The role of extension and financial services in boosting the effect of innovation investments for reducing poverty and hunger: A DEA approach

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Commission on Sustainable Agriculture Intensification

Foreign, Commonwealth & Development Office

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Alejandro Nin-Pratt, International Food Policy Research Institute. 2021. *The role of extension and financial services in boosting the effect of innovation investments for reducing poverty and hunger: A DEA approach.* Colombo, Sri Lanka: Commission on Sustainable Agriculture Intensification. 36p.

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Acknowledgements

The Commission on Sustainable Agriculture Intensification (CoSAI) was initiated and is supported by the CGIAR Research Program on Water, Land and Ecosystems (WLE), funded by the CGIAR Trust Fund and other donors. CoSAI Commissioners are independent. CoSAI is facilitated by a Secretariat based at the International Water Management Institute (IWMI) headquarters in Colombo, Sri Lanka.

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Executive summary

Increasing investment and spending in agricultural innovation is not enough to meet Sustainable Development Goal (SDG) targets of ending poverty and hunger because the effectiveness of investments in low- and middle-income (LMI) countries is affected by the low quality of infrastructure and services provided, and by different norms and practices that create a considerable gap between financing known technical solutions and achieving the outcomes called for in the SDGs. As an important part of a nation's common innovation infrastructure, financial and extension services are major "enablers" of investments, favorably contributing to national innovative capacity. However, the contribution of these services to innovation in LMI countries has been limited. Financial services in LMI countries face low rates of return; high risks and lack of acceptable collateral; and limited outreach in rural areas. Similarly, the performance of extension services has been affected by ineffective and costly strategies that have promoted rigid recommendations with poor understanding of how farmers learn and lacked context-specific focus on solving problems.

At present, a wide variety of information and communications technology (ICT) tools and innovations in financial and extension services offer new opportunities to improve performance, increase access and reduce costs through economies of scale and more efficient operations. Recent innovations in financial technology offer new ways of expanding the inclusion of the financially excluded into the financial system by providing them with a wider range of financial services and products; reaching sparse customer bases spread over difficult-to-access rural geography; reducing costs through economies of scale and more efficient operations; and enabling profitable inclusion of low-cost products or services that meet the needs of previously excluded populations. In the case of extension, the new ICT technologies can make services more demand-driven, up-to-date and inclusive, contributing to revitalizing the interaction between extension services and farmers.

Considering the new opportunities that ICT innovations bring to improve performance of financial and extension services, this study looks at the potential contribution of financial and extension services to the SDGs. The approach used extends the standard Data Envelopment Analysis (DEA) model to include longer-term management goals and find a solution that balances the efficient use of innovation investments and the achievement of policy goals, making this approach well suited for the analysis of the SDGs.

How does the extended DEA approach work? First, DEA is not a foresight model to make projections based on economic theory, nor a model that needs to be calibrated to historical data and that can be evaluated based on its accuracy in "predicting" historical events. Instead, it is a powerful method for comparing and analyzing data. Specifically, in this case, it compares poverty and undernourishment levels across countries, relating those levels with the resources that each country has allocated to reduce poverty and undernourishment. It then finds out which countries have achieved the best results in terms of poverty and malnutrition alleviation given the quantity of resources allocated to this goal. These countries constitute the best-practice frontier in the use of investment for poverty and malnutrition alleviation. Countries that do not lie on the frontier are less efficient in the use of investments. In other words, a country is deemed inefficient because comparisons show that other

countries, using the same level of resources as this country, have achieved better policy results. The model allows the setting of policy targets (levels of poverty and undernourishment) and provides three major results for each country: a) it determines if the country can or cannot achieve the policy target given investments; b) it gives the minimum level of poverty and undernourishment a country can reach; and c) it estimates the level of investment needed to achieve the policy goals if the country falls short of the target.

The model is solved for the 69 LMI countries, setting as a policy target the reduction of the poverty headcount (PHC) and the prevalence of undernourishment (PoU) to 5% or less to obtain the maximum level of output (minimum level of poverty and undernourishment) that the country can achieve, given public and private levels of investment in innovation and of fixed or structural variables. PHC and PoU were chosen to measure policy targets because they are among the main indicators used to quantify the achievement of SDG 1 (eradicate extreme poverty for all people everywhere) and SDG 2 (end hunger, achieve food security and improve nutrition). The analysis is conducted using average values of variables for the period 2000-2018. Results of the impact of increased access to financial and extension services are obtained from a scenario that determines the levels of financial and extension services that maximize achievement of policy goals.

Results show that LMI countries fall short of achieving the policy target of 5% PHC and PoU. The attainable poverty and undernourishment levels calculated by the model were 25% and 15%, respectively. This is equivalent to an attainable poverty reduction of 100 million people, bringing the number of poor people from 618 million to 518 million. The number of undernourished can be reduced by 96 million, from 560 to 463 million people.

To further reduce poverty and malnutrition, countries could increase investment in innovations and services like finance and extension that facilitate producers' access to those innovations. The DEA model is then used to determine how far countries can go on the reduction of poverty and undernourishment if they improve access to financial and extension services without changing levels of innovation investment in agriculture. Results show that the combined effect of improved access to financial and extension services is a reduction in the attainable number of poor people from 518 to 488 million (a reduction of 30 million poor people) and in the attainable number of undernourished people from 463 to 428 million (a reduction of 35 million undernourished people).

1. Introduction

Increasing investment and spending in innovation, defined here as the development and application of new ways to produce goods and services, is not enough to meet Sustainable Development Goal (SDG) targets because the effectiveness of investments in lower income countries is affected by the low quality of infrastructure and services provided, and by different norms and practices that create a considerable gap between financing known technical solutions and achieving the outcomes called for in the SDGs (Kenny and Snyder, 2017). As impact often depends on additional complementary activities and investments both within and beyond agriculture (Tomich et al., 2019), countries need to complement these investments with considerable improvement of institutions, services and policy tools to ensure that additional investment is effectively turned into improved outcomes.

In this context, financial and extension services are often considered major "enablers" of investments in innovations targeting achievement of SDGs, and in some cases could directly contribute to the outcome. The financial system is an important part of a nation's common innovation infrastructure which, together with sound institutions, a functioning educational system and effective research and development (R&D) policies, favorably determines national innovative capacity (Meierrieks, 2014), providing services that lower transaction costs and consequently facilitate investment in innovative entrepreneurial activities (Levine, 1997). Extension services are also part of the innovation infrastructure of a country, having played a pivotal role in agriculture by providing smallholders with the information, knowledge and qualifications required to exploit innovation emerging opportunities (Darr et al., 2014). But as in the case of financial services, the contribution of extension to innovation has been limited by ineffective strategies that have promoted rigid recommendations with insufficient understanding of how farmers learn, and have lacked context-specific focus on solving problems that can only be addressed through the engagement of multiple interdependent actors and through improving farmers' access to broader information relating to market and credit linkages (Davis and Franzel, 2018; Norton and Alwang, 2020).

At present, a wide variety of information and communications technology (ICT) tools and innovations in financial and extension services offer new opportunities to increase access and reduce costs through economies of scale and more efficient operations. For example, recent innovations in financial technology (FinTech) provide a wider range of financial services and products, reaching difficult-to-access rural areas. These innovations are also transforming extension services, where cell-phone-based networking and messaging apps are becoming common even in developing countries, and their use in extension is growing rapidly (Davis and Franzel, 2018; Beriya and Saroja, 2019).

In the context of the new opportunities that ICT innovations bring to enhance access to these enabling services, this study looks at the potential contribution of financial and extension services to the SDGs. Could enhanced access to financial and extension services contribute significantly to the achievement of SDGs, facilitating access to innovations brought about by investment efforts in LMI countries? Or, as discussed in Duvendack and Mader (2019) for the case of financial services, might they not even have a meaningful net positive effect on low-income users considering that they are only two among many possible determinants of their life chances to access and adopt innovations? We attempt an answer to these questions by using a model proposed by Stewart (2010) that extends the standard

Data Envelopment Analysis (DEA) model by balancing the efficient use of innovation investments and the achievement of policy goals. This goal-programming DEA (GP-DEA) model is therefore well suited to the analysis of SDGs. Here the model is used to determine values of SDGs that can be achieved by individual countries given their levels of investment in R&D and non-R&D innovation and to measure the impact that improved access to financial and extension services have on the achievement of SDGs. The rest of the paper is organized as follows: Section 2 presents a characterization of the financial and extension services in LMI countries; Section 3 describes the GP-DEA approach used in the analysis; Section 4 discusses results; and Section 5 concludes.

2. Financial and extension services in LMI countries

Financial services

Recent innovations in FinTech offer new ways of expanding the inclusion of the financially excluded into the financial system by providing them with a wider range of financial services and products; reaching sparse customer bases spread over difficult-to-access rural geography; reducing costs through economies of scale and more efficient operations; and enabling profitable inclusion of low-cost products or services that meet the needs of previously excluded populations (Hinson et al., 2019).

Several studies and development agencies have embraced digitalization of core functions of the financial system to scale up agricultural finance and include smallholder farmers. According to the World Bank (2017), digital technologies cut the cost of providing financial services by 80-90%, can promote digital payments in agriculture value chains, and facilitate innovation in agricultural finance by leveraging mobile technology. These technologies can also contribute to closing the financing gap between male and female farmers; create a digital footprint that can be leveraged to access credit and other financial services; increase the amount of savings; and contribute to poverty reduction, especially for women and female-headed households (World Bank, 2017; Bastian et al., 2018).

Figure 1 shows the importance of different financial indicators in LMI countries between 2015 and 2019, grouped by income per capita. The figure clearly shows that high values of the bottom four indicators in the figure are associated with developed financial systems, reaching high values in upper middle-income countries. On the other hand, the proportion of adults receiving payments in cash is highest in low-income countries and seems to be associated with underdeveloped financial systems. Three indicators show similar values across income groups: the proportion of rural population that borrowed to start, operate or expand a farm or business; the proportion of the population that received payments for agricultural products into a financial institution account; and the proportion of population that received payments for agricultural products through a mobile phone.

The observed importance of different indicators across income groups is valuable information used in the GP-DEA model to define variables that capture structural differences between financial systems across countries and indicators of financial services that do not depend on financial development and income.
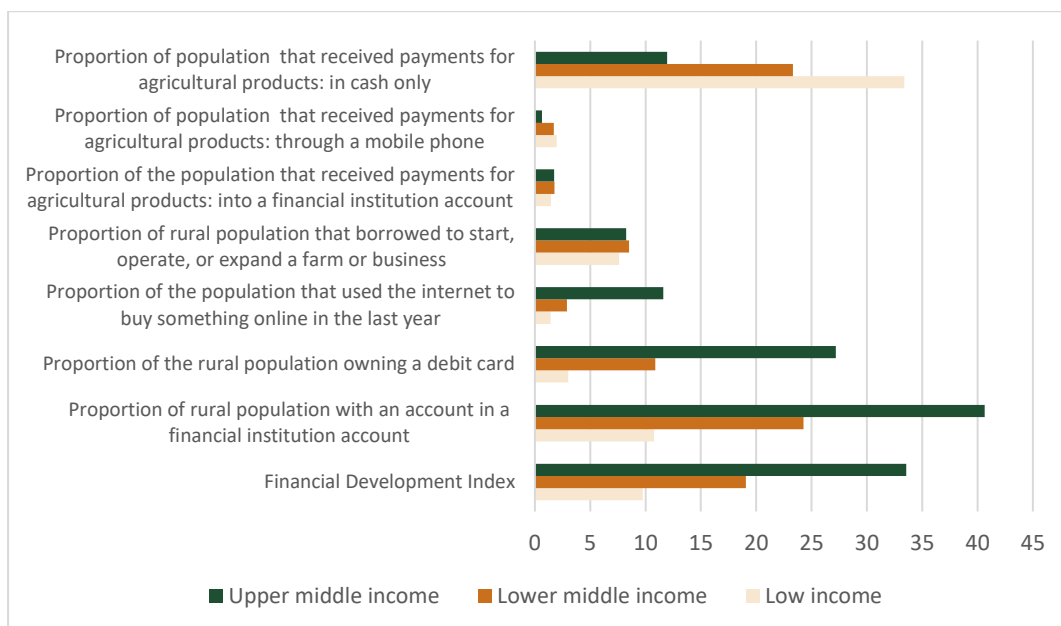
Figure 1. Financial indicators across LMI countries grouped by income, 2015-2019.

Source: Elaborated by authors using data from Demirgüç-Kunt et al. (2018).
Note: Country classification is from World Bank.

Extension and advisory services

Data on agricultural extension are much weaker than for financial services and estimates of the impact of extension on productivity and other relevant outcomes are rare. One global database has been recently made available, compiled by the Global Forum for Rural Advisory Services and covering the period 2009-2012 (Swanson and Davis, 2014; Davis et al., 2020). Information from this dataset is summarized below to present a characterization of extension services in LMI countries, comparing values of different indicators to those of high-income (HI) countries, including qualification and specialization of extension staff, the use of new communication technologies and the reach of extension services.

Major differences between extension services in LMI and HI countries are observed in staff qualification and use of ICT, as shown in Figure 2. Almost 60% of extension staff in LMI countries have no tertiary education while only 9% hold an MSc or PhD degree. In contrast, HI countries show only 29% of staff without tertiary education and 36% of staff holding an MSc or PhD degree.

Differences in the use of ICT in extension services are also significant. Only 48% of field extension staff in LMI countries have internet access in their office (versus 100% in high-income countries), while 40% of staff in LMI countries still work in print and mass media compared to only 8% in HI countries, where most of the staff work with computer-based information technology.

The reviewed literature on extension seems to agree on the fact that new ICT tools can make services more demand-driven, up-to-date and inclusive, contributing to revitalizing the interaction between extension services and farmers. However, ICT is but one element in the wider transformation toward improved reach of extension services. As a supporting tool, it can only achieve widespread support if used by an organized extension system and can neither do without nor replace face-to-face interaction

between farmers and extension agents. As shown in Figure 2, LMI countries are falling behind HI countries in the use of ICT tools, but are also significantly behind in qualification of extension staff. Support to enhance extension systems in LMI countries should therefore be broader than the introduction of ICTs, a task that will be difficult to advance in the medium term given the need of investment in infrastructure for ICT and the limited supply of skilled staff in these countries.
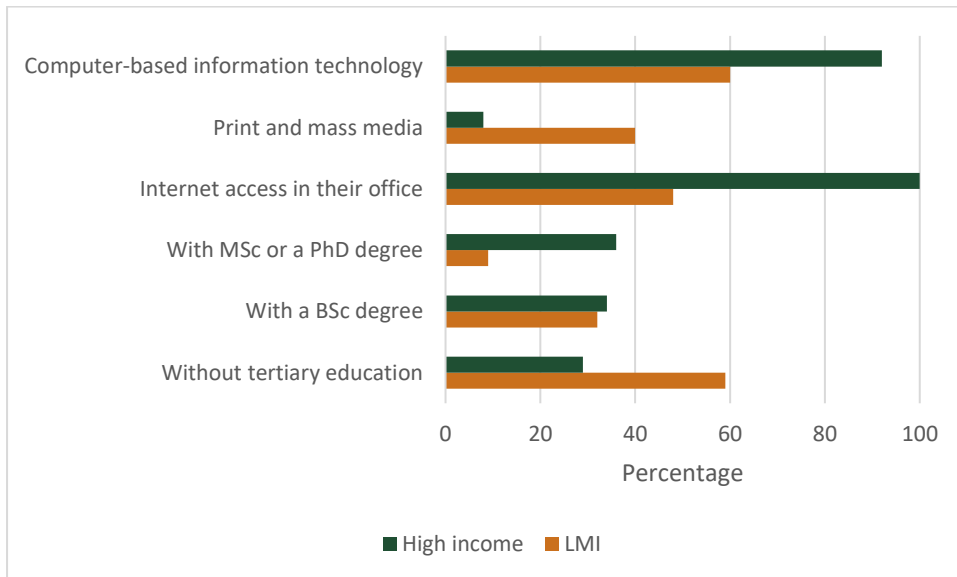
Figure 2. Qualifications and use of ICT by extension staff in high-income and LMI countries (share of staff in percentage).

Source: Elaborated by authors using data from Davis and Franzel (2018).

3. A goal-programming DEA approach

DEA is a mathematical programming approach originally developed to evaluate the individual efficiency or performance of a decision-making unit (DMU)[1] that operates in a certain application domain such as agriculture, energy, transportation, health care, education, the banking industry and many others. DEA has been widely used to identify sources of inefficiency, rank DMUs, evaluate management, evaluate the effectiveness of programs or policies, and to create a quantitative basis for reallocating resources, just to name some of the most frequent applications of this approach (Liu et al., 2013). At present, the use of DEA is not restricted to measuring operational performance of organizations but has moved beyond the analysis of efficiency to look at environmental and social performance of various enterprises, like assessments of the effectiveness of policies controlling CO_2 emissions; estimating energy saving and undesirable output abatement across countries; supervising methods in management and evaluation; and future planning (Shabanpour et al., 2017).

The GP-DEA model presented here was proposed by Stewart (2010), who extended the standard DEA model to include longer-term management goals. The model uses a goal-programming structure to find a solution that balances the efficient use of innovation investments and the achievement of policy goals. These characteristics make this approach well suited for the analysis of the SDGs committed in 2015 by leaders of all countries to "eradicate extreme poverty and hunger for all people everywhere".

Given the wide variety of DEA applications and the fact that the best-known applications of this method were used to assess historical efficiency of DMUs as part of monitoring and control, it is important to clarify up front how the approach used here differs from traditional DEA applications. First, DEA is not a foresight model to make projections based on economic theory, nor a model that needs to be calibrated to historical data and that can be evaluated based on its accuracy in "predicting" historical events. Instead, it is a powerful method for comparing and analyzing data.

Second, the use of GP-DEA regarding the SDGs is essentially prospective and relates to planning. It is not about how countries performed in the past, but rather about where countries want to be, specifying benchmarks for SDGs to define future attainable goals toward which countries should aspire given where they are at present (Stewart, 2010).

Third, the model allows the setting of policy targets (levels of poverty and undernourishment) and solves to get as close as possible to those targets (the SDG targets) given investments and structural constraints. GP-DEA works by comparing poverty and undernourishment levels across countries, relates those levels with the resources that each country allocated to reduce poverty and undernourishment, and then finds which countries have achieved the best results in terms of poverty and malnutrition alleviation given the quantity of resources allocated to this goal. These countries

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[1] DMU is a generic term used to emphasize the fact that DEA can be used not only to analyze profit-generating enterprises, but also other decision-making entities like non-profit organizations, government institutions or any other entity making decisions on the allocation of resources to achieve specific goals. In this study, the DMU is the country where policymakers decide on investments to achieve poverty and undernourishment goals.

constitute the best-practice frontier in the use of investment for poverty and malnutrition alleviation and can be used as reference or benchmarking countries to analyze performance of countries that are not at the best practice frontier.

Fourth, DEA models include the usual outputs and controlled inputs. These are inputs controlled by the policymaker over which policy decisions are made (for example, level of investments allocated to the achievement of SDGs; allocation of investment across R&D and non-R&D innovation, extension, etc.). However, there are some variables that directly affect the results of investment (poverty and undernourishment reduction) that are not controlled by policymakers or that are part of longer-term policy plans not directly related to the achievement of the SDGs. That is the case, for example, with structural variables like the share of agriculture in gross domestic product (GDP) and in total employment, urbanization, extent and quality of physical infrastructure (roads, railways, ports, airports), average income, quality of political institutions, and human capital. Non-controllable variables are introduced in the GP-DEA model as constraints that reshape the relationship between outputs and controllable inputs. When introducing non-controllable inputs, the benchmark point for a country obtained with the GP-DEA model is selected among countries with controllable input/output that cannot be improved with the actual levels of non-controllable inputs. For example, introducing income per capita as a non-controllable input forces the model to compare the country of interest to countries at the frontier with the same or smaller income per capita as the country being evaluated.

Finally, the model provides three major results for each country: a) it determines if the country can or cannot achieve the policy target, given investments and non-controllable variables; b) it gives the minimum level of poverty and undernourishment a country can reach, given investments and non-controllable variables; and c) it estimates the efficient level of investment toward achieving the policy goals if the country falls short of the target. This could be the case because non-controllable or fixed variables become more constraining than the levels of investment in R&D, which means that increasing investment would not affect poverty and undernourishment unless the levels of non-controllable variables are modified. If that is the case, the model defines the levels of investment that minimizes the gap between policy targets and the achievable levels of poverty and undernourishment, given fixed levels of other variables. Based on the three major results obtained from the model we define the following concepts:

- **Efficiency** is achieved by a DMU when the maximum possible output is obtained from a set of inputs. A DMU is inefficient if the same or greater output could be produced with less input. Maximum output refers here to the maximum output that can be produced with the available technology, while the term "efficiency" refers to the relationship between the amounts invested in R&D and non-R&D innovation and the levels of poverty and undernourishment achieved.
- **Effectiveness** addresses how well a DMU can meet its predetermined goals, and it is defined as the ratio of the observed output to the predetermined goal. In this study, the goals are the levels of poverty and undernourishment to be achieved as defined in the SDGs, while the output is the level of these two indicators reached by countries.
- **Attainable level of output** is defined as the maximum level of output a DMU can achieve given its levels of investment (other things being equal). By comparing outputs and investment from all countries, GP-DEA can determine the "efficient" level of investment needed to achieve different levels of output.

Using the proposed GP-DEA approach, we look at the performance of 69 LMI countries committed to minimizing poverty and undernourishment by investing in public agricultural R&D and non-R&D innovations. In this context, policymakers in each country decide on how much to invest in public agricultural R&D and non-R&D innovations to reduce poverty and undernourishment. The level of poverty and undernourishment obtained as the result of this investment is the policy output. The level of this output does not depend uniquely on the investment made by policymakers as discussed above but is also subject to non-controllable factors that are assumed to be fixed. These constraints can only be changed in the long term by some form of investment and/or policy changes.

The focus of the analysis is not on the levels of R&D and non-R&D innovations needed to achieve the SDG targets on poverty and undernourishment, but on the contribution of financial and extension services to achieving those targets, given the observed level of investment in innovations at the country level.

Outputs, investments controlled by policymakers, and structural constraints considered are presented in what follows. All variables used are averages for the period 2000-2018. For some variables, information for that period is only partially available, but in those cases, we also use an average of the available values for the period. The extension data is the most limited, as it is the result of the assessment of the status of agricultural extension and advisory services worldwide for the period 2009-2013.

Outputs

- Poverty headcount (PHC: percentage of people earning less than USD 1.90/day, dollars of 2011).
- Prevalence of undernourishment (PoU: percentage of the population whose food intake is insufficient to meet dietary energy requirements continuously).

Controllable investments

The best-practice frontier, the distance of non-frontier countries to the frontier, and the effectiveness in the use of investments are calculated by comparing countries' outputs and controllable investments:

- Public agricultural R&D
- Spending in non-R&D innovations.

Non-controllable inputs (structural constraints)

These determine the "environment" affecting potential performance of controllable investments in each country, and include indicators of economic structure, policy, infrastructure and private investment. They enter the GP-DEA model playing a different role than the controllable investments. Policy outputs are not directly compared to non-controllable inputs. The role of these inputs is to control for structural differences between countries, constraining the model to compare countries only against those with similar values. For example, including GDP per capita as a non-controllable variable implies that a country with an average income of USD 3,000 could only be compared to countries with an average income of USD 3,000 or less. In this way, constraints imposed by non-controllable variables define the subset of countries to which a country is compared, making sure that

comparisons are conducted between "similar" countries. The selection of these variables is central to the analysis, as it could determine the size of the response of poverty and undernourishment to changes in extension and financial services. If the model does not include some of the structural variables that determine the level of extension and financial services a country can achieve, the model would tend to overestimate the impact of increasing access to these services. This is because part of the response would be the result of a flawed comparison between countries at different levels of development (higher level of non-controllable variables), assuming increases in the short run that can only be achieved through structural changes.

The description of the nine non-controllable variables used for the analysis follows. Detailed information on the sources and methods used to construct these variables can be found in the Annexes.

- Economic development and economic structure: i) GDP per capita; and ii) index of economic structure, including information on the importance of agriculture on GDP and employment in a country's economy.
- Infrastructure: iii) index of quality of infrastructure summarizing information on the quality of roads, railways, ports, airports and electric generation and ICT development.
- Political institutions: iv) index of quality of political institutions, including information on voice and accountability, political stability, government effectiveness, regulatory quality, rule of law and control of corruption.
- Human capital, health and basic education: v) average years of schooling; vi) index on health and basic education, including information on the incidence of disease (HIV prevalence, incidence of malaria and tuberculosis, infant mortality, life expectancy) and the quality of basic education at the country level.
- Innovation capacity: vii) enrolment in tertiary education as a structural factor constraining the supply of researchers; and viii) index of innovation, including information on R&D investment at the country level, collaboration of business and universities for innovation, and sophistication of demand.
- Private R&D investment and knowledge spill-ins: ix) other R&D investment including information on private R&D investments, knowledge spill-ins from private and public investment in other countries, and spill-ins from CGIAR investment.

Financial and extension services

As the focus of the analysis, these services are treated differently in the two scenarios defined below to measure the impact on policy outputs of further extending the reach of each.

- Financial services (inputs): i) percentage of the rural population aged 15 or older that borrowed to start, operate or expand a farm or business; ii) percentage of the rural population aged 15 or older that used a mobile phone or the internet to access an account
- Extension services: iii) number of extension staff (in full-time equivalents).

The variables representing access to financial and extension services were selected by looking at the relationship between all available financial and extension variables and structural variables like income per capita and financial development. Those variables showing high and positive correlation with non-controllable variables were discarded assuming that they can only change in the long run as the result of a country's economic transformation. As the selected variables show low correlations

with income per capita and financial development, it is assumed that countries can change the level of those variables in the short and medium run to complement investments in innovations. Within this framework, the question to be answered using the GP-DEA model is: What is the contribution of increased access to credit, to financial accounts through ICT, and of expanding extension services (number of extensionists) to poverty and undernourishment reduction in LMI, given actual investments in innovation and structural characteristics of the countries? To answer this question, the model is solved separately for the 69 countries setting a policy target of 95% of the total population above the poverty and undernourishment lines in four scenarios.

Scenario 1: This scenario uses the percentage of poor and undernourished people as policy outputs to evaluate the effectiveness of the use of public R&D and non-R&D investment in the country to achieve policy goals. In this scenario, structural constraints and financial and extension services are treated as non-controllable variables, and the effectiveness of public investment in innovation is obtained by comparing countries with similar structural characteristics and similar development of financial and extension services.

Scenario 2: As in Scenario 1, Scenario 2 evaluates the effectiveness of the use of public R&D and non-R&D investment at the country level to achieve policy goals. The only difference from Scenario 1 is that here countries are given more flexibility to achieve policy goals, as the model defines the level of financial and extension variables the countries need to achieve to maximize the impact of public investment in innovation on policy outputs given structural variables. This means that the model increases the observed levels of these variables to the point where no more improvements in policy outputs are obtained because other variables become more constraining than financial and extension variables. The description of the model in Annex 3 includes an explanation of how increased values of extension and financial services are determined in the model.

Scenarios 3 and 4: While Scenario 2 simulates the increase of financial and extension services simultaneously, Scenario 3 focuses on the effect on poverty and undernourishment of an increase in financial services only, while Scenario 4 looks at the impact of increasing the number of extensionists with no changes in financial services.

4. Results

Results of the GP-DEA model setting a policy goal of 5% of the PHC and PoU for every country are shown in Figure 3. The model solves finding the closest value to the 5% goal of PHC and PoU for each country. Results indicate that the lowest average attainable PHC for the sample of 69 countries was 25%, while the lowest average attainable PoU was 15%. The figure also shows that the gap between observed (31%) and attainable (25%) PHC levels is 6 percentage points compared to 3 points in the case of PoU (18% and 15% respectively). This means that, on average, countries are investing enough in public innovation to reach 25% and 15% of PHC and PoU, respectively. The comparison between the number of poor and undernourished people in LMI countries (Figure 4) shows that closing the gap between observed and attainable levels of PHC and PoU could result in 100 million fewer poor people living in extreme poverty (518 million instead of 618 million) and 98 million fewer undernourished people (463 million instead of 560 million people).

There are two relevant comparisons to be made from these results that have different implications. One is the difference between the *attainable* level of PHC and PoU in each country and the *policy target* of 5%. The second comparison is between the *observed* level of PHC and PoU and the *attainable* level of these indicators. Whereas the differences between the 5% desirable goal and the attainable PHC and PoU goals are mostly the result of structural differences between countries, the differences between attainable goals and observed PHC and PoU in each country are the result of ineffective use of public innovation investment. Even though countries with attainable goals higher than 5% cannot achieve the 5% policy goal, they could further reduce PHC and PoU if they can improve their performance and move closer to the PHC and PoU values of their peers or reference countries in the best-practice frontier, closing the gap between attainable and observed values.

These results show how GP-DEA could be used to define policy targets that are attainable and represent best practices. Results could also be used to determine policy changes needed by countries to close the gap between attainable and observed values of PHC and PoU given investments in innovation. Even though this is a relevant policy issue in the context of achieving the SDGs, it is beyond the scope of this study. Instead, we turn to the analysis of the impact of enhanced access to financial and extension services on the achievement of policy goals.
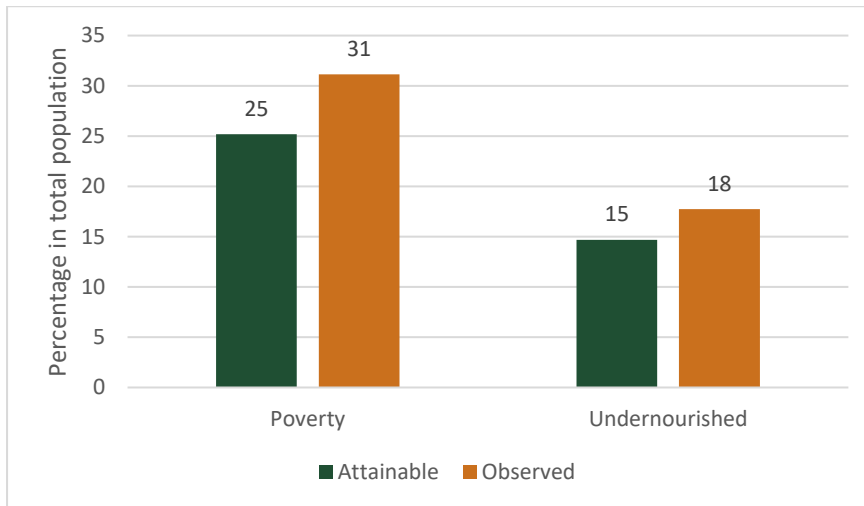
Figure 3. Observed and attainable levels of poverty headcount and prevalence of undernourishment.

Source: Elaborated by authors.
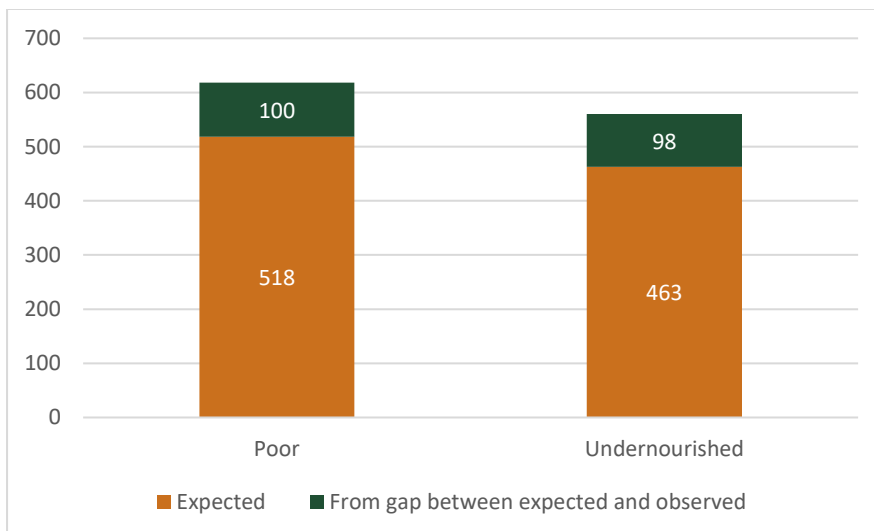
Figure 4. Total number of poor and undernourished people in 2018 and gap between observed and attainable estimates of poverty and undernourishment (millions).

Source: Elaborated by authors.

The impact of improved access to financial and extension services is shown in Figure 5. Expanding extension services has no impact on poverty as it only reduces the average attainable poverty level in LMI countries from 518 to 512 million – only 6 million fewer people living in extreme poverty. On the other hand, enhanced access to financial services has a much larger impact on poverty than increasing spending in extension, as it reduces the attainable poverty level in LMI countries by 20 million. Simultaneously increasing access to financial and extension services reduces the attainable level of poverty by 30 million – from 518 to 488 million people.

Reductions of the attainable level of PoU are also significant only when the number of extensionists and access to financial services are increased simultaneously, going from 18% with observed access

to finance and extension to 13% when financial and extension services are simultaneously increased. As shown in Figure 5, improving access to financial and extension services (other things being equal), the expected number of undernourished could potentially drop from 460 to 428 million – a reduction of 35 million in the number of undernourished people in LMI countries.

Our results so far show that improved access to financial and extension services could contribute to poverty and undernourishment alleviation, improving the effectiveness of investments in innovation. However, as only two among several factors affecting poverty and undernourishment, these services are not determinant of the achievement of poverty and undernourishment goals and can only contribute significantly to SDGs if they can effectively complement investments in innovation and structural economic changes in LMI economies. In a study on the impact of financial inclusion in LMI countries, Duvendack and Mader (2019) come to a similar conclusion when they state that:

> *From this review, the (perhaps boring) truth that seems to emerge about financial inclusion is that it is not changing the world. On average, financial services may not even have a meaningful net positive effect on poor or low-income users, although some services have some positive effects for some people. Considering that for most people financial inclusion … will be only one among many possible determinants of their life chances and their socio-economic well-being….*
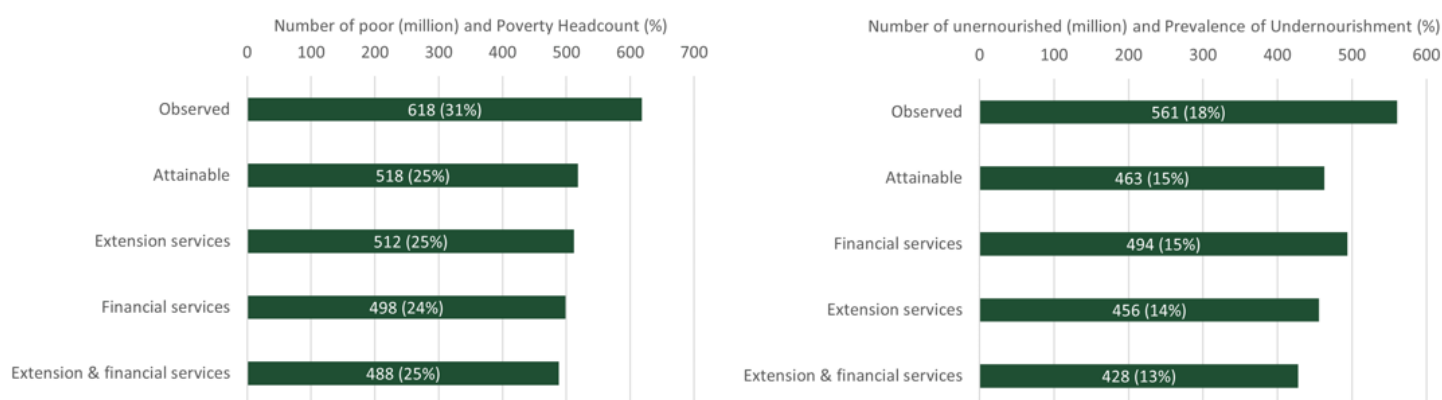
Figure 5. Total number of poor and undernourished people (in millions) and average values of the poverty headcount (%) and of the prevalence of undernourishment (%) in 2018, and gap between observed and attainable estimates of poverty and undernourishment with improved access to financial and extension services

Source: Elaborated by authors.
Note: The attainable level of the poverty headcount and of the prevalence of undernourishment is the level of these indicators a country can achieve given its actual investment in public innovation (and non-controllable variables). Increased access to financial and extension services is determined by the DEA model so as to minimize poverty and undernourishment given R&D and non-R&D investment and structural constraints.

Which are the major factors within extension and financial services explaining the different outcomes in Figure 5? Table 1 compares 2018 levels of financial and extension indicators to values of the same

variables under increased access to services. The table shows that increases in the number of extensionists (16.2%) and in the proportion of the population that borrowed to start or operate a farm or business (12.8%) are the main drivers of the reduction in attainable levels of extreme poverty and undernourishment in LMI countries. On the other hand, the proportion of rural population that used a mobile phone or the internet to access an account remained almost unchanged, decreasing from 12.6% to 12.3%, which means that increasing access to accounts through ICT has no effect on poverty and undernourishment.

Table 1. Financial and extension indicators in 2018 compared to values under improved access to services (Scenario 2).

	2018	Access to enabling services	Change
- Average number of extension staff (full-time equivalents)	14,975	17,394	+16.2%
- Percentage of rural population that borrowed to start, operate or expand a farm or business	8.0	9.0	+12.8%
- Percentage of rural population that used a mobile phone or the internet to access an account	12.6	12.3	-2.7%

Source: Elaborated by authors.

Finally, we look at the sensitivity of the results, assuming that results are mostly dependent on the selection of non-controllable variables for the model. As mentioned before, missing structural variables in the model could result, in most cases, in an overestimation of the effect of increasing access to financial and extension services. This is because part of that effect would be the result of structural changes wrongly attributed to financial and extension services when comparing countries with different characteristics. To check the effect of missing variables in our results we run Scenario 2 nine times, each time dropping one of the nine non-controllable variables. The results of these simulations compared to the original results for Scenario 2 are shown in Table 2. We focus on the attainable levels of poverty and undernourishment in each scenario. The effect of missing variables varies significantly with the different variables. For example, when dropping enrolment in tertiary education, increased access to financial and extension services reduces poverty by an extra 45 million people and undernourishment by 30 million. In contrast, not including one of the variables of infrastructure, innovation capacity, quality of institutions or years of schooling would result in a very small difference from the results obtained in Scenario 2 in both poverty and undernourishment. The fact that not all non-controllable variables affect poverty and undernourishment in the same way, however, makes it difficult to reduce the number of these variables in the model. Quality of political institutions and years of schooling seem to have a significant effect on results for undernourishment while having a smaller effect on poverty. The opposite seems to be true for health and basic education and GDP per capita. However, when dropping infrastructure, economic structure and innovation variables from the model we obtain similar results from those obtained with the original model, as shown in the last row of Table 2.

Table 2. Comparison between attainable levels of poverty and undernourishment in Scenario 2 and results in the same scenario when one of the non-controllable variables is dropped from the model.

	Poor (millions)		Undernourished (millions)	
	Attainable	Diff. with original	Attainable	Diff. with original
Original	510	0	427	0
Results when dropping:				
Infrastructure	511	-1	424	3
Economic structure	510	0	427	0
Innovation	509	1	418	9
Quality of political institutions	506	4	417	10
Years of schooling	506	5	415	12
Private R&D and spill-ins	492	19	398	29
Health and basic education	489	21	436	-9
GDP per capita	488	22	419	8
Enrolment in tertiary education	465	45	398	30
Infrastructure + Economic structure + Innovation	515	-5	413	14

Source: Elaborated by authors based on model simulations.

5. Conclusions

Increasing investment and spending in innovation is not enough to meet SDG targets without considerable improvement of institutions, services and policy tools to ensure that additional investment is effectively turned into improved outcomes. As an important part of a nation's common innovation infrastructure, financial and extension services are major "enablers" of investments, favorably contributing to national innovative capacity. At present, a wide variety of ICT tools and innovations in financial and extension services offer new ways of expanding the inclusion of the financially excluded into the financial system and could contribute to revitalize the interaction between extension services and farmers, making services more demand-driven, up-to-date and inclusive. In this context, this study looks at the potential contribution of financial and extension services to the SDGs as enhancers of the impact of public investment in innovation. The approach used extends the standard DEA model to include longer-term management goals and find a solution that balances the efficient use of innovation investments and the achievement of policy goals, making this approach well suited to the analysis of the SDGs. The model is solved for 69 LMI countries, setting as policy target the reduction of the PHC and PoU to 5% or less to obtain the minimum level of poverty and undernourishment that a country can achieve, given public and private levels of investment in innovation and fixed or structural variables. Results of the impact of increased access to financial and extension services are obtained from a scenario where the model determines the levels of financial and extension services that maximize achievement of policy goals.

Results show that given observed investment, LMI countries could reduce the number of people living in extreme poverty from 618 million observed in recent years to 518 million, while the number of undernourished people could be reduced from 560 to 463 million, without increasing investment in innovation – only increasing the effectiveness with which this investment is used.

To enhance the impact of investment in innovation on the reduction of poverty and malnutrition, countries could increase investment in extension and financial services that facilitate producers' access to those innovations. Results of a scenario simulating improved access to these services without changing levels of innovation investment in agriculture show that improved access to both financial and extension services would bring attainable poverty levels from 518 to 488 million (a reduction of 30 million poor people) and undernourishment levels from 463 to 428 million (35 million fewer undernourished people). This is achieved by increasing the number of extensionists in LMI countries by 16% and access to credit in rural areas by 12%. We conclude that improved access to financial and extension services could contribute to poverty and undernourishment alleviation, improving the effectiveness of investments in innovation. However, as only two among several factors affecting poverty and undernourishment, these services are not determinant to the achievement of poverty and undernourishment goals; their impact is limited and can only contribute to SDGs if they can effectively complement investments in innovation and structural changes in LMI economies.

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Annex 1. Data sources for the DEA analysis

Outputs

Poverty headcount (PHC): Percentage of people earning less than USD 1.90/day, dollars of 2011. Obtained from World Development Indicators (World Bank, 2021).

Prevalence of undernourishment (PoU): Percentage of the population whose food intake is insufficient to meet dietary energy requirements continuously. Obtained from FAOSTAT (FAO, 2021): http://www.fao.org/faostat/en/#data.

Investments in innovations

Public R&D investment: Knowledge stocks of public investment built using R&D data from ASTI (2021): https://www.asti.cgiar.org/.

Spending in non-R&D innovations: Adapted from data by Dalberg as reported in the sustainable agriculture Innovation Investment Study (Dalberg Asia, 2021): https://wle.cgiar.org/cosai/innovation-investment-study.

Financial and extension services

Access to credit: Proportion of rural population 15 years and older that borrowed to start, operate or expand a farm or business. Obtained from the Global Findex Database (Demirgüç-Kunt et al., 2018): https://globalfindex.worldbank.org.

Use of ICT to access account: Proportion of population 15 years and older that used a mobile phone or the internet to access an account in the past year. Obtained from the Global Findex Database (Demirgüç-Kunt et al., 2018).

Number of extensionists (in full-time equivalents): Obtained from the Worldwide Extension Study (International Food Policy Research Institute and University of Illinois, 2019): https://doi.org/10.7910/DVN/JEQ9BO.

Annex 2. Structural variables in the DEA model

Environmental or structural variables were included in the model as constraints in the optimization model that minimizes poverty and undernourishment. These constraints play a major role in the simulation of "realistic" targets for poverty and undernourishment alleviation. Variables were selected in six main areas: 1) economic development and economic structure; 2) infrastructure; 3) quality of political institutions; 4) human capital, health, and basic education; 5) innovation capacity; and 6) private R&D investment and knowledge spill-ins. Correlation between variables in each of the six main areas was measured and a principal component analysis (PCA) was run for each group of variables when needed. The final variables representing each structural area were selected to represent most of the variability of the overall group of variables as determined in the PCA while avoiding the inclusion of a large number of highly correlated and redundant variables in the model. Details on the definition of the nine structural variables follow.

Economic development and economic structure

GDP per capita: From ASTI (2021), is GDP in 2011 PPP USD calculated based on data from the World Development Indicators (World Bank, 2021).

Index of economic structure: Calculated as a simple average of the share of value added of agriculture, forestry and fishing in GDP and the share of agriculture, forestry and fishing in total employment. Agriculture corresponds to International Standard Industrial Classification (ISIC) divisions 1-5 and includes forestry, hunting and fishing, as well as cultivation of crops and livestock production. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. Data used is from the World Development Indicators (World Bank, 2021).

Infrastructure

The information for the Infrastructure Index used in the analysis was extracted from the Global Competitiveness Index developed by Xavier Sala-i-Martin and Elsa V. Artadi (World Bank, 2021). The index is built as a weighted average of many different components, each measuring a different aspect of competitiveness. The components are grouped into 12 categories, the pillars of competitiveness: 1) institutions; 2) infrastructure; 3) macroeconomic environment; 4) health and primary education; 5) higher education and training; 6) goods market efficiency; 7) labor market efficiency; 8) financial market development; 9) technological readiness; 10) market size; 11) business sophistication; and 12) innovation.

The Global Competitiveness Index is the tool used by the World Economic Forum in its Global Competitiveness Report to assesses the competitiveness landscape of 137 economies. Data and methodology are available at http://reports.weforum.org/global-competitiveness-index-2017-2018/.

Data used in this study to build the Infrastructure Index were extracted from the second pillar of the Global Competitiveness Index. Variables included in this second pillar are:

- Quality of railroad infrastructure
- Quality of port infrastructure
- Quality of air transport infrastructure
- Quality of roads
- Quality of electricity supply.

The ICT Development Index (see below) was included as the sixth variable of a composite index of quality of infrastructure. PCA was used to build a composite index of infrastructure. This approach combines the six indicators into eigenvectors which are linearly independent vectors (0 correlation between each other), each of them explaining a share of the total variation of the six variables. Table A2.1 shows the result of PCA. We built the index of quality of infrastructure using the first three eigenvectors, which explain 87% of the total variation of the six indicators. The final index is obtained by adding the three components weighted by their respective eigenvalues. Note that eigenvalues represent the contribution of each principal component to total variance.

Table A2.1. Principal components for quality of infrastructure.

Number of observations	69					
Number of components	6					
Component	Eigenvalue	Difference	Proportion	Cumulative		
Comp1	3.69332	2.84906	0.6156	0.6156		
Comp2	0.84426	0.15393	0.1407	0.7563		
Comp3	0.69032	0.31934	0.1151	0.8713		
Comp4	0.37098	0.11890	0.0618	0.9331		
Comp5	0.25208	0.10304	0.0420	0.9752		
Comp6	0.14904	.	0.0248	1		
Principal	Components	(eigenvectors)				
Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6
Roads	0.4546	-0.3157	-0.0793	-0.4545	-0.027	0.6929
Railroads	0.3242	-0.0254	0.9362	0.1245	0.0332	-0.0342
Ports	0.4066	-0.4646	-0.2435	0.4869	0.5432	-0.1657
Airports	0.4613	-0.2002	-0.1572	0.018	-0.7338	-0.4286
Generation of electricity	0.4194	0.4548	-0.0906	-0.5355	0.3879	-0.4145
ICT index	0.3664	0.661	-0.1583	0.5038	-0.119	0.3685

The ICT Development Index (International Telecommunication Union, 2021) is a composite index that combines 11 indicators into one benchmark measure. It is used to monitor and compare developments in ICT between countries and over time. The index is designed to be global and reflect changes taking place in countries at different levels of ICT development. The aggregated ICT index includes three sub-indices.

- Access: Indicators included in this group provide an indication of the available ICT infrastructure and individuals' access to basic ICTs.

- Usage: The indicators included in this group capture ICT intensity and usage.
- Skills: Data on mean years of schooling and gross secondary and tertiary enrolment ratios from the United Nations Educational, Scientific and Cultural Organization Institute for Statistics.

Available data is normalized and rescaled to identical ranges, from 1 to 10. We rescaled the index to run from 0 to 1. Information on the index and data is available at https://www.itu.int/en/ITU-D/Statistics/Pages/publications/mis2017/methodology.aspx.

Quality of political institutions

Data from Worldwide Governance Indicators (Kaufmann et al., 2021) was used to build the index of quality of political institutions. WGI reports aggregate and individual governance indicators for over 200 countries and territories over the period 1996-2020, for six dimensions of governance:

- Voice and accountability: Captures perceptions of the extent to which a country's citizens can participate in selecting their government, as well as freedom of expression, freedom of association and a free media.
- Political stability and absence of violence/terrorism: Measures perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism.
- Government effectiveness: Captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies.
- Regulatory quality: Captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.
- Rule of Law: Captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police and the courts, as well as the likelihood of crime and violence.
- Control of corruption: Captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests.

Each of the six aggregate WGI measures are constructed by averaging together data from the underlying sources that correspond to the concept of governance being measured. PCA of the six indicators included in the WGI dataset for 212 countries is used to summarize the information of the six variables into a synthetic measure of quality of political institutions.

Results of the PCA are presented in Table A2.2. The first component captures 86% of the total variation of the six indicators, so we used this first component as the index of quality of institutions, where indicators are added using the coefficients of the first eigenvector (Comp1) in the second part of Table A2.1.

Table A2.2. Principal components for quality of institutions.

Number of observations	212			
Number of components	6			
Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	5.17	4.77	0.86	0.86
Comp2	0.40	0.13	0.07	0.93
Comp3	0.27	0.17	0.05	0.97
Comp4	0.10	0.06	0.02	0.99
Comp5	0.03	0.00	0.01	1.00
Comp6	0.03	.	0.01	1.00

Principal components (eigenvectors)						
Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6
Voice & accountability	0.387	0.1426	0.8951	-0.0706	0.1373	-0.0694
Political stability & absence of violence/terrorism	0.3655	0.8357	-0.2837	0.2778	0.1009	0.0127
Government effectiveness	0.4225	-0.3235	-0.2321	0.0927	0.3336	-0.7370
Regulatory quality	0.4139	-0.4071	-0.0194	0.6507	-0.0360	0.4877
Rule of law	0.4325	-0.0299	-0.0808	-0.2456	-0.8533	-0.1306
Control of corruption	0.4240	-0.1003	-0.2397	-0.6523	0.3609	0.4438

Human capital, health and basic education

Years of schooling: Average total years of schooling for adult population from Barro and Lee (2013).

Index of health and basic education: Obtained from the database of the Global Competitiveness Index (World Bank, 2021), representing its fourth pillar. This pillar is measured by 10 components: HIV prevalence, primary education enrolment, business impact of malaria, malaria incidence, business impact of tuberculosis, tuberculosis incidence, business impact of HIV/AIDS, infant mortality, life expectancy, and quality of primary education.

Innovation capacity

Enrolment in tertiary education: Included as a structural factor constraining the supply of researchers.

Capacity for innovation: Obtained from the database of the Global Competitiveness Index (World Bank, 2021), representing its twelfth pillar. It includes the following indicators: capacity for innovation, quality of scientific research institutions, company spending on R&D, university–industry collaboration, availability of scientists and engineers, patent applications under the Patent Cooperation Treaty, and government procurement of advanced technology.

Private R&D investment and knowledge spill-ins

Other R&D investment: Includes information on private R&D investments, knowledge spill-ins from private and public investment in other countries and spill-ins from CGIAR investment. Data used to

build this indicator is from ASTI (2021), while private investment data was built by authors based on Fuglie (2016).

The information on R&D for this indicator and for public R&D and non-R&D investment in innovations was not used as such, but used first to build knowledge stocks to capture the lagged effect of research investment. This is because investment in a given period does not influence productivity, poverty or undernourishment in the same period; it takes time for this investment to have an effect. Once there is an effect, this same investment will continue affecting productivity or other related variables for several years to come. To capture this effect of investments in innovation we used the perpetual inventory method to calculate the level of capital built by investments from previous periods. This method is simple and uses only three parameters to define knowledge stocks based on past investments: a depreciation or decay rate of knowledge; a gestation period, or the number of years that takes to an investment to fully contribute to knowledge stock; and a parameter B that models the trajectory of the contribution of investment to the knowledge stock during the gestation period. A detailed discussion of the use of the perpetual inventory method to build knowledge stocks can be found in Nin-Pratt and Magalhaes (2016).

Annex 3. GP-DEA model

The model used in the analysis was proposed by Stewart (2010), extending the standard Data Envelopment Analysis model to include longer-term management goals. The model is solved for each country separately. Here we identify the country for which the model is solved as "o". Country "o" is compared to all other countries represented by subscript "c", with c=1,2,…,o,…K, where in this study K=69. The set "c" of countries includes country "o". In the model, the value of the variables z, x and y for country "o" appear on the right hand side of equations (A2)-(A4). On the left hand side of these equations appear the values of the same variables but for all countries in the sample weighted by the variable λ_c. The value of λ_c is not known a priori but results from the solution of the model. That is, the model assigns a value of λ_c to each country c, the same value in all equations. If this value is greater than 0, that means that the country is found to be a "best performer" and reference for country "o". Countries for which λ_c=0 are not reference for "o" and their values are not considered in the solution of the model defining reference values of inputs and outputs for country "o". Formally, the model is represented as follows.

Minimize:
$$\theta o = D + \left(\sum_m (w_{o,m} \times \delta_{o,m}) + \sum_n (u_{o,n} \times \varphi_{o,n}) \right) \tag{A1}$$

Solving for: $\theta o, \delta_{o,m}, \varphi_{o,n}, D$ and λ

Subject to:

$$\sum_c \lambda_c z_{c,r} \leq z_{o,r} \tag{A2}$$

$$\sum_c \lambda_c x_{c,n} \leq x_{o,n} - \varphi_{o,n} \tag{A3}$$

$$\sum_c \lambda_c y_{c,m} + \delta o_m \geq \alpha T_{o,m} + (1-\alpha)y_{o,m} \tag{A4}$$

$$D - w_{o,m}\delta_{o,m} \geq 0 \tag{A5}$$

$$D - u_{o,n}\varphi_{o,n} \geq 0 \tag{A6}$$

$$\sum_c \lambda_c \leq 1 \tag{A7}$$

Where:

$z_{c,r}$ value of non-controllable input r (fixed or structural inputs) in country c

$x_{c,n}$ = value of controllable input n in country c

$y_{c,m}$ = value of output m in country c

$z_{o,r}, x_{o,n}, y_{o,m}$ = non-controllable input r, controllable input n, and output m of evaluated country "o"

$T_{o,m}$ = goal or aspiration level specified for output m of country "o"

$\alpha T_{o,m} + (1-\alpha)y_{o,m}$ where $0 \leq \alpha \leq 1$ allows the generation of a series of efficient benchmarks by solving the reference point problem for values of α. When α=1, the right-hand-side of (A4) = $T_{o,m}$

which means that the model solves to minimize the distance between the attainable (optimal) level of output and the policy goal without consideration of the efficient allocation of output. When α=0, the model only considers efficiency, disregarding the policy goal. Values of α between 0 and 1 result in different ponderations of the importance of efficiency and goals.

$\delta o_m, \varphi_{o,n}$ = slack variables for outputs and inputs, capturing the difference between the benchmark values of y and x and the observed value of $x_{o,n}$ (A3) and the value of $\alpha T_{o,m} + (1-\alpha)y_{o,m}$ in (A4)

$w_{o,m}, u_{o,n}$ = subjective weights defining the importance given to different outputs and inputs. This means that the model allows for different results depending on the preferences or goals of the analyst. For example, a value of $w_{o,m} = 1$ for both outputs means that we are giving the same importance to achieving the target levels of poverty and undernourishment. Say that we are trying to achieve both policy goals, but the priority was given to poverty alleviation as two-thirds of investments in innovation target the achievement of this goal while the remaining one-third of investments was allocated to the reduction of undernourishment. Then we would want to evaluate the results based on our preferences. In this case we can give different weights to poverty and undernourishment (for example 0.66 to poverty and 0.33 to undernourishment) in the objective to evaluate results based on our preferences. For this study we used values of $w_{o,m} = 1$, so the same importance was given to the reduction of poverty and undernourishment.

Notice, as mentioned above, that all right hand side variables in equations (A1) $z_{o,r}$, (A2) $x_{o,n}$ and (A3) $y_{o,m}$ are actual values of the non-controllable variables, inputs (investments in innovations) and outputs (observed poverty and undernourishment), respectively in country "o", the country being compared with all countries ("c"). This is the model solved in Scenario 1. For Scenarios 2, 3 and 4, the model is modified as follows. First, equation (A2) is split into two equations:

$$\sum_c \lambda_c \, z_{c,fix} \leq z_{o,fix}$$
(A2.1)

$$\sum_c \lambda_c \, z_{c,finex} \leq v_{o,finex}$$
(A2.2)

Equation (A2.1) is equivalent to equation (A.2), but in this case, it includes only the non-controllable variables (represented by the set "fix") and does not include the financial and the extension variables. These are included in (A2.2) where "finex" is the set of financial and extension variables and where *v* on the right hand side is unknown and results from the solution of the model. *v* is the level of financial and extension services that maximizes the objective.

Notice that equation (A2) in the original problem is the equation that forces comparisons of country "o" with "similar" countries. Say that r=GDP per capita, $z_{o,r}$ is GDP per capita of "o" and $z_{c,r}$ is GDP per capita of country "c". Then the value of λ_c obtained from the solution of the problem (the same in all equations) needs to be such that complies with the inequality in (A2), that is, comparisons for "o" are done with countries in "c" with GDP per capita equal or smaller than that of "o".

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