with respect to developing-country agriculture. In doing so, the paper attempts to measure the emergent properties of an innovation system—properties that go beyond the sum of a system's constituent parts—by combining conventional input and output indicators with more process-oriented, systems-specific indicators.

2 Conceptual framework

Arnold and Bell (2001) describe a national innovation system as consisting of three main components: the knowledge and education domain; the business and enterprise domain; and the bridging institutions that facilitate the transfer of knowledge and information between these two domains. Bounding these domains are the socioeconomic institutions that influence innovation processes, or the enabling environment (Figure 1).

Underlying this system are the essential processes that facilitate innovation, including: the capacity of individuals and organizations to learn, change and innovate; iterative and interactive learning processes among innovation agents; and the types of interventions that enhance such capacities and processes. By highlighting these hidden attributes and relationships, the innovation systems framework model innovation as a complex web of related individuals and organizations that all contribute to a process of social, economic, or technological change.

To date, however, most agricultural innovation systems (AIS) studies of developing-country agriculture have focused on specific commodities or specific technologies. There is still a lack of broader, macro-level analysis on issues such as the measurement and quantification of innovation in developing-country agriculture.

3 The Agriculture, Development, and Innovation Index (ADII)

In an effort to address this deficiency in the literature, this paper presents a composite index of key innovation indicators for developing-country agriculture and based solely on secondary data sources. Highlights of this new "Agriculture, Development, and Innovation Index" (ADII) are discussed in detail below.

The design of the ADII is driven primarily by the identification and selection of key indicators that are consistent with the innovation systems model set forth above. Data from secondary data sources were used to measure the properties and performance of agricultural innovation systems in two focal countries—Ethiopia and Vietnam—alongside an additional 33 developing countries. Of these 33 countries, 6 were chosen as regional comparators against which Ethiopia and Vietnam could be benchmarked (Kenya, Tanzania, and Uganda for the case of Ethiopia; Malaysia, Philippines, and Thailand for the case of Vietnam), while 5 were chosen as global comparators (China, India, South Africa, Brazil, and Mexico) for the same purposes.

Indicator selection is also influenced by several additional factors, including: (a) data availability, a non-trivial issue for many indicators relating to developing-country agriculture; (b) an exclusive focus on input indicators that potentially explain a domain's performance; and (c) other methodological issues highlighted by prior innovation measurement initiatives (see Archibugi and Coco 2005).[1] Indicator selection was accompanied by a detailed data validation and standardization process that focused on eliminating potential errors caused by different measures (levels, rates, intensities, and indices), different data sources (hard and soft data),

[1] To provide comparability across indicators and countries, all indicators were normalized to an intuitive scale of 1 to 10, ranging from the lowest to highest level of performance for a given indicator. The aggregate ADII was then calculated as the simple average of the scores for each of the domain's sub-index. An additional four innovation outcome indicators were identified to inform further inferences into the relationship between the ADII to its possible economic outcomes. These indicators were: agriculture GDP per worker; agricultural total factor productivity change; per capita agricultural production index, and cereal yields.

varying time intervals (single years or multi-year averages), correlations among similar indicators, and missing values.

Ultimately, several hundred indicators relating to agriculture, development, and the individual domains described earlier were reviewed and validated. This process yielded 41 indicators from 25 sources that offered relatively complete coverage of the 35-country sample. These indicators are combined in a single measure called the Agriculture, Development, and Innovation Index (ADII).

3.1 Findings from the ADII

Descriptive statistics for the 35-country ADII and its subcomponents are provided in Table 1. These results reveal two immediate properties of the ADII. First, actual ADII scores for this sample tend to be clustered within a range (2.47 to 6.15) that is narrower than the index's possible range (1.00 to 10.00). Second, the ADII sub-index scores show somewhat greater variance than the actual ADII scores, suggesting that they hold a degree of analytical interest that is independent of the aggregate ADII.

Figure 2 provides a ranking of aggregate ADII scores for 22 countries selected from the 35-country sample, ranging from highest to lowest. Overall, Thailand emerges as an innovation leader with an ADII score greater than 6; followed by Malaysia, Senegal, Uganda and Botswana, Kenya, South Africa and Brazil with ADII scores all greater than 5. Overall, Ethiopia, Nepal, Cameroon, Nigeria, Zimbabwe, Chad, and Myanmar emerge with the lowest ADII scores, representing the bottom 20 percent interval of scores from the 35-country sample. The mean ADII score (4.5241) falls between Ghana and Sri Lanka.

To better illustrate the composition—and variations in the composition—of these ADII scores, consider the individual scores for domains that comprise the agricultural innovation system. Figure 3 maps each country's sub-index score for its Knowledge and Education domain against the corresponding score for its Business and Enterprise domain. This mapping is a useful way of classifying countries according to different innovation system properties.

The first type of country might be described as host to a strong Knowledge and Education domain and a weak Business and Enterprise domain. This describes a country where investments in innovative capabilities—in research institutes, universities, technical training, and other formal knowledge sources—exceed investments in knowledge-based commerce and enterprise. Here, the drivers of innovative performance are more "supply oriented," i.e., more developed in the fields of science and education relative to business. Agricultural innovation systems in Kenya, Zambia, and India may fit into this category relative to the other countries studied in the 35-country sample presented here.

The second type of country might be described as host to a strong Business and Enterprise domain and a weak Knowledge and Education domain. This could describe the case of more "demand-oriented" countries where technological leap-frogging and imitation in the commercial sector are drivers of innovation performance, and where scientific and education performance lags. Agricultural innovation systems in Vietnam, Tanzania, and China may fit into this category relative to the other countries studied in the 35-country sample presented here.

The third and fourth types of countries might be described as "leaders" and "followers," respectively. For example, leaders in the study sample—countries such as Thailand, Malaysia, and Botswana—are characterized by relatively strong scores in both the Knowledge and Education and Business and Enterprise domains. Necessarily, followers in the study sample—

countries such as Ethiopia, Nigeria, Ghana, Chad and Cameroon—are characterized by relatively low scores in these domains.

Another classification maps the performance of the innovation system's Enabling Environment against the mean of its other three components—the Knowledge and Education, Bridging Institutions, and Business and Enterprise domains (Figure 4). Again, leader and follower countries emerge from this characterization, as does a positive relationship between enabling environment and performance of a system's principle component.

To illustrate the potential impact of innovation system performance on agriculture, Figure 5 maps ADII scores against agricultural GDP per capita. Despite the close clustering of countries with low ADII scores and low agricultural GDP per capita, there is some evidence of a positive relationship between the two. Key comparators such as Malaysia, Brazil, Colombia, South Africa, and Mexico perform well on both counts, suggesting that innovation contributes to agricultural productivity. However, other comparators such as Thailand, Senegal, Uganda, Botswana, and Kenya do not exhibit a clear relationship between agricultural innovation and productivity. Moreover, our two countries of interest—Ethiopia and Vietnam—score fairly low against both variables of interest, thus providing limited evidence of a clear relationship.

The findings presented above illustrate how a conceptual modelling of an agricultural innovation system can be quantified with data from a range of secondary sources. As a first demonstration, the ADII goes some distance in illustrating the feasibility of measuring innovation system properties and performance. However, the ADII can be further improved by incorporating more up-to-date information, introducing additional or alternative indicators, and expanding the sample of countries.

4 Tools for generating more "systems-oriented" indicators

The ADII can also be improved on by introducing indicators that are more "systems-oriented." This section proposed and tests an integrated, multi-step toolkit for doing exactly this. Specifically, this toolkit focuses on measuring and analyzing underlying systems-oriented properties such linkages, relationships, and influence between and among heterogeneous actors. While there are many different ways of examining such properties, the toolkit combines participatory data collection tools with expert opinion surveys and organization/firm-level surveys to obtain relational data that better characterize an innovation system. Data generated by this toolkit can be introduced into the ADII as a means of capturing relational data, or used as a separate means of measuring and benchmarking altogether. These tools are experimented with in Ethiopia and Vietnam.

The first step in measuring and analyzing more systems-oriented indicators is to define the primary unit of analysis. Here, this unit is defined as the main subsectors of a given country's agricultural economy, grouped into three main categories: Food staples, high value/traditional exports, and livestock. Arguably, each subsector is host to its own innovation subsystems, and can thus be examined as a separate unit.

The choice of exactly which subsectors might be examined is determined by: (a) their degree of representativeness of the wider agricultural economy, such that their inclusion can usefully inform the measurement and analysis of an innovation system; and (b) the resources available to the researcher (i.e., with greater resources, a larger number and broader range of subsectors can be examined). In Ethiopia, the selected subsectors were maize (a major food staple with a high growth rate in terms of production), coffee (a traditional export with significant importance to the economy), and poultry (a small but rapidly growing commodity in the livestock subsector). In Vietnam, similar criteria lead to the selection of rice (the food staple crop), cashews and coffee (the high value crops), and piggery (a key livestock crop).

The second step is to generate a diagnosis of the innovation subsystems in question. To do this, participatory or consultative tools are useful ways of identifying key actors, their salient characteristics, the nature of their relationships and interactions, and their influence or power within a system. Here, a participatory analysis tool known as Influence Network Mapping or "Net-Map" (Schiffer 2007) is used. Net-Map is useful because it allows for the study of formal and informal networks that link actors involved in innovation processes, and provides a means of assessing the influence these actors have on such processes. Importantly, Net-Map generates relational data that are absent in the largely attributional data from secondary sources presented earlier.

For this paper, Net-Map was used only in Ethiopia as a diagnostic tool to map the innovation landscape relating to the poultry subsector, and to identify and describe (a) key innovation actors (by sector: public, private, civil society; by domain; knowledge, enterprise, etc.), (b) their respective roles in the sector (input supply, knowledge and information, finance and credit, etc.), (c) the nature of their relationships (command/administration, collaborative/cooperative, financial, other), and (d) their influence or power in the system.

The third step is to obtain data on specific properties and performance from each innovation subsystem. Here, the findings of the Net-Map exercise can provide useful information on the key actors to interview as a means of obtaining such data. Once key actors are identified, tools such as expert opinion surveys can be used to collect a range of soft data types. For this paper, expert opinion surveys were used to obtain information on the following characteristics of specific subsystems: effectiveness of organizations and organizational collaborations;

responsiveness of organizations to technological, market and other opportunities; accountability of organizations to different types of stakeholders; accessibility of organizations to different types of stakeholders; and the innovativeness of organizations in terms of introducing new efficiency-improving products and processes.[2]

A total of 22 experts in Ethiopia were interviewed in person in mid 2008: 9 from the maize subsector, 8 from the poultry subsector, and 5 from the coffee subsector. To avoid weighting of their aggregated responses in favour of one subsector over another, responses were averaged first by individual subsector, and then across all subsectors.

An alternative to this approach was used in the case of Vietnam, where experts were chosen from secondary sources and without the benefit of a Net-Map exercise. A total of 24 experts responded to the survey by email or on paper in late 2007 and early 2008. Respondents included experts from public agricultural research organizations (7), public agricultural extension services (4), private agribusinesses (3), agricultural education and training institutions (6), and relevant government ministries and agencies (4) in Vietnam.[3]

4.1 Illustrations from Ethiopia and Vietnam

Indicators that capture some of the more systems-oriented characteristics of agriculture in Ethiopia and Vietnam, based on the expert opinion surveys described above, are presented here.

First, expert opinions on key systems characteristics based on responses from key informants representing selected subsectors of Ethiopia's innovation systems are considered. Figure 6 shows expert opinions from the 22 experts in the maize, coffee and poultry subsectors

[2] See http://www.surveymonkey.com/s.aspx?sm=1Rg41mJ7cBkhMnjHIjE0pQ_3d_3d for an online version of the survey.
[3] See http://www.surveymonkey.com/s.aspx?sm=FhZTQlvx019s5rNDSJ_2fLtg_3d_3d for an online version of one of the surveys used in Vietnam (for reference purposes only).

surveyed in mid 2008. These results provide some interesting insights into key innovation systems properties—accountability, responsiveness, accessibility, and effectiveness—for each of the four system domains.

For instance, while the surveyed experts found that their respective collaborators were overwhelmingly accessible, actual responsiveness and accountability to other stakeholders and opportunities were relatively limited. Overall, these surveyed experts also found the system, particularly the domains that capture bridging institutions and the enabling environment, to be minimally effective in promoting innovation.

Figure 7 provides a similar measure of expert opinions from Vietnam based on reflective responses from the 24 respondents. Owing to the different survey tools tested in Vietnam, these results are not immediately comparable to those from Ethiopia. However, they do illustrate the fact that variations exist in expert opinions on innovation system properties such as responsiveness, accountability and innovativeness among key innovation actors.

For example, while respondents indicated that educational, research, and extension organizations (represented in the Knowledge and Education domain and Bridging Institutions domain) were strongly innovative, both the business community and enabling policy environment (i.e., key ministries and public agencies) were less so. Similarly, while educational and research organizations were viewed as strongly responsive to different and emerging innovation opportunities, the corresponding organizations involved in extension were viewed as being weakly responsive.

Importantly, this exercise shows how an expert opinion survey approach can provide an entirely new set of indicators—measures of accountability, responsiveness, accessibility, effectiveness, and innovativeness—that can significantly improve on the secondary data used in the ADII.

Moreover, this exercise also show how the expert opinion survey approach can be used to generate relational data—a form of data that captures the essence of "systems-oriented" properties by measuring phenomena beyond the straight-forward attributes of an actor. For example, the surveys conducted in Ethiopia and Vietnam collected data on (a) the main types of linkages between key system actors, (b) the effectiveness or importance of these linkages, and (c) the level of satisfaction on the collaborations with the organizations they work with most closely.

4.2 A revised ADII with systems-oriented indicators

As a next step, these systems-oriented indicators are introduced into the ADII scores for Ethiopia and Vietnam. For Ethiopia, a total of 20 new variables (each the simple average of domain-specific scores for accountability, responsiveness, accessibility, effectiveness, and satisfaction) were introduced to the existing ADII calculations. For Vietnam, 16 new variables (each the simple average of domain-specific scores for responsiveness, accountability, innovativeness and importance) were similarly introduced. Revised index scores (ADII′) are given in Table 2.

Because of the differences in survey design, note that ADII′ scores are not immediately comparable across these two countries. But the within-country differences between the ADII and ADII′ scores appear to be substantial and positive. Moreover, there is some variation in the domain-specific differences in scores resulting from the introduction of these systems-oriented variables.

In summary, although the contribution of these measures depends acutely on the way the survey questions are framed, they do generate an important set of data that is useful in measuring relational elements of an innovation system. These are precisely the types of systems-oriented indicators that are difficult to obtain from secondary sources, but are nonetheless critical to quantifying system properties and performance. And importantly, while the data presented above are highly sensitive to the different survey methods used, they demonstrate the feasibility of collecting more systems-oriented indicators. Provided that a consistent and rigorous methodology is pursued across a large set of countries and system actors, these data can strengthen the ADII by adding indicators that capture organizational/firm attributes such as accountability, responsiveness, accessibility, effectiveness, and innovativeness, and indicators that capture organizational/firm relations such as satisfaction, importance, or effectiveness of collaboration. Ultimately, these types of indicators can be valuable to future ADII-type exercises that seek to convey a more accurate and more nuanced characterization of innovation system properties and performance.

5 Conclusion

Rapid changes in the global food and agricultural system suggest that developing-country agriculture must become more dynamic, responsive, and competitive to survive. But without adequate measurements of the properties and performance of innovativeness in the agricultural sector, it is difficult for decision-makers to make policies and investments that promote innovation in agriculture.

This paper attempts to bridge that knowledge gap by providing a "proof of concept" that innovativeness in developing-country agriculture can be measured. We do so first by identifying a set of indicators from secondary data sources that provide appropriate measures of the key elements of an agricultural innovation system. Several hundred indicators were reviewed, validated, and quantified, ultimately resulting in 41 key indicators used to develop the Agriculture, Development, and Innovation Index (ADII) presented earlier. We then design and test the elements of a toolkit for collecting and analyzing more “systems-oriented” indicators that add more process-oriented nuances to ADII with both attributional and relational data. The results of this exercise, and the tools used in the exercise, are presented with reference to expert opinion survey data collected in Ethiopia and Vietnam in 2007-08.

Ultimately, this paper provides a combined qualitative/quantitative toolkit for measuring innovation systems properties and performance; and an analysis that emphasizes not only on inputs and outputs, but also more-difficult-to-measure systems properties. While there is scope for more work on developing appropriate indicators and the tools to measure them, it is hoped that this paper will lay the groundwork for future efforts.

Furthermore, in the long run, it is expected that the paper will contribute to improving systems-level measurements and benchmarks to help guide the formulation and implementation of pro-poor innovation policies. With better information and analysis, it is also expected that policymakers, investors, donors, and other development actors will be able to make decisions that strengthen innovation systems in developing-country agriculture and, ultimately, support national and global efforts to foster agricultural development, economic growth, and poverty reduction.

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Table 1. ADII and ADII sub-indices, descriptive statistics

Index/domain	No. of indicators	No. of observations (countries)	Mean	S.D.	Min	Max
Aggregate ADII	41	35	4.5241	0.7997	2.4798	6.1507
Knowledge & Education domain	11	35	4.0514	0.9009	2.1406	6.7590
Bridging Institutions domain	3	35	3.5435	1.4600	1.0000	7.0000
Business and Enterprise domain	12	35	4.2282	0.8482	1.1618	5.6101
Enabling Environment domain	15	35	6.2732	1.0083	3.0904	7.8747

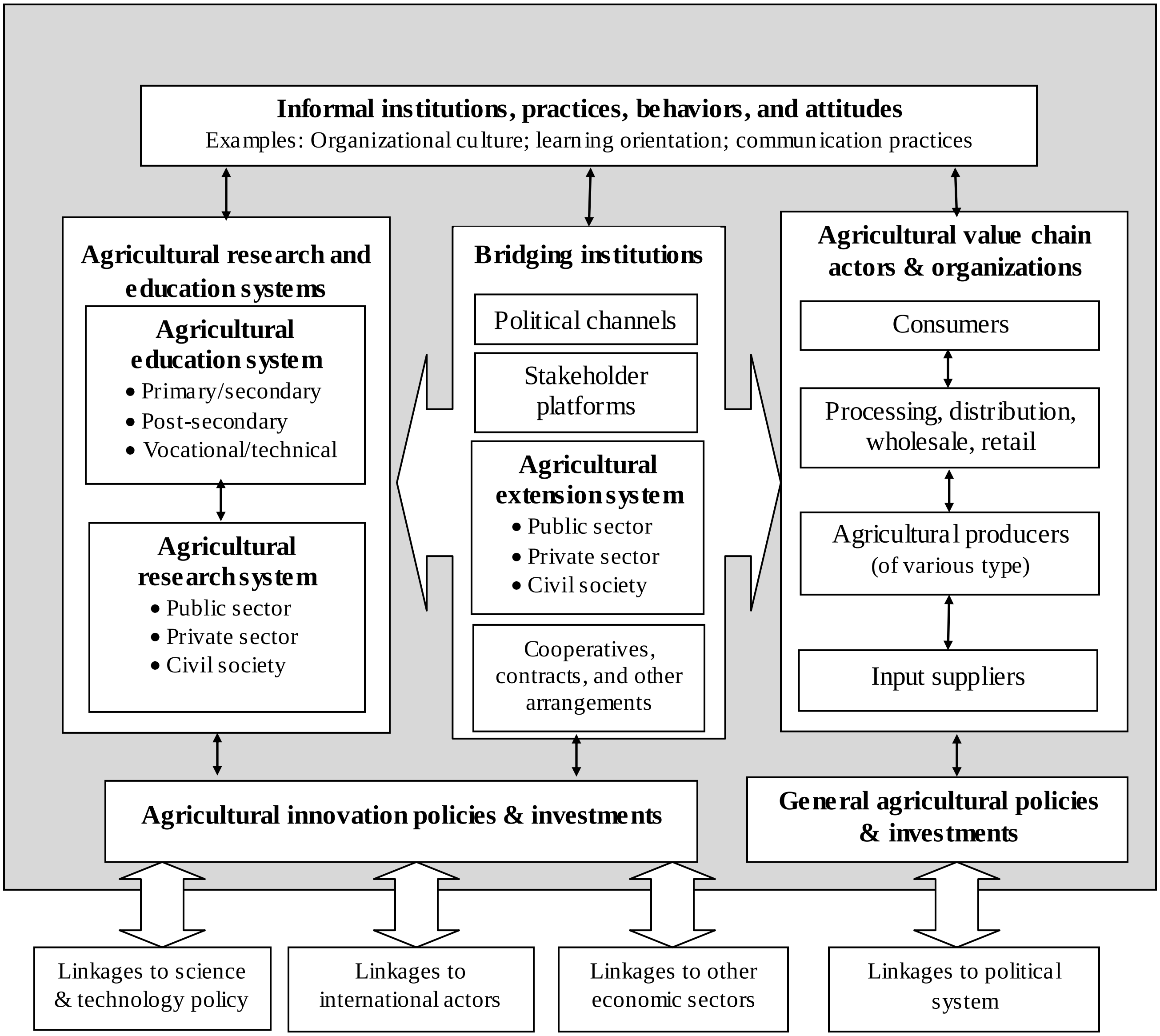
Note: ADII and ADII domain scores are scaled from 1 to 10. S.D. denotes standard deviation.
Source: Authors.

Table 2. ADII scores using systems-oriented indicators, by domain, Ethiopia and Vietnam

	ADII: Original scores						ADII′: Revised scores					
Country	ADII	KE	BI	BE	EE	No. of indicators	ADII′	KE	BI	BE	EE	No. of indicators
Ethiopia	3.81	2.99	3.14	3.58	5.54	41[a]	4.23	3.26	4.63	3.93	5.13	61
Vietnam	4.38	2.81	3.56	5.37	5.78	35[a]	5.08	4.39	5.95	4.70	5.27	51

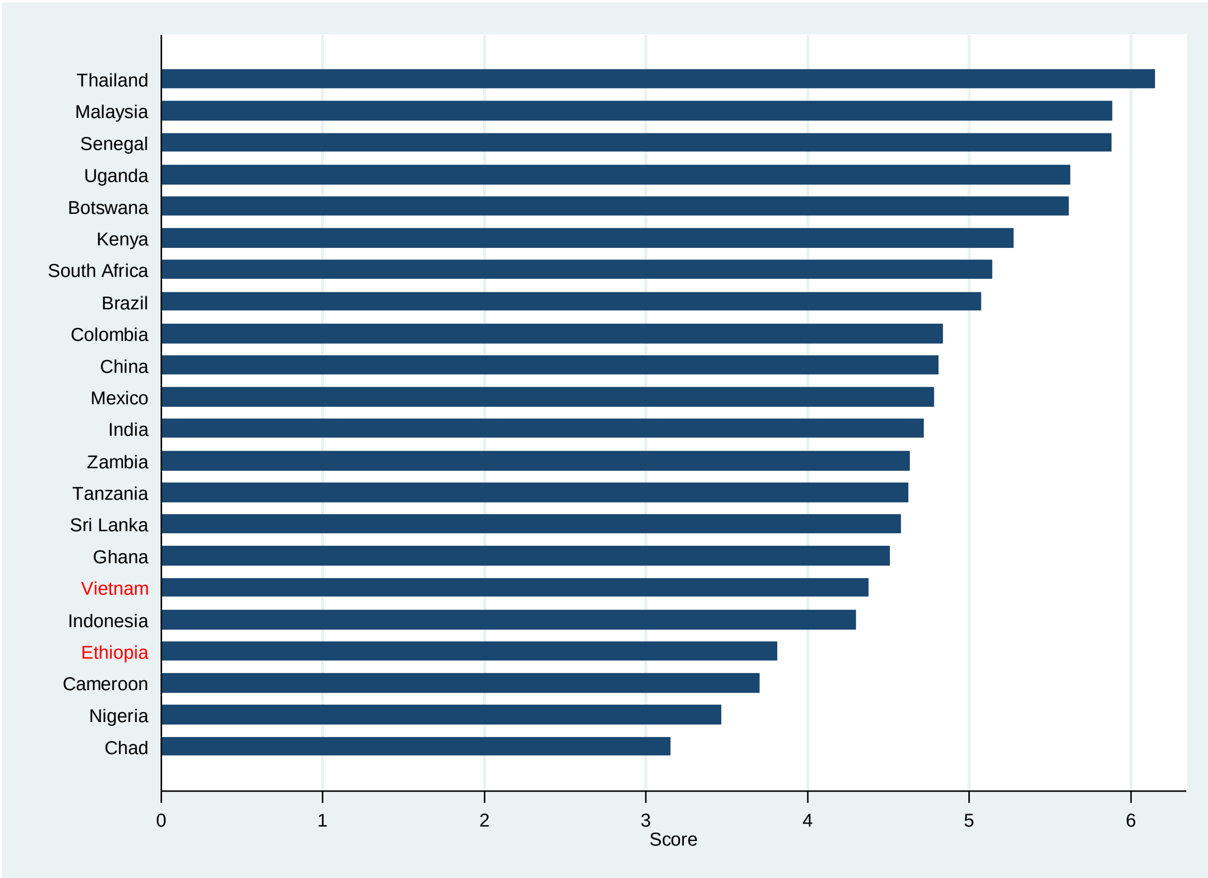
[a] Number of indicators totals less than 41 for both countries due to missing values.
Source: Authors.

Figure 1. A conceptual diagram of an agricultural innovation system



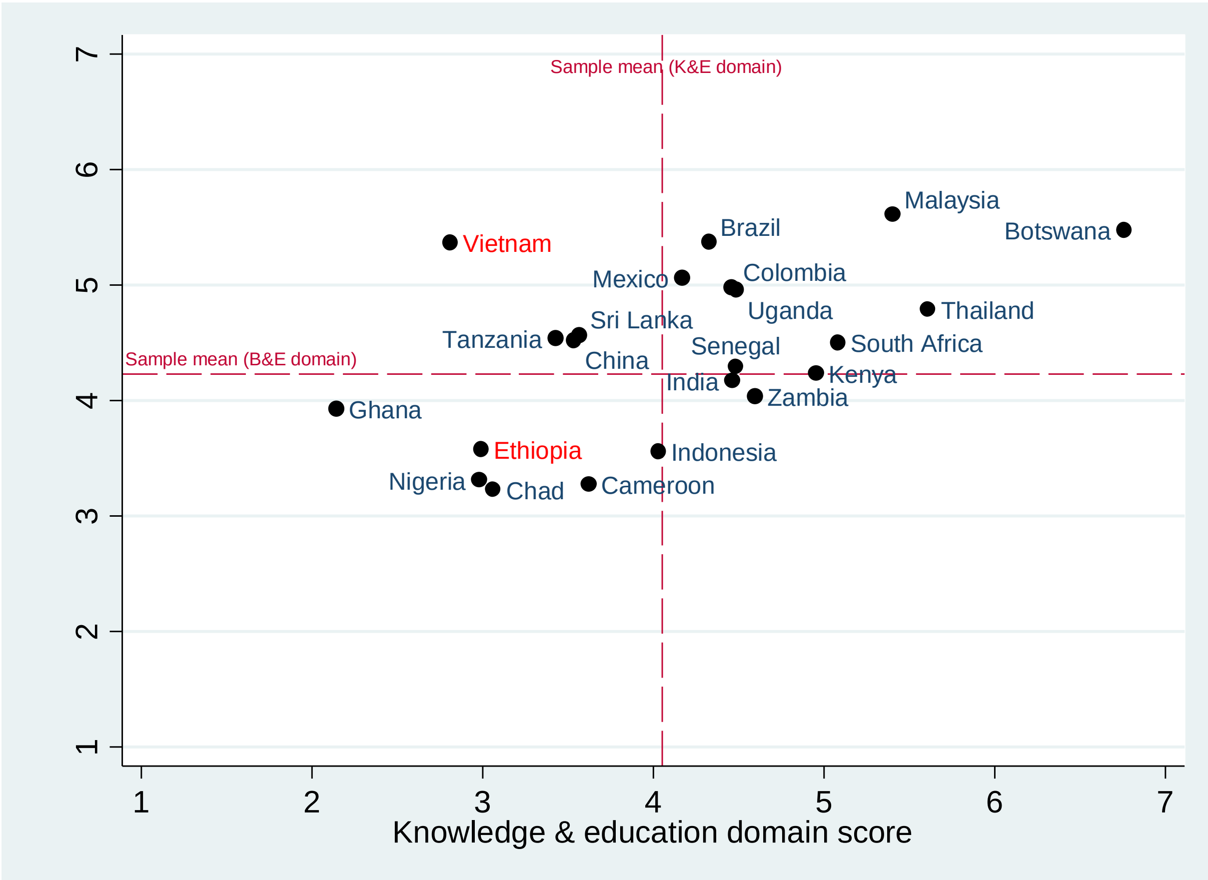
Source: Spielman and Birner (2008); adapted from Arnold and Bell (2001).

Figure 2. Aggregate ADII scores, selected countries



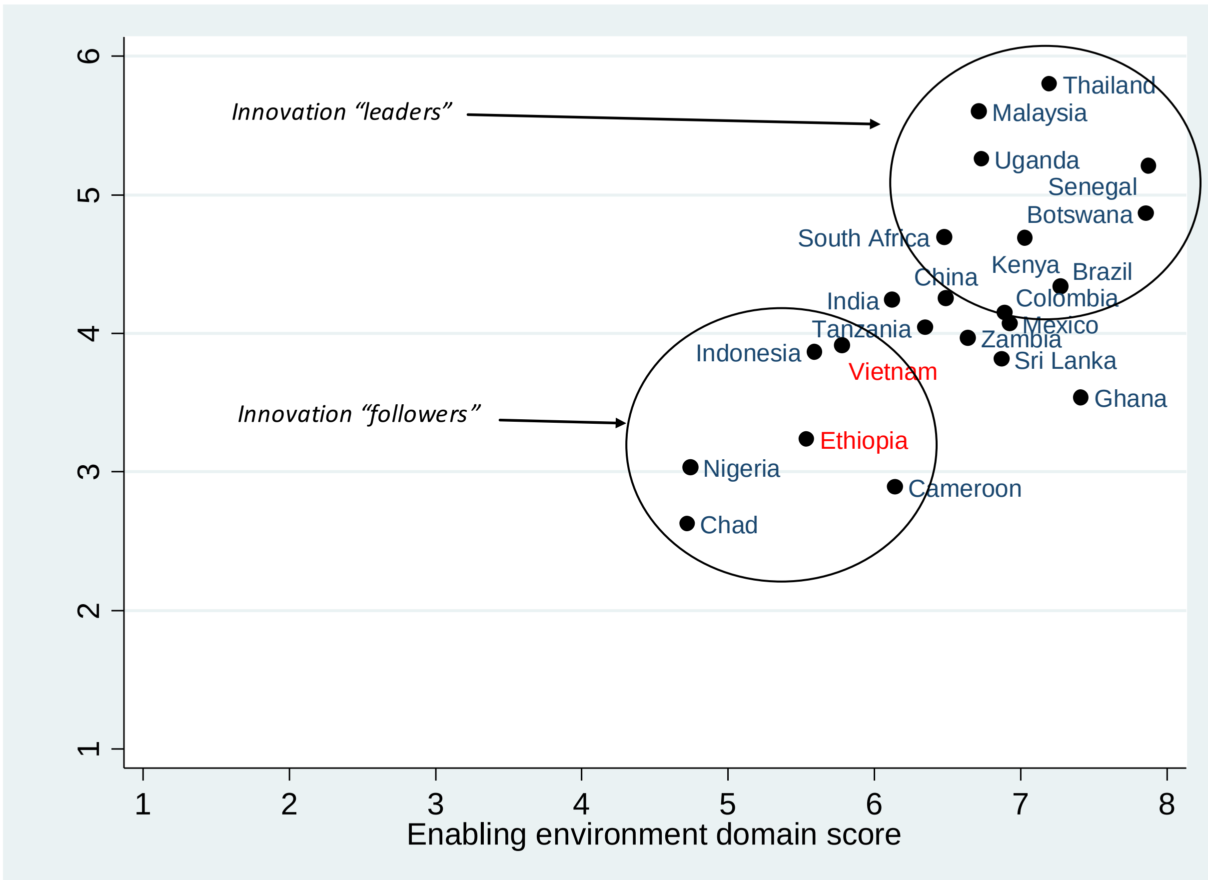
Source: Authors.

Figure 3. Science and commerce: Key ADII domain scores



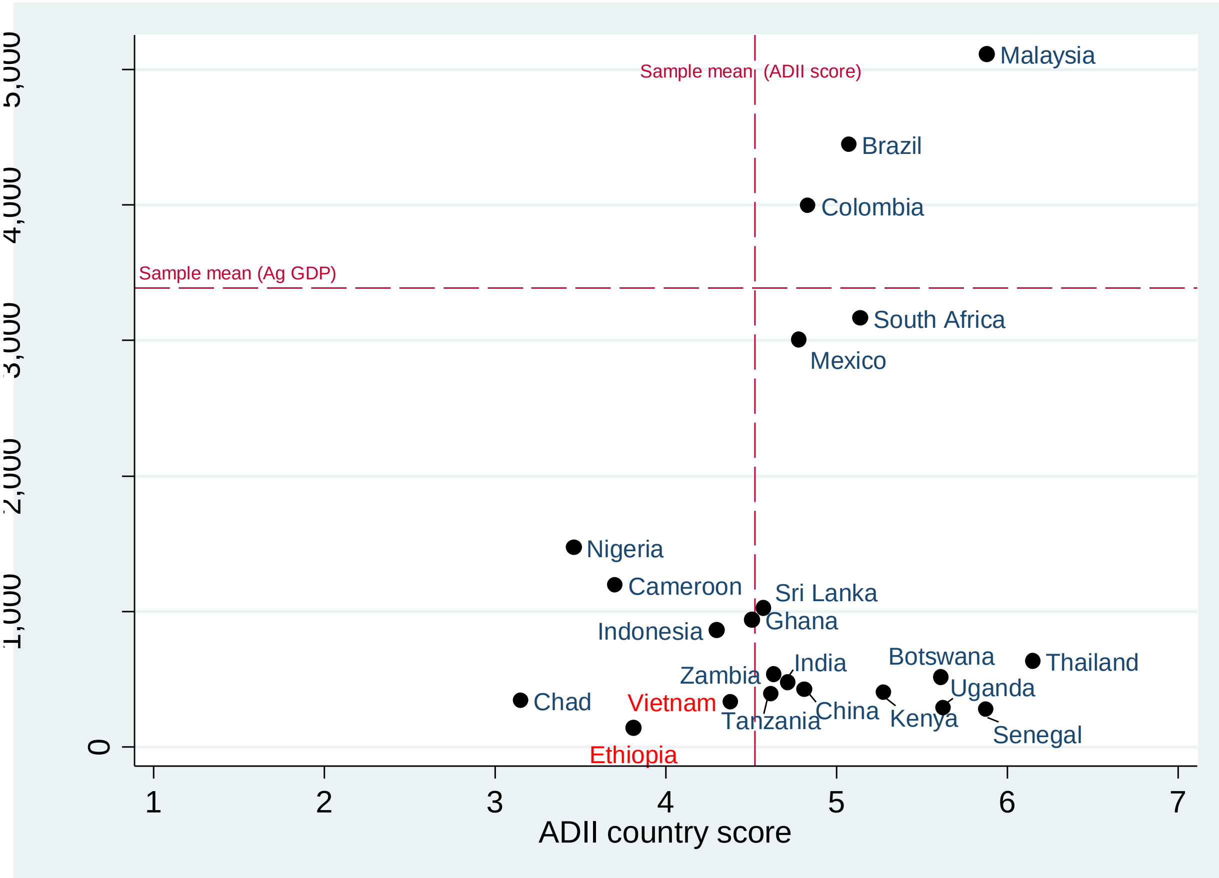
Source: Authors.

Figure 4. Enabling environment and principle components: Key ADII domain scores



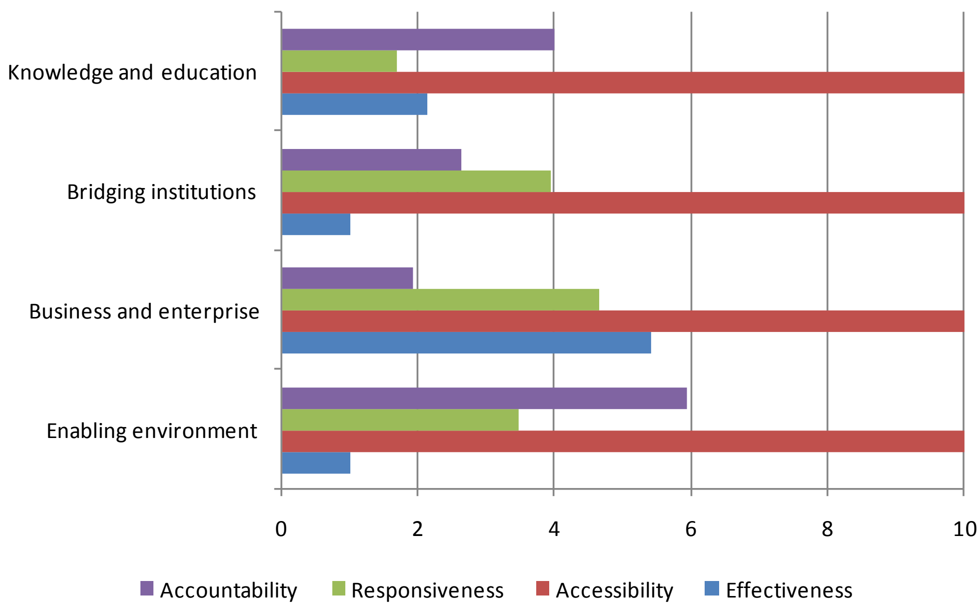
Source: Authors.

Figure 5. Agricultural GDP per capita and ADII country scores



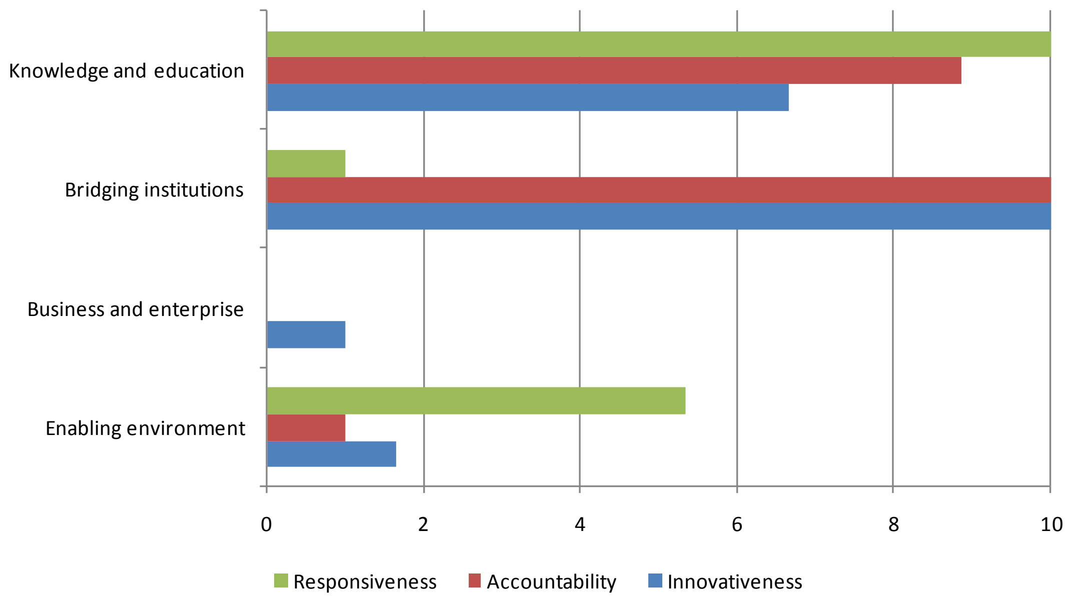
Note: Agricultural GDP per capita is measured in constant (2005) US dollars.
Source: Authors.

Figure 6. Expert opinions: Innovation system properties, by domain, Ethiopia



Note: Scores range from 1-10.
Source: Authors.

Figure 7. Expert opinions: Innovation system properties, by domain, Vietnam



Note: Scores range from 1-10. Expert opinions from business and enterprise domain respondents on responsiveness and accountability were not available.
Source: Authors.