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Public investment prioritization for Rwanda's inclusive agricultural transformation

Evidence from Rural Investment and Policy Analysis Modeling

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ABSTRACT

As Rwanda is expected to return to its rapid growth trajectory following the COVID-19 pandemic, agriculture will continue to play a central role in the structural transformation of the entire economy. To this end, the Government of Rwanda continues to invest in the agricultural sector by building on Strategic Plans for the Transformation of Agriculture (PSTAs) that began in the early 2000s. The challenging question is how to prioritize public expenditures across a broad portfolio of policies and programs.

Ambitious plans, whether in the short or long term, require difficult decisions. The prioritization of public investment becomes even more complex as Rwanda's structural transformation advances and as new investments—beyond the farm—become critically important for the agricultural sector. The structural transformation process itself means that as agriculture becomes more integrated with the rest of the economy, public resource allocations need to address a wider range of issues across the entire food system; these include nutrition-sensitive food production systems, inclusive value chain development, nonfarm rural enterprise development, and climate-resilient sustainable intensification of both crops and livestock.

This study provides evidence that is designed to assist the Government of Rwanda in its selection of agricultural policy, investment, and expenditure portfolios that reflect the country's broad focus on its food system and structural transformation. This process of prioritization will need to incorporate multiple public investments targeting multiple development outcomes and will need to be grounded in the cost-effective use of public resources in a largely market-led transformation process. This data-driven and evidence-based approach must critically underpin an informed investment prioritization process that helps achieve ambitious targets in an environment constrained by limited public resources.

The study uses the Rural Investment and Policy Analysis (RIAPA) economywide model developed by the International Food Policy Research Institute (IFPRI), with contributions from colleagues at the Ministry of Agriculture and Animal Resources (MINAGRI), the Ministry of Finance and Economic Planning (MINECOFIN) and the National Institute of Statistics of Rwanda (NISR). The study draws on data from multiple sources as well as expert insights to inform the application of RIAPA's Agricultural Investment for Data Analyzer (AIDA) module as a tool to measure the impacts of alternative public expenditure options on multiple development outcomes. Using this integrated modeling framework, the study links agricultural and rural development spending to four specific outcomes: economic growth, job creation, poverty reduction, and diet quality improvement; at the same time, it considers the synergies and trade-offs associated with the different investment options in the transformation process.

The paper first assesses the contribution of public expenditures to agricultural and rural development under the fourth Strategic Plan for Agriculture Transformation (PSTA 4) that extends between 2018 and 2024. These findings are important, given the fact that since the beginning of PSTA 4, the budget allocated to MINAGRI (measured in constant prices) has stagnated. Our results suggest that increased spending on agriculture is well justified and that such spending is essential if the Government of Rwanda is to achieve its long-term development goals.

Summary of findings

- Agricultural expenditures are, by and large, efficiently allocated in Rwanda. Our estimates indicate that each US dollar of agricultural spending under PSTA 4 corresponds to a US$2.05[1] gain in GDP. The total gains in the entire period of PSTA 4's seven years (2018-2024) could be as high as $1.57 billion, of which, $1.17 billion is gain in agricultural GDP while $0.18 billion and $0.22 billion are gains in off-farm economic activities that are situated within and outside the food system, respectively.
- Our estimates further indicate that annual agricultural expenditures of approximately $109 million contributed to 1.6 percentage points of additional growth in GDP in 2018 and 0.4 percentage points in 2019. As expected, the growth effects are stronger within agriculture and the food system, contributing an additional 2.7 and 3.2 percentage points of growth in the food system and in agricultural GDP, respectively, in 2018. The unprecedented COVID-19 pandemic negatively shocked the economy in 2020, although agricultural spending helped the economy mitigate the shock particularly for the food system and the agricultural sector. Without the support from agricultural expenditure, the growth rate could have been negative for the food system and close to zero for agriculture.
- Agricultural expenditures are expected to help create 2.57 million additional employment opportunities in 2018-2024. Many employment opportunities are expected to be created outside the -food system, in addition to the movement of labor from agriculture to rural nonfarm activities within the food system. This movement of labor contributes positively to the transformation process at the same time increasing growth in agricultural production.
- Agricultural expenditures under PSTA 4 also contribute to reductions in poverty. Our estimates indicate that the number of poor people could fall by 2.34 million during 2018–2024 as a result of these expenditures.
- Estimates further suggest that Rwanda's agricultural expenditures contribute to improvements in diet, particularly among rural households that rely on agriculture for their livelihood.

The study further identifies the contributions made by different types of investments and expenditures across the different agricultural programs set forth under the current PSTA 4 budget allocation. Findings indicate the following.

- The current PSTA4 budget allocation is generally effective in terms of promoting economic growth, employment, poverty reduction, and improvements in diet.
- Agricultural sectors with large shares of GDP and employment that receive more attention in PSTA 4 budget allocations often have larger impacts on focal development outcomes.
- Programs that enhance productivity growth in vegetables and Irish potatoes have larger impacts with relatively higher returns per unit of spending. Irish potatoes, however, rank low in terms of employment and effect on diet quality.
- Of the types of investment programs considered, small-scale irrigation consistently generates larger impacts and appears with higher efficiency in terms of returns per dollar spent.

[1] All dollar amounts in the paper are in constant (2017) US dollars. The exchange rate of 831.53 RWF per US$ in 2017 is used for the conversion.

- The returns from some investments, such as irrigation, are higher when these infrastructural developments target crops that can be grown multiple times per year than, for example, sugarcane, which requires a longer growing period.

Our estimates show that no single expenditure option is the most effective or efficient in achieving all four development outcomes. To help policymakers identify options for achieving marked progress jointly across all outcomes, a single composite index is generated to combine scores with equal weights for the four outcome indicators. Findings indicate the following:

- Of the sectors analyzed, highly tradable high-value crops such as vegetables, coffee and tea, and Irish potatoes rank at the top with the highest composite scores; this suggests that increasing investments to support value chains of high-value agriculture would help the country achieve broad development outcomes faster than would focusing on certain other value chains.
- In terms of investment types, small-scale irrigation ranks at the top with the highest composite score, both in its contribution to development outcomes and in its cost-effectiveness. Hillside irrigation and marshland development, on the other hand, rank near the bottom, with lower scores than many other types of investment. These results do not suggest that marshland or hillside development should necessarily be scaled back; rather, it indicates the critical importance of searching for lower-cost approaches to these investments when public resources are limited. This is also true for terracing investments.
- The same is also true for other investment and expenditure options: differences in the impact and cost-effectiveness should not be interpreted as indications of how desirable they are but rather as highlighting the importance of prioritizing investment options by considering both their costs and achievable development outcomes.

The paper assesses whether there is room to improve the current agricultural budget allocations under PSTA 4 such that the same amount of spending generates larger impacts on the assessed development outcomes. The results are as follows:

- A modest reallocation of the current budget distribution can improve the effectiveness of current levels of agricultural expenditure under PSTA 4.
- Our estimates indicate that with modest reallocations of the PSTA 4 budget, total GDP during the PSTA4 period of 2018-2024 would be $154 million higher, with a slightly larger increase for the overall food system.
- Our estimates further indicate that additional gains can be achieved in employment outcome: 22,700 more jobs would be created at the national level, of which 17,000 (75 percent) are in agriculture.
- Our estimates also indicate that with a modest budget redistribution, the number of poor at the national level would be 222,000 less than the number under the current budget allocation. Of this figure, 210,000 individuals (95 percent) are in rural areas.
- This budget reallocation at the margins is also expected to lead to improvements in diet quality, particularly among rural households.
- If the reallocation of the current budget occurs only in the remaining years (2022-2024) of PSTA 4, GDP is expected to gain $79 million in 2022-24 when compared to a situation without such

reallocation. Approximately 11,000 new jobs would be created in the economy, and 103,000 people would be lifted out of poverty.

- Our estimates further show that increasing the share of the budget that is allocated to input subsidies targeting those crops that have already grown in the areas with developed progressive terraces can improve returns to total agricultural expenditures. This is because productivity gains are modest on progressive terraces without adoption of modern inputs and better management practices.

Overall findings from this study demonstrate the continued importance of public investment and expenditure for growth and job creation beyond agriculture and for poverty reduction and diet quality improvement among rural and urban households. These findings justify an increase in the budget allocated to MINAGRI, which has been stagnant—and even declining, when measured in constant prices—since PSTA 4 began in 2018.

- Our estimates from a 5 percent annual growth in public expenditures on agriculture—when accompanied by a more efficient allocation—indicate that returns to the four focal outcomes would be higher than the returns to the current PSTA 4 expenditures. A budget increase allows more spending on agricultural R&D, small-scale irrigation, and terracing that is jointly promoted with adoption of modern inputs and the provision of extension services as a package. The same is true when more public funds are allocated to coffee and tea production when the use of modern inputs and extension services are jointly promoted.
- Specifically, if agricultural expenditures increase by 5 percent annually, which is about $170 million of accumulated additional spending over the 7 years between 2018 and 2024, the additional cumulative GDP could exceed $800 million over the same period. If 5 percent of annual growth in agricultural spending only occurs in the remaining years (2022-2024) of PSTA 4, the gains in GDP are $300 million in this later period. The gains are realized against a total budget increase of just $34 million because a more cost-effective reallocation is for the total budget of 2022-2024. If growth rate rises to 10 percent per year, the total gains of GDP are about $380 million in 2022-2024.
- With 5 percent annual growth in agricultural expenditures, over 35,000 new jobs would be created in the remaining period of PSTA 4, 436,000 people would be lifted out of poverty, and significant improvements in diet quality would be realized. If the budget growth rate rises to 10 percent per year, the number of people lifted out of poverty reaches to 527,000 and the diet quality index also improves considerably for both urban and rural households.

Taken together, these results suggest that PSTA 4—now at its midterm point—is generally well structured in terms of its investment portfolio and the cost-effectiveness of these investments. However, there is scope for budgetary adjustments that could enhance its impacts on economic growth, employment, poverty, and diet quality; there are also indications that impacts could be improved with an increase in budget allocations to agriculture. These results highlight the important potential synergies and trade-offs across development outcomes resulting from adjustments to the PSTA 4 investment portfolio.

Looking to the future, there is scope to strengthen and expand the application of the economywide modeling tool described here. Better data and analysis of coverage rates, unit costs, and other key parameters will improve the precision of impact estimates. The design of alternative allocation scenarios will inform future planning efforts. These efforts will enable government and its development partners to address many of the pressing questions and difficult decisions they face in prioritizing public investments and expenditures for a sustainable and inclusive agricultural transformation in Rwanda.

INTRODUCTION

Public investment in agriculture is a key driver of economic growth, employment, poverty reduction, and dietary improvement in many developing countries (Ebaidalla 2013; Muthui et al. 2013) and in many transition economies (Gangal and Gupta 2013; Yilgör, Ertuørul, Celepcioølu 2012). This is certainly true of Rwanda, where agriculture accounts for 65 percent of employment, 31 percent of household income, and 52 percent of export earnings (NISR 2019, 2021; Rwanda, Ministry of Agriculture and Animal Resources 2018). As such, agriculture plays a natural leadership role in the country's structural transformation process.

In the early 2000s, in an effort to strengthen the role of agriculture in economic growth, poverty reduction, and nutritional outcomes, the Government of Rwanda began implementing a series of strategic plans for agricultural transformation (PSTAs). These PSTAs have made critical contributions to improving food security, modernizing the agricultural sector, conserving the country's fragile natural resource base, and creating new economic opportunities. The Rwandan government and its partners, however, continually ask themselves whether PSTA budget allocations represent the best use of scarce public resources. Each PSTA design process, annual budget preparation, and midterm course correction faces the perennial question of which policies, investments, and expenditures to prioritize. Given the ambitious short- and long-term goals set forth in each PSTA, the answer to this question necessarily leads to some difficult decision-making.

The challenges of the prioritization of public investment become even more complex as Rwanda's structural transformation advances and new investments beyond the farm become critically important. The structural transformation process itself means that as agriculture becomes more integrated with the rest of the economy, public resource allocations need to address a wider range of issues across the entire food system; these issues include nutrition-sensitive food production systems, inclusive value chain development, nonfarm rural enterprise development, and climate-resilient sustainable intensification of both crops and livestock.

Moreover, with agricultural transformation, the benefits and trade-offs associated with different expenditure options reach well beyond farming. They have come to include downstream processing, trading, and food services in both rural and urban areas. A food systems lens has increasingly become important for ensuring that agriculture-related public expenditure remains coherent with broad development objectives. When prioritizing limited resources, governments are expected to consider a wide range of outcomes that are often in competition with each other. Economic growth remains the core of agricultural transformation; however, it has become equally important to ensure that growth is broad-based to reach the majority of rural households, that it is inclusive of vulnerable households and is both socially and environmentally sustainable, that it achieves maximum nutrition improvement, and that it promotes gender-equality outcomes.

This study aims to generate evidence that can help the Rwandan government to design agricultural policies and expenditure portfolios that reflect today's broader food system focus, embody multiple development goals, and promote cost-effective market-led transformation. The study builds on prior research on Rwanda that assesses the impact of public expenditure on issues such as agricultural research and development (R&D) (Al-Mamun et al. 2018), urbanization and agglomeration (World Bank and GoR 2020), and fiscal spending more generally (Almanzar and Torero 2017).

The study focuses on the implementation of the fourth Strategic Plan for Agriculture Transformation (PSTA 4), which covers the 7-year period from 2018 to 2024. PSTA 4 is a continuation of previous PSTAs and focuses on ensuring that agricultural production in Rwanda is moving toward greater nutrition sensitivity, sustainability, and resilience to climate change. The PSTA 4 portfolio is structured around four specific pillars: (1) innovation and extension, (2) productivity and resilience, (3) inclusive markets and value addition, and (4) an enabling environment and responsive institutions. Each of these priority areas is addressed with specific policy reforms, public investments, and budget expenditures.

This study provides evidence to assist the Government of Rwanda in its selection of agricultural policy, investment, and expenditure portfolios that reflect the country's broad focus not only on agriculture and rural development, but also on its food system and structural transformation. The study primarily focuses on multiple public investment options and multiple development outcomes; it is grounded in the analysis of cost-effectiveness in the use of public resources through a largely market-led transformation process.

It addresses the following four questions:

1. How much would agricultural and rural development expenditures contribute to economic growth, employment creation, poverty reduction, and improvements in diet under the current PSTA 4 allocations for 2018 to 2024?
2. What are the contributions to these development outcomes of the different types of investment such as irrigation, terracing, agricultural R&D, and rural infrastructural development?
3. Is there room to improve agricultural budget allocations under PSTA 4 such that the same amount of spending can generate larger impacts on these development outcomes?
4. Where should the additional public funds be allocated to maximize returns to these development outcomes?

Answers to these questions are intended to: (1) assist MINAGRI and its development partners in assessing the progress of PSTA 4, which is now just past its midterm point; (2) identify the synergies and trade-offs of a PSTA 4 investment portfolio that is better targeted to different and multiple development outcomes, including growth, employment, poverty, and diet quality; (3) improve the cost-effectiveness of the PSTA 4 portfolio in the coming years; and (4) provide informative suggestions for future planning of public expenditures.

The study uses the economywide Rural Investment and Policy Analysis (RIAPA) model that has been developed by the International Food Policy Research Institute (IFPRI). This includes RIAPA's Agricultural Investment for Data Analyzer (AIDA) module. AIDA is a tool to measure the impacts of alternative public expenditure options on multiple development outcomes. It includes two microsimulation modules that focus on growth outcomes of poverty reduction and dietary improvements at the household level. Using this integrated modeling framework, the study links agricultural and rural development spending to four specific outcomes: economic growth, job creation, poverty reduction, and diet quality improvement. It simultaneously considers the synergies and trade-offs associated with the different investment options in the transformation process.

The study relies on data, insights, and other contributions made by colleagues at the Ministry of Agriculture and Animal Resources (MINAGRI), the Ministry of Finance and Economic Planning (MINECOFIN), and the National Institute of Statistics of Rwanda (NISR).

Results of the study indicate that agricultural expenditures under PSTA 4 are, by and large, cost-effective. Each US dollar of agricultural spending is associated with a $2.05 gain in GDP during the period 2018–2024. The total gains in seven years are $1.67 billion, of which, $1.17 billion is gain in agricultural GDP, and $0.18 billion and $0.22 billion are gains in off-farm economic activity from within and outside the food system, respectively. Our estimates indicate that agricultural expenditures under PSTA 4 contributed an additional 1.5 percentage points of GDP growth in 2018 and 0.4 percentage points in 2019; these growth effects were relatively stronger within the agricultural sector and food system, relative to other sectors of the economy. Our estimates also indicate that PSTA 4's agricultural spending also creates more jobs outside agriculture; without lowering agricultural production, the number of rural farm workers declines as workers move into nonfarm activities, thus contributing to rural economic growth and structural transformation. We further find that agricultural expenditures under PSTA 4 have a strong poverty reduction impact, lowering the number of poor persons by 2.34 million during 2018–2024. Agricultural expenditures also improve diet quality, particularly among rural households.

By decomposing the contribution of agricultural expenditures, the study finds that, broadly speaking, the current budget allocation under PSTA 4 is generally effective in promoting economic growth, employment, poverty reduction, and diet quality improvement. The sectors that have large shares of GDP and employment and are given due attention in the allocation of the PSTA 4 budget often have larger impacts on these development outcomes. Productivity-enhancing investments in vegetables and Irish potatoes are found to have larger impacts on growth and poverty reduction, with relatively high returns per unit of spending; however, investments that enhance productivity in the production of Irish potatoes rank lower than other crop-related investments in terms of employment and diet quality outcomes. Furthermore, among the various types of PSTA 4 investments considered, small-scale irrigation consistently generates larger impacts on all four outcomes, with higher efficiency in terms of returns per dollar spent.

The modeling results show that no single expenditure option is the most effective or efficient in achieving all four development outcomes. To help policymakers identify options for achieving marked progress jointly across all the outcomes, a single composite index is generated to combine scores with equal weights for the four outcome indicators. Findings indicate the following:

- Of the sectors analyzed, high value crops, including vegetables, coffee and tea, and Irish potatoes, rank at the top with the highest composite scores. This suggests that increasing investments to support high value agriculture would help the country achieve broad development outcomes faster than focusing on other crops.

- In terms of investment types, small-scale irrigation ranks at the top with the highest composite score both in its contribution to development outcomes and its cost-effectiveness. Hillside irrigation and marshland development, on the other hand, rank near the bottom, with lower scores than many other types of investment. These results do not suggest that marshland or hillside development efforts should necessarily be scaled back; rather, it indicates the critical importance of searching for lower-cost approaches to these investments when public resources are limited. This is also true for investment in terracing.

The study shows that there is room for further improvement in budget allocation. Using a modest reallocation of the current budget distribution as an example, the study shows that, without increasing the total amount of spending, a reallocation can significantly improve the effectiveness of PSTA 4's expenditures. With such a reallocation, over the period 2018–2024 overall, GDP would be $154 million higher, and even slightly higher within the food system. Over 22,700 new jobs would be created, of which 17,000 would be in agriculture. There would be 222,000 fewer poor people than under the current budget allocation, with most of the additional poverty reduction occurring in rural areas. The reallocation at the margins would also improve diet quality, particularly among rural households.

Our estimates further indicate that increasing subsidies of modern inputs that are being applied to already-developed progressive terracing can improve returns on total agricultural expenditure; costly investment on progressive terracing alone yields only modest productivity gains, while productivity gains are much higher when investment in terracing is combined with modern inputs.

Overall findings from the study demonstrate the continued importance of public policy, investment, and expenditures for growth and job creation beyond agriculture and for poverty reduction and diet quality improvement among rural and urban households. These findings justify an increase in the budget allocated to MINAGRI, which has been stagnant (in constant prices) since PSTA 4 began in 2018.

Our estimates indicate that when additional public funds are allocated disproportionately more to agricultural R&D, to small-scale irrigation, and to terracing with the promotion of modern inputs and extension services as a package, returns to our focal outcomes are higher than returns to the current allocation portfolio. The same is true when additional public funds are allocated to coffee and tea with a similar promotion of modern inputs and extension services.

Specifically, if agricultural expenditures increase by 5 percent annually—which is $170 million of accumulated additional spending over the 7 years from 2018–2024—the additional cumulative GDP in that period could exceed more than $800 million. For each additional US dollar of agricultural spending under the new allocation, it is expected that $4.82 of GDP will be generated, while in the current allocation portfolio the GDP gains are only $2.16.

The remainder of the paper is organized as follows. Section 2 introduces the RIAPA model, the AIDA module, and two microsimulation modules that are used to assess household poverty and diet quality. Section 3 describes data sources, the social accounting matrix (SAM), and key parameters. Section 4 introduces the scenarios and discusses the parameters used in the economywide model, and Section 5 provides an analysis of the Rwanda-RIAPA model results from a set of simulations. Section 6 concludes with a discussion of forward-looking policy implications and suggestions for future analysis.

THE ECONOMYWIDE MODELING APPROACH

The RIAPA model

Computable general equilibrium (CGE) models are used widely in policy analysis (Devarajan and Robinson 2010). With a capacity to capture linkages between sectors, households, and rural–urban economies and to measure changes in the broader economy, CGE models are suitable for assessing the economywide effects of various public policies. Furthermore, a dynamic CGE model brings in growth over time, making it suitable for assessing the medium- to longer-term economywide impacts of policies, public expenditures, and unexpected exogenous shocks; it thus can help policymakers understand the mechanisms and channels through which different shocks affect flows throughout the economy. While the direct and indirect effects of these shocks are largely determined by the current structure of an economy, the policies, public expenditures, and exogenous shocks can affect economic sectors and rural and urban households differentially, leading to structural changes over time.

Three types of linkages are crucial to an understanding of general equilibrium modeling. Backward production linkages arise when producers demand intermediate inputs produced by other sectors. When an economy becomes more complex, with production in multiple economic sectors relying more heavily on each other, intermediate inputs become more intensively used in the economy; this leads to stronger backward production linkages. Also, the more input-intensive a sector, the stronger its backward linkages.

The second type of linkage is forward production linkage. This accounts for the supply of inputs from individual production sectors to downstream sectors. When an upstream sector such as agriculture becomes more productive, it can supply more goods to downstream sectors such as food processors without causing prices to change.

Linkages also occur between final consumption by households, public sector spending, and private investment on one side, and the domestic production of goods and services on the other side. This third linkage between supply and final demand is important in a dynamic CGE model since household spending grows with population growth and incomes increase with economic growth, while investment becomes future capital to further enhance demand and supply linkages. Over time and with growth in per capita income and increases in investment, demand structure changes, affecting prices differentially; different linkages are thus created to different production sectors for domestically supplied commodities and services.

Economic growth, however, is not the only outcome that a dynamic CGE can address; nor is it the only outcome that matters to a country's development trajectory or economic transformation process. Economic growth, for example, affects a household's poverty status, employment situation, and dietary choices. Assessing the linkages between economic growth and poverty, employment, and diet quality outcomes is a topic of increasing importance to both policymakers and development partners. Understanding how linkages affect multiple development outcomes is especially important when national development ambitions are multiple and varied but public resources are limited. A question that is thus frequently raised by policymakers is how one might allocate public resources more efficiently in order to maximize their impacts across different development outcomes. This is particularly important for agricultural and rural development, where public expenditures are historically one of the most important drivers of agricultural growth and rural transformation.

The RIAPA model used in this study is the result of efforts to model the linkages between public expenditure and economic growth alongside the synergies and trade-offs between economic growth and other development outcomes. The RIAPA model was developed in 2016 with support from the International Fund for Agricultural Development (IFAD), and it has been continuously improved since. It builds on prior work by IFPRI on dynamic CGE modeling (Diao and Thurlow 2015). Since its introduction, RIAPA has generated considerable interest among IFPRI's government counterparts and development partners and it has received multiyear grants for its further development and improvement (see, for example, Thurlow, Randriamamonjy, Benson 2018).[2]

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[2] Key donors include the Bill & Melinda Gates Foundation, the United States Agency for International Development (USAID), and the CGIAR Research Program on Policies, Institutions, and Markets (PIM).

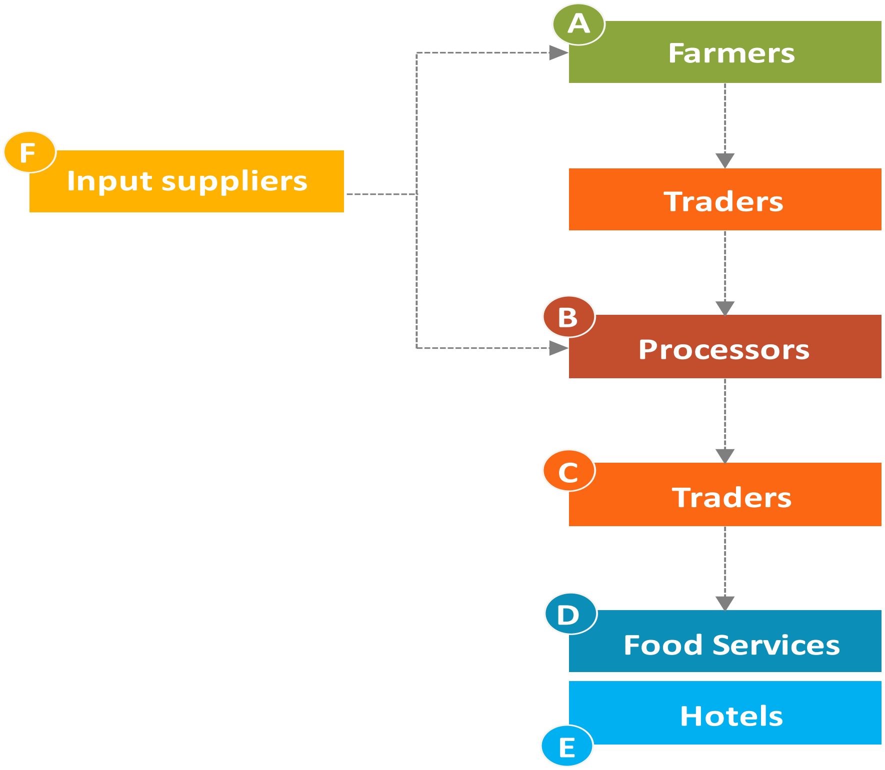
Like other CGE models, the RIAPA model represents an economy by a set of disaggregated sectors. The RIAPA model pays greater attention to the details in agriculture and in agriculture-related industry and service sectors than do other models because of the questions and contexts associated with its use. To explicitly capture economic activities related to agriculture and the broader food system, significant effort is put into the creation of country-level social accounting matrixes (SAMs) with detailed agricultural and agriculture-related sectors. SAMs are databases that capture resource flows associated with all economic transactions taking place in an economy. They represent an economy's structure at a point in time by quantifying linkages and relationships between productive activities, households, firms, governments, and trade with the rest of the world. RIAPA's emphasis on sectors and activities that relate directly or indirectly to food and agriculture ensures that the model is capable of properly capturing the structure of the whole food system and its interaction with the process of structural transformation.

While the RIAPA model tries to standardize the number of sectors across different country SAMs, country-specific information is taken into consideration when deciding on the final structure of the sectors and households for a particular country. In the case of Rwanda, for example, the 2017 SAM used in this study comprises 29 agricultural subsectors, including 21 crops or groups of crops, six livestock production sectors, as well as both forestry and fisheries. The Rwanda SAM also includes 23 industrial sectors and 11 service sectors, many of which are agriculture related. This includes 11 agro-processing activities in the industrial sector and plus trade and transport activities in the service sector; the latter further disaggregated according to their relationship with agriculture.

The RIAPA model also distinguishes 15 representative households, each of which is an aggregation of a group of households captured in the Fifth Integrated Household Living Conditions Survey (EICV5) (NISR 2018). These households are defined by rural and urban income quintiles, with urban households further separated into Kigali and "other urban" groups. Households in the model earn employment income and receive returns on their assets (land and capital) as well as domestic or foreign transfers.

Once the SAM explicitly includes highly disaggregated economic sectors that are directly related to agriculture, the RIAPA model can properly capture the linkages within the food system that run between primary agriculture and agriculture-related economic activities. Broadly speaking, economic activities within the food system can be defined as having six components (Figure 1). Our outcomes of interest—economic growth, employment, poverty, and diet quality—can be generated for the economy as a whole, for only the agricultural sector, or for the food system.

Figure 1: Definition of a food system in a SAM and in the RIAPA model



Source: Authors' compilation.
Note: SAM = social accounting matrix; RIAPA = Rural Investment and Policy Analysis

Of course, the traditional primary agricultural sector—crops, livestock, forestry, and fisheries—is still the dominant component of the food system ("A" in Figure 1). While most agricultural products are directly consumed, a share is also used as intermediate inputs in food processing and in nonfood industrial subsectors ("B"). Products that move from farms to processing or from processing to markets involve activities performed by traders and transporters ("C"). A portion of both primary and processed products is, in turn, consumed in the food services industry (restaurants, bars, and cafés) and by food vendors ("D"). A large share of these primary and processed products is also consumed in hotels ("E"). Alongside these linkages are the agents and activities that supply inputs to farmers, processors, and other actors in the food system ("F").

In a standard recursive dynamic CGE model, productivity growth is often modeled exogenously. By focusing on the growth of total factor productivity (TFP) across different agricultural and nonagricultural subsectors, a dynamic CGE model can compare different outcomes of growth led by different sectors, such as growth led by staple foods vs. growth led by export agriculture (Diao et al. 2015). As such, these models can estimate and compare growth led by the different agricultural subsectors of the economy in terms of the broader economywide growth elasticities and growth-to-poverty-reduction elasticities.

Comparing development outcomes that follow from growth led by the respective economic sectors is informative to policymakers in prioritizing their support for sectors that have stronger linkages to growth or poverty reduction. These comparisons, however, are unable to address the question that is frequently asked of modeling experts: what interventions are required to achieve a targeted growth rate and what is the cost of such interventions. For example, using an early dynamic CGE model, Diao and Thurlow (2015) show that for an African country where the rural poverty rate is high and the rural population mainly depends on agriculture, a 1 percent rate of economic growth led by productivity increases in the staple food sectors leads to much larger income effects—and hence poverty reduction effects—when compared to a 1 percent economywide growth rate led by export agriculture. This exercise, however, was not able to answer the following questions: (1) in order to achieve a uniform level of economywide growth, which is more costly: growth led by the staple food sector or growth led by export agriculture; and (2) with limited public resources, where should a government allocate spending in order to maximize the returns in both growth and poverty reduction.

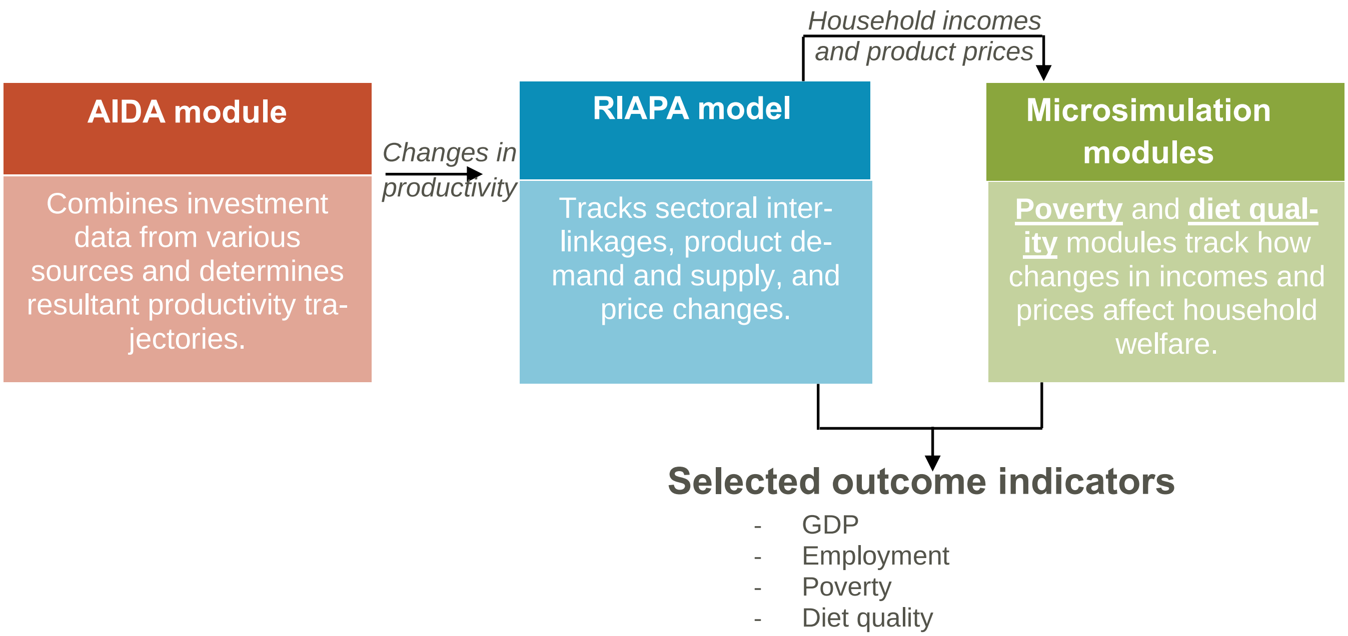
These questions have led to the development of the RIAPA model, which considers both the cost of alternate public interventions as well as the direct benefits of such interventions. Subsidization of agricultural inputs, for example, is an intervention that is frequently used by many African governments to boost crop yields. The RIAPA model uses information on the types of inputs that are subsidized, the area of farmland that benefits from such subsidies, the total budget allocated to input subsidies according to crop, and the direct yield gains from adoption of subsidized inputs according to crop. Obviously, such analysis goes beyond what a standard macroeconomy-oriented CGE model can do and requires a considerable amount of microeconomic data, information, and analysis.

IFPRI developed the AIDA module (Raouf et al. 2018) for this purpose. It has become a key component of the RIAPA model when RIAPA is applied to questions such as those posed by this study. Employing the AIDA module within the RIAPA model, productivity growth can be calculated for each agricultural sector and other agriculture-related sectors from trends in spending on various interventions targeted at improving sectoral productivity. Growth and employment outcomes can be directly obtained from the RIAPA model, while poverty and diet quality outcomes require microsimulation modules linked to the RIAPA model results (Figure 2).

This combined modeling framework—the economywide model from RIAPA and the investment and policy analysis module from AIDA, in addition to poverty and diet quality microsimulation modules—is used in combination to assess the impacts of policy and public expenditure interventions on selected outcome indicators, including GDP, employment, poverty, and diet quality. This assessment is further used to examine alternative policy and expenditure options and to identify more efficient interventions that can effectively maximize impacts.

In the case of the present study on Rwanda, the AIDA module combines spending and investment data obtained from several sources and determines the gains in productivity from agricultural and rural development interventions that are primarily set forth under PSTA 4. The results in productivity gains are then linked to the RIAPA model's economywide productivity parameters across sectors. Results from the RIAPA model include changes in prices and production supply that led directly to changes in growth outcomes in total GDP, food system GDP, and agricultural GDP, as well as employment outcomes. The resulting changes in household consumption demand and incomes are further linked to two microsimulation modules in order to assess changes in poverty and diet quality at the household level that are led by changes in productivity and other policy interventions. In the two microsimulation modules, detailed information on the level and structure of incomes and consumption at the household level is drawn from EICV5.

Figure 2: A framework integrating the RIAPA model with the AIDA module and the poverty and diet quality microsimulation modules



Source: Authors' compilation.
Note: RIAPA = Rural Investment and Policy Analysis; AIDA = Agricultural Investment for Data Analyzer

The AIDA Model

The utility and structure of the Agricultural Investment for Data Analyzer (AIDA) module warrant further description since they are key to the current modeling exercise. We begin with the conventional assumptions that public resources for development are scarce and that policymakers are often expected to allocate these scarce resources in an efficient—if not optimal—manner. By using data, information, and analyses of past costs and benefits—especially when considered in the context of future spending plans—the impacts of such allocations can be evaluated *in advance of* implementation. As such, AIDA may be best classified as a forward-looking investment planning tool (Raouf et al. 2018).

The AIDA module combines data from a range of sources to estimate investment impacts in the form of direct productivity gains. These sources include surveys, as well as monitoring and evaluation studies. In effect, AIDA is an accounting system that estimates how public spending directly affects productivity across sectors. This is the first step in helping policymakers identify more optimal allocations of scarce public resources to achieve development outcomes more efficiently.

In AIDA, the productivity effect from an expenditure package is determined by its investment outcome, I_{it}. This can be understood as the additional coverage achieved by public investment in a technology, service, or infrastructural facility; an example might be an expansion of irrigated farmland that is accomplished with public funding. The investment outcome is determined by information on the current level of public investment spending, E_{it} (conventionally measured in US dollars or local currency units), and the unit cost per area of farmland, U_{it} (measured in hectares), with π_{it} measuring the share of unit cost paid by the government, that is, the subsidy rate (Equation 1).

$$I_{it} = \frac{E_{it}}{U_{it} \cdot \pi_i} \quad [1]$$

The outcome of an expenditure package considers the stock from previous public investments, X_{it-1}, such that the present level of stock, X_{it}, is determined by adding the new investment outcomes after netting out annual depreciation, δ_{it}, of the infrastructure (Equation 2).

$$X_{it} = (1 - \delta_i) \cdot X_{it-1} + I_{it} \quad [2]$$

The coverage rate $C_{it,}$ in Equation 3, is thus determined by dividing the present level of stock, X_{it}, by the maximum potential beneficials, P_{it}; these gains can simply be in the form of the total number of farm households or the total cultivated area for a specific crop. In calculating the coverage rate, private investment outcomes, Z_{it}, are also considered.

$$c_{it} = \frac{(X_{it} + Z_{it})}{P_{it}} \quad [3]$$

Elasticities (measures of impact per unit of expenditure outcome) determine the direct productivity gains from such investments (Equation 4). Elasticities, or impact coefficients, β_{it}, are assessed by different types of expenditures, for example, subsidies of fertilizer or improved seeds vs. investments in irrigation or terracing. Taking into consideration the additional coverage rate from new investments at the sectoral level, productivity gains can now be specified to different sectors; this combines different types of expenditures that directly benefit this sector(*s*) in Equation 4. The combined sector-level productivity gains from a particular package of investments (Equation 4) are then imposed on sector productivity parameters in the RIAPA model; in this way, the overall economic impacts of these investments are estimated, including indirect or spillovers effects. We denote $\bar{a}_s$ in Equation 4 as the initial total factor productivity (TFP)—a shift parameter in the RIAPA production function—while a_{st} denotes TFP after accounting for productivity gains from investments. θ_{si} takes on values of 0 and 1 and provides the mapping between investments and affected sectors.

$$a_{st} = \overline{a_s} \cdot (1 + \textstyle\sum_i c_{it} \cdot \beta_{it} \cdot \theta_{si}) \quad [4]$$

With the help of RIAPA and AIDA, investment options can be ranked by broad development outcome indicators, including economic growth, employment, poverty, and diet quality; this ranking can help prioritize investments in the agricultural sector, the rural economy, and in the wider food system. The coupling of AIDA and RIAPA allows a national investment planning perspective that integrates investment and policy analysis with *ex ante* economywide modeling. With its flexibility in assigning specific weights to different development outcomes, the RIAPA–AIDA framework can compare investment portfolio options and can assess the trade-offs that accompany the respective priorities of policymakers.

Microsimulation modules to determine poverty and diet quality index

Whereas measures of changes in economic growth and employment are directly embedded within the core RIAPA–AIDA framework, deriving changes in poverty and diet quality requires microlevel household data. The RIAPA–AIDA model system thus integrates two household-level microsimulation modules, one for measuring changes in levels of poverty and the other for assessing changes in diet quality.

Changes in poverty levels result from changes in economic performance, which are driven by different public expenditure choices. Information on changes in poverty levels is obtained by linking a microsimulation module to the CGE model outcome variables; these variables include changes in household income, prices, and consumption, in the spirit of Arndt et al. (2012). Changes in real consumption across commodities and services in the RIAPA model are passed down to 15 representative household types that are drawn from nationally representative household surveys. Information on these changes is then used to calculate the new poverty status across all sampled households. EICV5, for example, surveyed over 14,580 Rwandan households that were representative of the country's rural and urban populations which, at the time, were 9.2 million and 2.6 million, respectively. EICV5 also provides information on a wide range of social, demographic, and economic variables, including poverty, inequality, employment, living conditions, education, health, housing conditions, and household consumption.

Changes in diet quality follow a similar logic. A diet quality microeconomic module was recently developed by Pauw et al. (2021) to provide an in-depth analysis of diet quality outcomes; this module uses data from all the EICV5-surveyed households and then links them to the RIAPA model's representative household groups. This diet quality module has two outcome indicators: an estimate of the change in the cost of a reference diet that is based on observed relative food price changes in the RIAPA model, and a Reference Diet Deprivation (ReDD) index which is a multidimensional indicator of the quality of a household's diet. In this study, we used the ReDD indicators, which track changes in the gap between a reference diet and a household's actual diet composition.

The ReDD indicator itself follows two approaches. The first is an expenditure-based approach referred to as ReDD-X, in which changes in a household's food-group-specific expenditures are compared to reference food expenditure thresholds (or diet costs) that are derived from the food prices and caloric requirements that are specified in a reference diet. The second approach is a consumption-based microsimulation approach. It compares calorie consumption by major food groups against the calorie thresholds in the reference diet. The current study uses the latter approach. Rather than base the analysis on a notional expenditure threshold, households' actual food consumption choices are used to determine whether balanced calories are obtained from each food group. In effect, the diet quality module helps to evaluate and compare agricultural expenditure options in terms of their relative effects on dietary diversity, which is a key development indicator that has been identified as such by the Government of Rwanda.

SOURCES OF DATA, THE SOCIAL ACCOUNTING MATRIX, AND PARAMETER ESTIMATION

The 2017 SAM for Rwanda provides the core database for the RIAPA model, as described earlier, and detailed in Appendix Table A1. The impacts of policy reforms, spending, and investments are influenced by the initial structures of institutions (households, enterprises, the government, and the rest of the world), the input–output relationships across sectors, and the factor and product market linkages between consumers and producers that are captured in a SAM. The construction of 2017 SAM is based on a recent supply-and-use table (SUT) representing Rwanda's economy in 2017. The SUT is further combined with data obtained from other sources, including national accounts, government financial statistics, balance of payments figures, and surveys of Rwanda's labor force and agricultural sector from

2017 or around that year. The 2017 Rwanda SAM was jointly developed by IFPRI, MINECOFIN, and NISR.[3]

The 2017 SAM for Rwanda contains a detailed breakdown of the agricultural sector, making it ideal for the RIAPA model to study policy and public investment prioritization in the context of Rwanda's inclusive agricultural transformation. There are four individual cereal crops and a group that captures the remaining cereal crops; five types of roots, tubers, and banana crops (RTBs); four types of horticulture crops; and six export crops, including (as individual crops) coffee, tea, and pyrethrum. The Rwanda SAM also includes six livestock subsectors; these provide an opportunity to analyze livestock sector policies and investments in detail (see Appendix Table A1 for the list of sectors in the SAM). The downstream segments of the food system comprise 12 agro-processing and foodservice sectors that together contribute nearly 10 percent to GDP. In the model simulations, policy and investment options are linked or mapped to the appropriate sector, commodity, subsector, and activity defined in the SAM.

AIDA's parameters are calibrated using Rwandan data. The key parameters include base-year measures of:

1. Total spending and unit cost of different types of expenditures;
2. Rate of subsidy for targeted inputs/investments that is part of the contribution from the government;
3. Depreciation/discount rate or lifespans of different expenditures; these can vary broadly as, for example, infrastructural investments such as irrigation systems or terraces can have lifespans of 10, 20, or more years once they are constructed, whereas fertilizer subsidy spending occurs every year and thus fully depreciates within that year;
4. Current coverage rate that measures the relationship between current and potential beneficiaries of public investments; and
5. Estimates of direct productivity gains across different expenditures at the crop/livestock production level.

Calculation of these parameters requires multiple sources of data. These sources include the level and pattern of public expenditures by type of intervention (for example, irrigation, fertilizer/seed subsidies, or extension provision); the quantities of inputs subsidized; the amount of services generated; and/or the physical infrastructure developed for farmland or rural households from these expenditures (that is, the benefits of previous and newly developed infrastructures to farmland or households). Data on unit costs, input subsidies, or public service provision also needs to be gathered on the basis of units of farmland, head of livestock, or other units. (Further discussion of these measures is provided in Section 4.)

The expenditure data for the various PSTA 4 program interventions are obtained from the Government of Rwanda and from the Monitoring and Analysing Food and Agricultural Policies (MAFAP) program (MAFAP 2021) of the Food and Agriculture Organization of the United Nations (FAO). Additional expenditure data are drawn from development plans outside of the agricultural sector, for example, the 2023/2024 Energy Sector Strategic Plan (Rwanda, Ministry of Infrastructure 2018). Unit costs calculated from PSTA 4 planning documents and from other sector-specific development plans are obtained by dividing the budget amount by the planned areas to be developed or covered, with additional

[3] Construction of the SAM was conducted with financial support from GIZ under the project entitled "SAM-CGE Modeling Capacity Building for Evidence-based Policy Analysis and Strategy in Rwanda." See Aragie et al. (2021b) for a detailed description of the 2017 Rwanda SAM.

validation using estimates from project evaluations from World Bank and other documents (for example, World Bank 2018, 2019, 2021a). Subsidy rates for fertilizer and improved seeds are also obtained directly from MINAGRI, from the World Bank (2021a), and from other sources, as discussed in further detail below.

The direct impact of a given investment type depends notably on the current rate of coverage and the additional coverage rate that results over time from new spending. Baseline level of coverage refers to the use of subsidized fertilizer, adoption of improved seeds, access to extension services, or cultivation of irrigated or terraced land. Figures on the share of land covered (or head of livestock reached) by the existing programs are obtained mainly from Rwanda's Seasonal Agricultural Surveys (SASs), the 2017 Agricultural Household Survey (AHS), and the EICV5 from NISR. Data on coverage rates shows considerable heterogeneity across crops in the usage of modern inputs[4] and access to agricultural infrastructure. (This is discussed in detail in Section 4.)

Measures of yield gains per unit of additional spending—that is, productivity elasticity estimates—are the direct impact of public spending. New marshland development, for example, allows crop yields to increase by providing access to irrigation and drainage. Ideally, these parameters are estimated from country-specific survey data and from rigorous impact evaluations; however, given the cost, time, and analytical effort required to estimate such parameters, they are rarely available for the full suite of public investments under consideration.[5] Alternative sources of these parameters include reviews of prior published or unpublished studies on economies with similar structures, or crop simulation models that use biophysical data to estimate productivity effects.

In this study, the productivity elasticity coefficients are estimated for several crops using a wide range of survey data including EICV5, multiple years and seasons of the SAS, and the AHS. When survey data was not available to estimate these parameters, informed assumptions were made. Because the sample size is very small for the many crops covered by this study, we rely on the results for estimated crops together with consultations with experts at MINAGRI and other relevant entities. (Additional details are provided in Section 4.)

Assessing the impact of policy reforms is equally important, and AIDA is able to integrate both expenditures and policy reforms into an assessment. Parameters measuring the magnitude of changes due to policy reforms are required, for example a decline in import tariff rates. Policy measures of relevance to Rwanda include improvements in agri-export logistics, fertilizer import facilitation, subsidies of nutritious food, and scaled-up rural cash transfer programs. This policy-related data is compiled from various sources and processed within the AIDA module.

[4] The term “modern inputs” is used here in a conventional sense to denote the use of a suite of inputs, technologies, and practices such as improved cultivars, inorganic fertilizers, and intensive management practices. It is not intended to be pejorative or dismissive of traditional inputs, technologies, or practices, all of which play an important role in agricultural production.

[5] An exception to this is an impact evaluation of hillside irrigation schemes in Rwanda by Jones et al. (2019).

SCENARIO DESIGN

The structure of the economy and food system

The 2017 Rwanda SAM provides a structure of the Rwandan economy, agricultural sector, and food system at the inception point of PSTA 4. Figures 3a and 3b provide a snapshot of this structure, highlighting the shares in GDP and employment of Rwanda's food system from total.

Figure 3a: Rwanda's food system as a share of national GDP, 2017

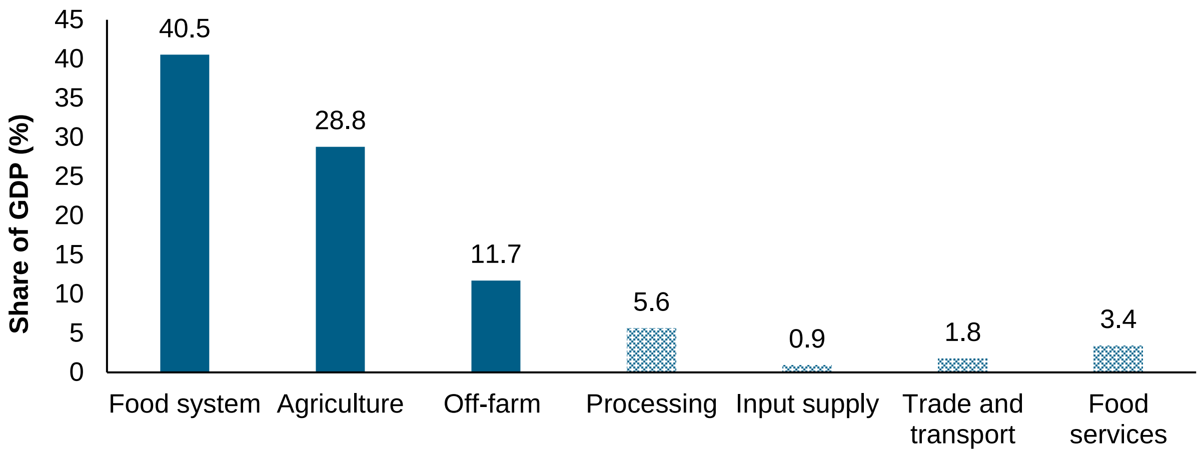
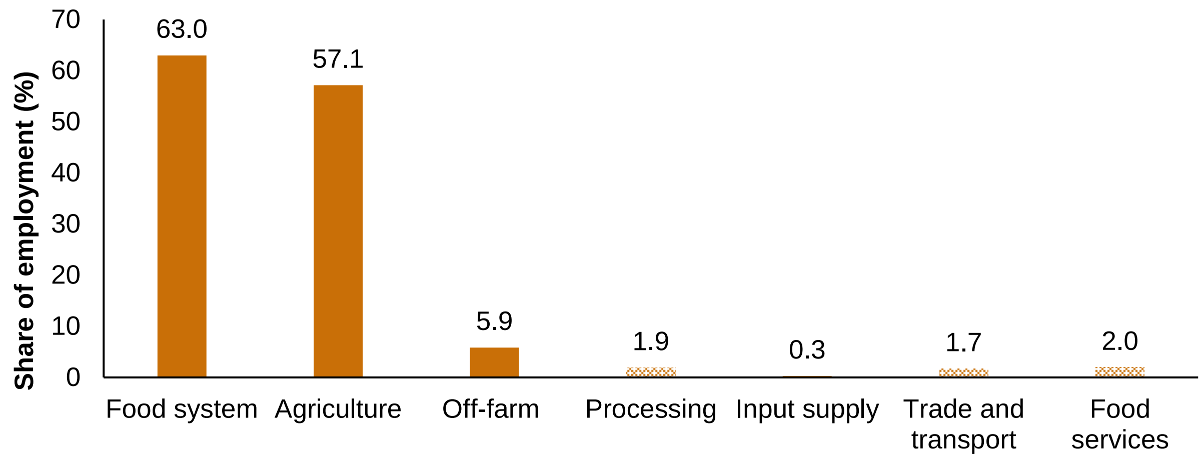


Figure 3b: Rwanda's food system as a share of total employment, 2017



Source: Rwanda 2017 SAM.

As it is traditionally measured, Rwanda's agricultural sector accounted for about 29 percent of GDP in 2017; the whole food system, however, accounted for more than 40 percent of GDP. This implies that more than 11 percent of GDP exists outside of traditional agriculture but is still related to it; this is what is referred to as "off-farm" GDP and employment (Figures 3a and 3b) and is further broken down into processing, input supply, trade and transport, and food services.

Both the agricultural sector and the food system as a whole account for a much larger share of total employment than of GDP. Within the food system, employment is also dominated by agriculture. This implies that the productivity of agriculture is relatively lower than that of the off-farm component of the food system; indeed, the latter accounts for only 5.9 percent of total employment but 11.7 percent of total GDP. During the structural transformation process, improvements in agricultural productivity are expected to lower the share of agricultural employment and increase off-farm employment in the food system. As will be discussed in detail later, however, the rate at which such changes occur depends on the nature of the public investments made.

Scenarios

As briefly mentioned in the introduction, PSTA 4 identifies four priority areas: (1) supporting innovation and extension, (2) enhancing productivity and resilience, (3) creating inclusive markets and improving value addition, and (4) creating a more enabling environment and more responsive institutions. The design of the RIAPA–AIDA scenarios closely follows these four priority areas, taking into consideration the availability of the data and information needed for a comprehensive quantitative assessment of public expenditure options.

Table 1 describes the scenarios and their relationship to the PSTA 4 priority areas. Many scenarios focus on interventions that are directly related to improving productivity in the agricultural sector, while other scenarios expand beyond the farm gate to involve broader aspects of rural development. Examples of these include public investments in feeder roads, rural education and rural electricity, and policies such as reductions in import barriers or promotion of exports. Exploration of these broader scenarios is acutely dependent on the availability and quality of policy-related parameter data.

The mapping of specific agricultural crop and livestock products to the different policy and spending scenarios is based on crops and livestock that are identified in PSTA 4 as being more “strategic”. These crop- and livestock-related activities are simulated in the model either individually or as groups. (Table 2 provides the mapping of sectors to the relevant spending scenarios.) When we map crops to different investments, we think in terms of the multiseason year that is common to Rwandan crops. Specifically, with sufficient access to irrigation, the same piece of farmland may grow maize in season A, Irish potatoes in season B, and vegetables in season C. Irrigation and terracing can increase such multiseason cultivation and can be a more efficient use of both farmland and infrastructure investments.

Generally speaking, maize, rice, Irish potatoes, beans, and soybeans—all of which are identified as strategic crops in PSTA 4—are simulated by the model as individual crops; meanwhile, vegetables, other cereals, RTBs, other crops, and livestock products are simulated as groups, either because of a lack of detail in the SAM (for example, for vegetables) or because of insufficient information for conducting a proper assessment of expenditure options at a more disaggregated level (as is the case, for example, for livestock).

Table 1: Mapping scenarios to PSTA 4 priority areas

No.	Related PSTA 4 priority areas	Policy/spending scenarios
1	2	Fertilizer only
2	2	Seeds only
3	2	Fertilizer and seeds
4	1	Extension—crops
5	1&2	Fertilizer and seeds with extension
6	2	Irrigation—marshland development
7	2	Irrigation—hillside
8	2	Irrigation—small-scale
9	2	Terracing—progressive
10	2	Terracing—radical
11	1	Crop R&D
12	1	Livestock R&D
13	3	Feeder roads
14	2	Education
15	2	Electricity
16	2	Animal breeding
17	2	Animal health
18	1	Extension—livestock
19	3	Postharvest loss reduction
20	3	Policies reducing import barriers and promoting exports
21	4	Policies creating a more enabling environment and responsive institutions

The model also considers the synergy between investment in irrigation and terracing, on the one hand, and spending on input subsidies and extension services on the other. We refer to the first group of interventions as "investments" and the second group as "spending", and for most scenarios we consider a combination of investments and spending. These combined investment–spending scenarios are crop-specific, while the spending on various interventions on livestock (such as for feed and animal health) is combined as one scenario. The exception is livestock R&D which, like crop R&D, is treated as a separate scenario that benefits all livestock (or all crops).

Simulations start with the current allocation under PSTA 4. The baseline is the first scenario that captures the past growth trends of the economy and the expected growth through 2024. The COVID-19 pandemic and the corresponding interventions undertaken as part of the Government of Rwanda's

National Economic Recovery Plan are taken into consideration in 2020–2022, and growth is assumed to return to normal in 2023/2024.

Built on the baseline simulation, the second group of simulations is designed to address the first question asked in this study: how much would the 2018-to-2024 PSTA 4 allocations to agricultural and rural development contribute to development outcomes, including economic growth, employment creation, poverty reduction, and improvements in diet? To that end, we consider a hypothetical situation in which agricultural spending is reduced beginning in 2018, negatively affecting economic growth and other development outcomes. The amount by which agricultural and rural spending is reduced in the simulation is derived from existing budgets that are broken down by type of investment or spending. Based on PSTA 4 budget data, and with the help of MINAGRI, we are able to identify $109 million budget by investment and spending types. This is further classified into types of crops, livestock, agricultural R&D, and various rural infrastructural investments and spending. In the process, 52 scenarios are designed without overlap, but fully capturing the allocation of the $109 million. (The budget allocations of $109 million can be found in Appendix Tables A2 and A3, while the 52 scenarios can be found in Appendix Table A4.)

These 52 unique scenarios are also used to address the second and third questions underlying this study. The second question addresses the contributions of different types of investment and spending (such as for irrigation, terracing, agricultural R&D, and rural development) to different developmental outcomes. The third question explores whether there is room to improve agricultural budget allocations under PSTA 4 such that the same amount of spending can generate better outcomes in economic growth, employment, poverty reduction, and improvement in diet quality.

In addressing these questions, we consider the contributions of different types of investments and spending across different agricultural crops/livestock. We measure contributions to increases in GDP and to changes in employment, poverty, and diet quality. We also measure the effectiveness of the different types of investments and spending across agricultural activities by calculating their expenditure elasticity; that is, for a given amount of investment or spending, say $1 million, how much GDP can be generated, how many additional workers can be employed, how many poor people can be lifted out of poverty, and how much can diet quality be improved?

The effectiveness of agricultural expenditures and their contribution to economic and other development outcomes informs the reallocation scenario in which we increase the budget share of more-efficient spending programs and reduce the budget share of less-efficient spending programs, within a given investment structure and total budget. Considering that PSTA 4 is currently in its fourth year of implementation, budget reallocation is done only at the margins, without altering existing investments in infrastructures such as irrigation and terracing, and without adjusting allocations to different nonagricultural rural investments or agricultural R&D.

Table 2: Scenarios and related agricultural production sectors

No.	PSTA 4 Priority Areas	Policy/spending scenarios	Simulated crops/livestock production
1	2	Fertilizer only	Maize, rice, Irish potatoes, beans, soybeans, vegetables, sugarcane, other cereals, other roots, tubers, and bananas (RTBs), coffee and tea, other crops
2	2	Seeds only	Maize, rice, Irish potatoes, beans, soybeans, vegetables, sugarcane other cereals, other RTBs, coffee and tea, other crops
3	2	Fertilizer and seeds	Maize, rice, Irish potatoes, beans, soybeans, vegetables, sugarcane other cereals, other RTBs, coffee and tea, other crops
4	1	Extension—crops	Maize, rice, Irish potatoes, beans, soybeans, vegetables, sugarcane other cereals, other RTBs, coffee and tea, other crops
5	1&2	Fertilizer and seed and extension	Maize, rice, Irish potatoes, beans, soybeans, vegetables, sugarcane other cereals, other RTBs, coffee and tea, other crops
6	2	Irrigation—marshland development	Maize, rice, Irish potatoes, beans, soybeans, vegetables, sugarcane other cereals, other crops
7	2	Irrigation—hillside	Maize, vegetables, other cereals, other RTBs, beans, other crops
8	2	Irrigation—small-scale	Maize, soybean, vegetables, other cereals, other RTBs, beans, other crops
9	2	Terracing—progressive	Maize, Irish potatoes, beans, vegetables, other cereals, other RTBs, other crops
10	2	Terracing—radical	Maize, Irish potatoes, beans, vegetables, other cereals, other RTBs, other crops
11	1	Crop R&D	All crops
12	1	Livestock R&D	All livestock production
13	3	Feeder roads	All primary agriculture and agriculture-related nonagricultural activities
14	2	Education	All primary agriculture and agriculture-related nonagricultural activities
15	2	Electricity	All primary agriculture and agriculture-related nonagricultural activities
16	2	Artificial insemination and animal breeding	All livestock production
17	2	Animal health (vaccines, antibiotics)	All livestock production
18	1	Extension—livestock	All livestock production
19	3	Postharvest loss reduction	Maize, Irish potatoes
20	3	Policies to reduce import barriers and promote exports	Exports and import-substitutable crops/livestock
21	4	Policies to improve the enabling environment and increase responsiveness of institutions	All investment/policy areas above

Note**:** PSTA = Strategic Plan for Agriculture Transformation.

Parameters

The direct benefit of a particular type of public spending (such as fertilizer subsidies) on a particular crop (such as maize) is measured by the gain in productivity of this crop (increases in yield due to the use of the subsidized fertilizer). For an economywide model, information on these direct benefits must come from outside the model. For this study, such information is obtained from three different sources. First, for maize, rice, and several other crops and crop groups, direct gains in productivity from input use and extension services are estimated econometrically using household and farm survey data from Rwanda, as discussed earlier. Some of the estimated elasticities are directly applied in the model.

The second source of information is from a review of existing studies in Rwanda and from cross-country estimates. Gains from terracing and irrigation for a few crops such as maize, beans, and Irish potatoes are drawn from a range of World Bank documents (for example, World Bank 2018, 2019). Gains from R&D are drawn from cross-country estimates conducted in Africa by Fan and colleagues (Fan 2008). Our estimates of gains are further validated against empirical literature on the productivity impacts of public investments and policy reforms in Rwanda, which cover such topics as land tenure regularization (Bizoza and Opio-Omoding 2021; Ali and Deininger 2015; Ali, Deininger, Goldstein 2014), land use consolidation and crop intensification (Nsabimana et al. 2021; Weatherspoon et al. 2021; Nilsson 2019; Bizimana, Nieuwoudt, Ferrer 2004), and hillside terracing and irrigation (Jones et al. 2019; Bizoza and de Graaf 2012). Additional triangulation is conducted through consultations with experts, including colleagues at MINAGRI, RAB, and other organizations operating in the agricultural sector and food system.

To assess gains at the subsectoral level or the commodity level such as for maize or Irish potatoes, we also need baseline data on the adoption or use rates of the different types of modern inputs, technologies, and services, and on the coverage rate of infrastructure; these include use of inorganic fertilizer and improved seeds, access to extension services, and expansion of irrigation and terracing. Baseline data on adoption and coverage rates are used as a benchmark against which the impact of current expenditure trends is evaluated. As described earlier, data on adoption and coverage rates are retrieved from household surveys, farm surveys, existing studies, and expert opinions.

Farmers, necessarily, also pay a share of the costs incurred in the use of modern inputs or the adoption of technologies; they may also contribute their labor when infrastructure is built. This factor is considered in the assessment and is captured by subsidy rates that net out farmers' own costs. Specifically, fertilizer, seeds, and other input costs are assumed to be 30 to 70 percent subsidized by the government, while it covers most of the cost of terracing and irrigation; an exception is the development of small-scale irrigation, to which local communities contribute their labor. Extension services and agricultural R&D are also 100 percent covered by the government. (See Appendix Table A5 for details.)

We further note that different expenditures have impacts spanning different time periods. Inorganic fertilizer and improved seeds, for example—particularly hybrid maize seeds and seeds for certain other crops—must be purchased and applied every year in order to maintain yield gains, while irrigation systems in marshland development areas can last for a long time with a relatively low maintenance cost. The life cycle of different types of spending is thus used in measuring their returns. We use a "discount" or "depreciation" rate to capture differences in the life cycle. When spending needs to be repeated each year to generate benefits, we treat it as a recurring expenditure and assign it a discount rate of 100 percent. Other cases, according to MINAGRI, require an additional 5 percent of the initial investment cost to retain the infrastructure's quality through maintenance, and for these, we set a significantly lower discount rate; examples include investments in marshland development, hillside irrigation, and radical terracing, for which we set a 5 percent discount rate. Given their relatively shorter lifespans, we set a 15 percent discount rate for small-scale irrigation and progressive terracing.

To model the direct impact of different investments in a comparable and consistent way, we convert most parameters to a per-hectare rate, including gains in productivity and the unit cost of most investments and spending. Coverage and adoption rates are measured against all cultivated areas for a specific crop or all livestock production, while the discount rate is applied to the full value of the amount of additional spending. Only nonagricultural investments have different units; these include feeder roads, rural education, and electricity, and will be discussed later. Tables 3a to 3d provide values for the parameters discussed here and applied in the model.

Table 3a: Productivity gains for crop-related expenditures, measured as percentage increases from baseline

Investment/spending category	Productivity gain (percent of the base-year level)										
	Maize	Rice	Irish Potatoes	Soybeans	Vegeta-bles	Sugar-cane	Coffee and tea	Other ce-reals	Other RTBs	Beans	Other crops
Inorganic fertilizer	16.2	4.1	16.2	6.2	8.3	8.3	8.3	16.2	16.2	6.2	16.2
Improved seed	35.0	35.0	35.0	35.0	8.3	17.4	37.7	35.0	35.0	35.0	35.0
Crop extension services	16.2	16.2	16.2	17.1	8.2	8.2	8.2	16.2	16.2	17.1	16.2
Marshland irrigation	107.5	35.0	35.0		6.3	13.0		107.5			35.0
Hillside irrigation	198.9				9.6			198.9	56.8	132.5	56.8
Small-scale irrigation	72.9			29.5	4.7			72.9	25.2	52.5	9.6
Progressive terracing	22.1		22.1		6.3			14.3	12.7	22.1	10.5
Radical terracing	82.2		94.8		20.1			59.5	43.3	49.2	35.0
Marshland irrigation plus f + s + e	209.8	108.3	122.8		37.4	56.3		209.8			122.8
Hillside irrigation plus f + s + e	319.5				41.4			319.5	149.0	228.9	149.0
Small-scale irrigation plus f + s + e	168.3			105.4	35.5			168.3	111.1	132.9	92.3
Progressive terracing plus f + s + e	116.3		116.3		40.5			106.1	104.1	104.6	101.2
Radical terracing plus f + s + e	194.4		210.8		58.4			164.9	143.9	139.7	133.0

Source: Own econometric estimation from various surveys (EICV5, SAS, and AHS), literature such as (World Bank 2018), and informed assumptions.
Note: f + s + e = inorganic fertilizer, improved seeds, and crop extension services. Productivity gains from inorganic fertilizer and improved seeds are estimated for maize, rice, Irish potatoes, soybeans, other cereals, other RTBs (roots, tubers and bananas), beans, and other crops using data from EICV5, SAS, and AHS. Estimated coefficients are adjusted to their exponential values. Vegetables, sugarcane, and coffee and tea are not covered by the survey and the productivity gains for these crops are assumed, based on the estimation of other crops. Productivity gains for the various types of irrigation are calculated from World Bank documents (World Bank 2018). Little information for the productivity gains of terracing is available and, as described above, the values in this table are mainly based on informed assumptions. See Appendix Tables A6–A11 for details.

Table 3b: Input use, technology adoption, and infrastructure coverage rates, measured as a share of cultivated area

	Share of cultivated area (percent)										
Investment/spending category	Maize	Rice	Irish Potatoes	Soybeans	Vegeta-bles	Sugar-cane	Coffee and tea	Other ce-reals	Other RTBs	Beans	Other crops
F + s + e	42.0	87.8	27.0	10.1	80.0	91.8	40.0	19.0	15.0	5.0	44.0
F + e without s				31.1			80.0				
Marshland irrigation plus f + s + e	5.0	87.8	10.2		31.6	91.8		1.3			1.8
Hillside irrigation plus f + s + e	1.0				10.6			0.8	1.2	1.9	1.0
Small-scale irrigation plus f + s + e	0.4			10.1	21.9			0.2	0.3	0.7	
Progressive terracing plus f + s + e	14.0		9.2		11.5			8.2	10.6	0.2	10.1
Radical terracing plus f + s + e	21.6		7.6		4.4			8.5	2.8	2.2	31.2
Progressive terracing plus f + e without s			12.8						16.0	25.0	36.2
Progressive terracing only	38.5		40.3		32.2			19.6	39.9	25.2	36.7

Source: Own econometric estimation from EICV5, SAS, AHS, and informed assumption. See Appendix Tables A6–A11 for details.
Note: f + s + e = inorganic fertilizer, improved seeds, and crop extension services. The adoption rates of modern input uses and extension provision to maize, rice, Irish potatoes, soybeans, other cereals, other RTBs (roots, tubers, and bananas), beans, and other crops are calculated using data from EICV5, SAS, and AHS. Vegetables, sugarcane, and coffee and tea are not covered by the surveys and their coverage rates are assumed based on the information for other crops.

Table 3c: **Unit costs, subsidy rates, discount rates, and increases in production for non-crop-related expenditures**

Investment/spending category	Unit cost (US$ per rural household or head of livestock)	Subsidy rate (percent)	Discount rate (percent)	Increase in production (% from base year level)
Crop R&D	3.9	100.0	12.5	9.6
Livestock R&D	3.9	100.0	12.5	32.0
Feeder roads	61,265	100.0	5.0	16.8
Education	113.4	90.0	5.0	9.2
Electricity	700.0	100.0	5.0	20.0
Animal breeding	43.0	96.8	100.0	41.5
Animal health	6.5	91.7	75.0	18.0
Animal feed	14.1	48.0	100.0	24.6
Livestock extension	10.9	100.0	33.4	59.8
Livestock extension, health, and breeding	74.4	87.6	88.1	143.8

Source: Parameters for agricultural R&D are developed based on Nin-Pratt and Magalhaes (2018), and EU (2016) for feeder roads.
Note: Unit cost for feeder roads is in US$ per kilometer.

Table 3d: Unit cost, subsidy rate, and discount rate for crop-related expenditures

Investment/spending category	Unit cost (US$ per rural household or head of livestock)	Subsidy rate (percent)	Discount rate (per-cent)
Marshland irrigation plus f + s + e			
Maize	3,236	95.5	11.3
Rice	3,341	92.4	14.1
Irish potatoes	3,222	94.1	10.9
Vegetables	3,341	91.8	14.1
Sugarcane	6,341	96.2	9.8
Other cereals	3,236	95.5	11.3
Other crops	3,341	94.2	14.1
Hillside irrigation plus f + s + e			
Maize	5,836	97.0	8.5
Vegetables	5,941	94.9	10.1
Other cereals	5,836	97.0	8.5
Other roots, tubers, and bananas (RTBs)	5,941	96.2	10.1
Beans	5,822	97.1	8.3
Other crops	5,941	96.2	10.1
Small-scale irrigation plus f + s + e			
Maize	473	63.5	53.2
Soybeans	578	58.8	61.7
Vegetables	578	58.1	57.6
Other cereals	473	63.5	53.2
Other RTBs	578	61.6	61.7
Beans	459	63.8	51.7
Progressive terracing plus f + s + e			
Maize	640	81.9	43.2
Irish potatoes	626	74.4	41.9
Vegetables	745	67.2	51.2
Other cereals	640	81.9	43.2
Other RTBs	745	77.9	51.2
Beans	626	82.6	41.9
Other crops	745	77.9	51.2
Radical terracing plus f + s + e			
Maize	1,919	93.2	15.6
Irish potatoes	1,904	90.8	15.0
Vegetables	2,023	87.2	20.0
Other cereals	1,919	93.2	15.6
Other RTBs	2,023	91.1	20.0
Beans	1,904	93.5	15.0
Other crops	2,023	91.1	20.0

Source: Various; see details in the paper

Note**:** f + s + e = inorganic fertilizer, improved seeds, and crop extension services; RTB = roots, tubers, and bananas. Sources are described in detail above.

We note several important points in the tables above. First, in Table 3a, the productivity gains from individual interventions such as inorganic fertilizer, improved seeds, and irrigation (as well as the combined effects of fertilizer and seeds) are estimated from different data sources (see Appendix Tables A6–A11 for details), as well as from reviews of published and unpublished documents and expert consultations.

Second, Table 3a also considers the productivity gains resulting from synergistic effects between combinations of investments and spending categories. This synergistic effect is assumed to be roughly 20 to 30 percent. Consider maize, for example. The productivity gains resulted from the adoption of modern inputs in conjunction with the access to extension services are the sum of individual gains from the use of inorganic fertilizer, improved seed, and extension, which represents a 67.4 percent increase in productivity. The productivity gains for the cultivation of maize on progressive terraces without modern inputs and extension services is 22.1 percent. Without a synergistic effect, the joint productivity gain would be 89.5 percent (that is, the sum of 67.4 percent and 22.1 percent); with a 20 percent synergistic effect, however, the productivity gains for maize cultivated on progressive terraces with modern inputs and extension services becomes 116.3 percent, with the 20 and 30 percent synergy effect being arbitrarily assigned to irrigation and terracing. While this may seem rather subjective, we posit that the magnitude of the synergistic effect is actually a relatively modest assumption to account for increased unpredictability of rainfall patterns under climate change and the long-term environmental degradation and productivity losses from soil erosion that occur in the absence of terracing.

The third point relates to adoption, use, and coverage rates. Information is drawn primarily from SAS data and supplemented by data from the 2015/2016 EICV5, the 2017 AHS, expert knowledge, and informed assumptions. Table 3b reports these rates for scenarios that combine modern inputs, extension services, and infrastructural investments (irrigation and terracing). While the government has promoted modern input use as a package for more than two decades, it is important to note that, for many crops, baseline adoption rates for improved seeds are lower than baseline rates for fertilizer. As such, there are scenarios that include fertilizer use and extension provision without the adoption of improved seeds.

Next, we note that the number of farmland hectares under different types of irrigation (marshland, hillside, and small-scale irrigation) and terracing (radical and progressive) are obtained from PSTA 4 documentation. We assume that marshlands can be cultivated for two seasons, while hillside and land with small-scale irrigation—covering only 15,000 ha of farmland in 2017—can be cultivated for three. More cultivated areas are made possible by the introduction of irrigation in Season C, which comprised about 10 percent of Rwanda's total cultivated crop area, possibly due to the development of hillside and small-scale irrigation. With these assumptions, irrigation can cover 119,000 ha of cultivated land in Rwanda; this still accounts only for a modest 6 percent of the country's total cultivated area, which is less than the country's cultivated area in Season C.

We also note that in PSTA 4 document it is stated that in 2017, progressive terracing covers more than 900,000 ha while radical terracing covers only 120,000 ha (Rwanda, Ministry of Agriculture and Animal Resources 2018). We assume that radical terraces can be cultivated for two seasons (similar to marshlands), while only 20 percent of progressive terraces can be cultivated for two seasons; the total terraced land thus includes 1.3 million ha of cultivated area.[6]

[6] We recognize that double-season cultivation is common throughout Rwanda and is also common on land under progressive terracing; however, the data on total cultivated area in Rwanda—just 1.9 million ha—does not allow us to double the land under progressive terracing since this causes the total cultivated area covered by irrigation and terracing to exceed the total cultivated area at the national level. We therefore assume that only 20 percent of the land under progressive terracing is cultivated for two seasons.

The next challenge is how to determine the allocation of irrigation and terracing across crops. Without available data and information, informed assumptions need to be made. Given that rice is highly dependent on irrigation and that sugarcane is an irrigated crop, and given that both are mainly cultivated in developed marshland areas, large portions of marshland irrigation are allocated to rice (38 percent) and sugarcane (9.5 percent); this results in nearly 88 percent of rice and 92 percent of sugarcane plots being under irrigation (Table 3b). While 21 percent of irrigated marshland is allocated to maize, it accounts for only 5 percent of the total maize cultivated area. Together with hillside irrigation and small-scale irrigation, about 6.4 percent of maize is irrigated (Table 3b). Marshland is also allocated to other crops; this includes 13 percent for Irish potatoes (accounting for 10 percent of Irish potato cultivated area); it also includes 14 percent for vegetables and 3 percent for other cereals, which can be grown either in the season following rice cultivation or in rotation with maize. Cultivated land that is situated on hillsides and has access to small-scale irrigation is allocated to a variety of crops which do not include rice, sugarcane, or Irish potatoes. Vegetables are the third-most irrigated crop after sugarcane and rice, with cultivation, particularly in season C. Outside of the land used for rice, sugarcane, and vegetables, irrigation coverage rates for most crops are very low; this is particularly the case for the crops and crop groups defined as other cereals, other RTBs, beans, and other crops (Table 3b).

The fourth point is that the coverage of progressive terracing for many crops is much more than the use of modern inputs such as improved seeds; this helps explain the high coverage rates of progressive terracing without modern inputs that are shown in Table 3b, and the high figures for progressive terracing without improved seeds that are also shown in the table. Taking maize as an example again, modern input use and extension provision account for 42.0 percent of the area under maize cultivation. Considering only modern input use and extension provision on irrigated land and land with radical terracing, we find that modern inputs are applied on just 14.0 percent of cultivated maize area under progressive terracing, while 38.5 percent of progressive terraced land used for maize production is without modern input use (Table 3b). Whereas investment in terracing is costly, the productivity gains from this investment are modest in the absence of modern input use. This phenomenon is considered when designing scenarios that are aimed at analyzing alternative ways of improving the effectiveness of the current budget allocation. (This will be discussed further in Section 5.)

The fifth point is that unit cost measurements differ between interventions that affect the broad rural economy (such as rural roads) and interventions that are related to crops or livestock (such as modern inputs, irrigation, or terracing). Table 3c reports unit cost, subsidy rate, and discount rate for those investments that affect the broad rural economy and hence the whole food system, while Table 3d reports the unit costs for crop- or livestock-specific spending/investments. All unit costs are measured in US dollars and represent the additional investment/spending that would be incurred to expand the current coverage rate.

The unit chosen differs according to whether investments benefit the broad rural economy, the entire food system, or specific crops and livestock. As shown in Table 3c, feeder roads stand out as the most expensive intervention, but only because this intervention is measured in terms of investment cost per km. Information on unit costs is drawn from a European Union-funded study conducted in 2016 (EU 2016) which considers the cost per km of more than 10 feeder road projects. While the unit costs seem relatively high, the public-good attributes of feeder roads are significant, such that they tend to benefit not only agricultural activities but the rural economy and the wider food system. Crop and livestock R&D, on the other hand, appears to be the least expensive investment because it is measured in terms of all the potential benefits to farmland or livestock, for example new cultivars or livestock breeds that are resistant to biotic and abiotic stresses. The expenditure on crop R&D that is required in order to attain its potential benefits was obtained from Nin-Pratt and Magalhaes (2018); this is also used to measure the R&D coverage rate, which is the ratio of the actual spending on R&D over potential R&D expenditure needed. Nin-Pratt and Magalhaes (2018) did not contain figures for livestock R&D; we have therefore assumed that the effect of livestock R&D is a threefold multiple of the estimate provided in Nin-Pratt and Magalhaes (2018) for crop R&D.

The unit cost and productivity effects of individual livestock-sector interventions are determined using a newly developed Linked Economic and Animal Systems (LEAS)-lite framework (see Aragie et al. 2021 for an advanced version of LEAS). This framework considers the underlying structure of Rwanda's livestock sector, focusing on cattle. Given the underlying features of the livestock sector, including breed structure, baseline adoption rates of animal-sector interventions, and baseline milk and meat productivity, the LEAS-lite model determines the cost of increasing coverage by one unit and then recalculating to find the gain in productivity. Unlike the full LEAS model, which tracks livestock at disaggregated age levels, the LEAS-lite model is less detailed and less data-intensive. Key parameters include number of cattle holders, cattle stock, share of improved breeds, milk yield by breed type, share of female cattle artificially inseminated (AI), likelihood of vaccine use at the herd level, access to livestock antibiotics and dewormers, share of improved feed, and access to livestock extension. Data for deriving these parameters is obtained from AHS (NISR 2017). Other parameters, including share of live births and meat yield, are based on informed assumptions drawn from estimates from comparable countries such as Tanzania. Marginal effects of livestock interventions such as health services and AI are calculated assuming a budget change that amounts to a 1 percentage point increase in coverage rate, which would ultimately lead to growth in meat and milk production. We assume a zero cattle stock growth rate, such that the growth rates of meat and milk production are solely interpreted as changes in productivity; and it is further assumed that these productivity increases are due to the intervention that is being studied, which is expressed as a scenario in the model combines livestock health and extension-related individual interventions. Livestock R&D is still treated as a standalone scenario, and the costs and benefits of the composite livestock intervention scenario are simple additions of the costs and benefits of their individual components.

The unit cost, subsidy rate, and discount rate in Table 3d are defined at the crop level for the combination of spending on input subsidies, extension services, and investment in irrigation or terracing (see Table A5 for the details). Underlying these unit costs, subsidy rates, and discount rates for combined expenditures in Table 3d, however, are the estimates of unit cost, subsidy rate, and discount rate for their individual components. As indicated in Section 3, unit cost data for crop-specific interventions are retrieved from various reports including World Bank documents and PSTA 4; in certain circumstances, they are derived by simply dividing the budget figures by the amount of the input that is reported to have been used by farmers during the year. It is worth further explaining the calculation of unit costs for the three types of irrigation and two types of terracing investments.

The calculation of the unit costs of three types of irrigation considers two different sources of information. Based on the budget allocation and targeted achievement in farmland coverage from the development of the three types of irrigation for 2018 to 2024 in PSTA 4, the unit cost is $10,077/ha for marshland irrigation investment, $18,993/ha for hillside irrigation, and $3,112/ha for small-scale irrigation. Based on the World Bank's assessment of their projects (World Bank 2018, 2019), the unit cost is $6,000/ha for marshland development and $16,800/ha for hillside irrigation investment. We decided to use the World Bank's assessments for the unit costs of marshland and hillside irrigation investments because they show a more significant difference between marshland and hillside irrigation investments in terms of cost. Based on various sources of information, including internal MINAGRI documents that were used in the preparation of PSTA 3, small-scale irrigation investments are diverse but are generally much less expensive than the assessment of their cost found in PSTA 4. We pick up an average from different sources of information, including the assessment in PSTA 4, and arrive at a unit cost of $700/ha for small-scale irrigation investment. Since irrigated marshland can have two crops per year and since investment cost is reported for target farmland, the unit cost for cultivated areas is equivalent to 50 percent of the investment cost, which is $3,000 per cultivated hectare.[7] Hillside irrigation and small-scale irrigation make season C planting possible; this lowers the unit cost for these two types of irrigation to about $5,600 per cultivated hectare for hillside irrigation investment and $240 per cultivated hectare for small-scale irrigation investment, that is, at one-third of the unit investment cost measured by farmland.

The unit costs of progressive and radical terracing investments are calculated based only on the costing information provided in PSTA 4 documentation. By dividing budget allocation by targeted land areas planned for the development of the two types of terraces from 2018 to 2024 in PSTA 4, we obtain unit costs of $445/ha for progressive terracing and $3,365/ha for radical terracing. Again, with two seasons for radical terracing, its unit cost is about $1,680 per cultivated hectare. As explained earlier, since it is assumed that only 20 percent of progressive terracing is covered by two seasons of cultivation, the unit cost is about $400 per cultivated hectare. (Table 3d shows the unit costs for irrigation and terracing combined with the unit costs of modern inputs and extension.)

The final point to consider is the reported subsidy and discount rates shown in Table 3d; these highlight the differences in lifespan among infrastructural investments and input subsidy spending, as well as the different amounts of government subsidization of their costs. When investments in irrigation and terracing are combined with the use of agricultural inputs and extension (Table 3d), the subsidy and discount rates are weighted averages between investments and spending, where unit costs for each type of spending/investment are the weights. The combined unit cost is a simple addition of the investment cost and spending cost of inputs and extension.

DISCUSSION OF SIMULATION RESULTS

Contribution of agricultural public expenditures to growth and development

We first consider a baseline, with 2017 as our starting year and 2024 as the ending year. This is a period consistent with PSTA 4 in which agricultural expenditures under PSTA 4 are embedded. The baseline also considers the unprecedented shocks from the COVID-19 pandemic and the expected impacts of the National Economic Recovery Plan. GDP and sectoral GDP growth rates in the baseline are consistent with our analysis of the impact of COVID-19 and the recovery plan (see Aragie et al. 2021a for the details of this analysis).

Building on the baseline, we reduce annual agricultural expenditures by $109 million in 2018–2024; this is the total that can be allocated across different types of investment and spending (Table A2). Growth is expected to slowdown, and comparing this scenario with the baseline helps us assess the impact of

[7] Land allocated to sugarcane is an exception. Sugarcane needs a growing period of 11 to 13 months; this makes second-season cultivation impossible once land has been allocated to sugarcane. In the simulation analysis that will be discussed in Section 5, we show that this is the main reason behind the indication in our results that investments associated with sugarcane production are much less efficient than investments in other crops.

agricultural expenditures not only on economic growth but also on employment, poverty, and diet quality.

Figures 4a to 4c report the annual growth rate of total GDP, food system GDP, and agricultural GDP under the baseline with PSTA 4 and under the scenario that is characterized by an annual $109 million reduction in agricultural spending. As shown in the figures, the growth effect of an annual agricultural expenditure of $109 million is stronger in the first three years. GDP is 1.6 percentage points higher, and food system GDP and agricultural GDP are 2.7 and 3.2 percentage points higher, respectively, than growth without the $109 million of annual agricultural expenditure that is implemented under PSTA 4.

In 2020, with the economy negatively affected by COVID-19, agricultural spending helps the economy mitigate the negative shock. Over time and with continued economic growth, the same amount of agricultural spending is expected to have a relatively small impact on growth, ranging from 0.1 percentage points for GDP to 0.5 percentage points for agricultural GDP in 2024. The main reason is that the spending on input subsidies for crop and livestock production, which is about 12 percent of the $109 million annual expenditure (Table A2), can only benefit the same percentage of farmland cultivated with the same amount of fertilizer and seeds after the first year, helping these crops maintain the yields achieved by the increased use of fertilizer and seeds in 2018.

Crop and livestock extension account for about 10 percent of the $109 million annual expenditure (Table A2). The discount rate for the two types of extension is 33.4 percent (Table A5), which means that their spending can have a continuous but rapidly diminishing growth effect after the first year (2018) until 2020. Without increasing the amount spent on extension, the spending in 2018 will not generate additional gains after 2020. Thus, the 0.1 and 0.5 percentage points of additional growth in GDP and agriculture GDP after 2020 come from infrastructural investments that are the main part of the $109 million annual expenditure, as they have a longer lifespan and can have longer-lasting growth effects, while the discount rates make such effects diminish slowly. The fact that the same amount of agricultural expenditure cannot have longer-term impacts on growth rates implies that agricultural expenditures have to increase over time to support sustainable growth and that larger allocations to investments with longer lifespans can further maximize longer-term growth effects.

Figure 4a: Annual growth rate in GDP with and without $109 million in annual agricultural expenditures, 2018–2024

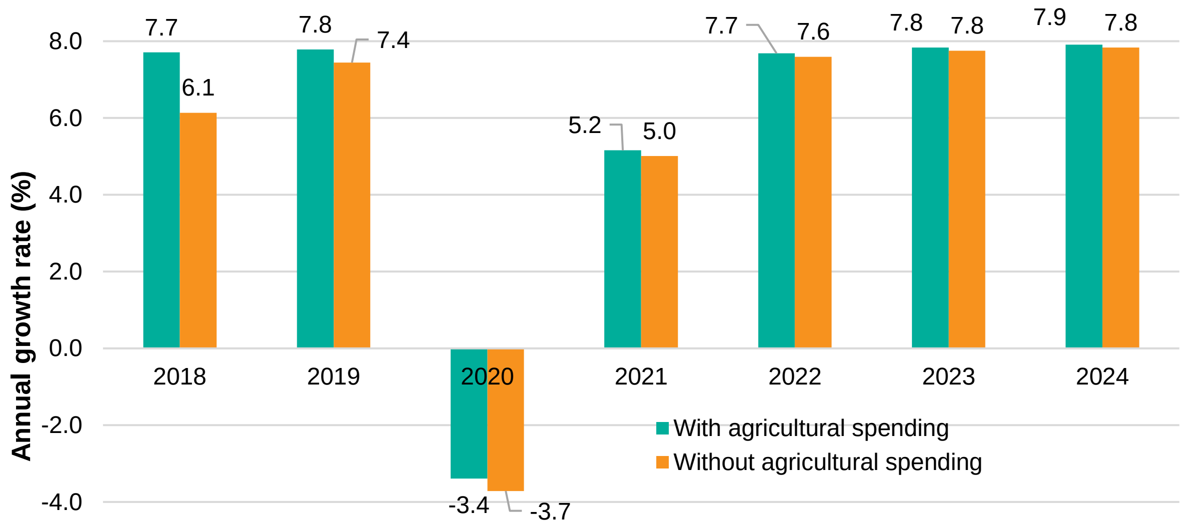


Figure 4b: Annual growth rate in food system GDP with and without $109 million in annual agricultural expenditures, 2018–2024

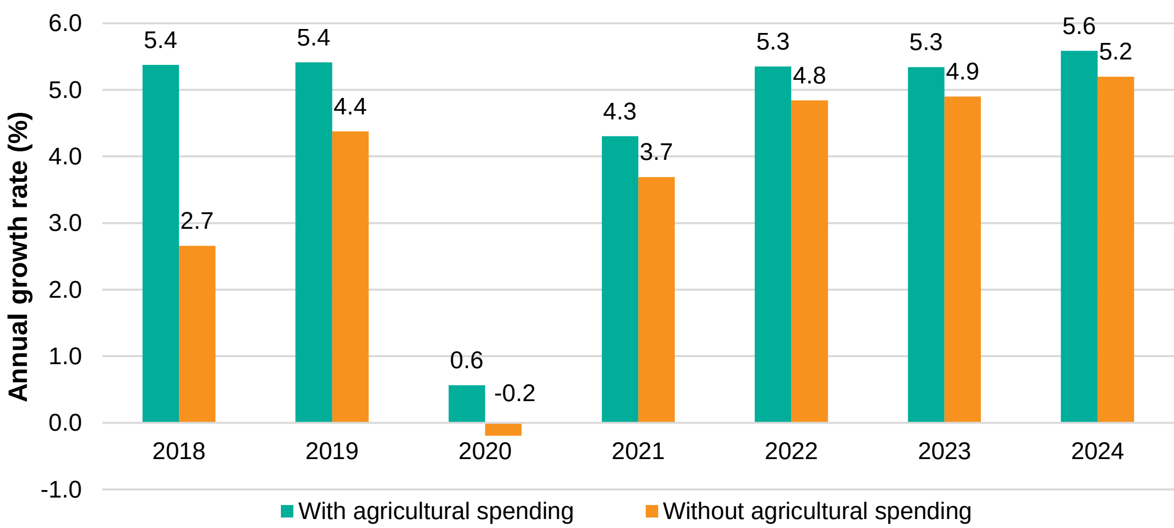
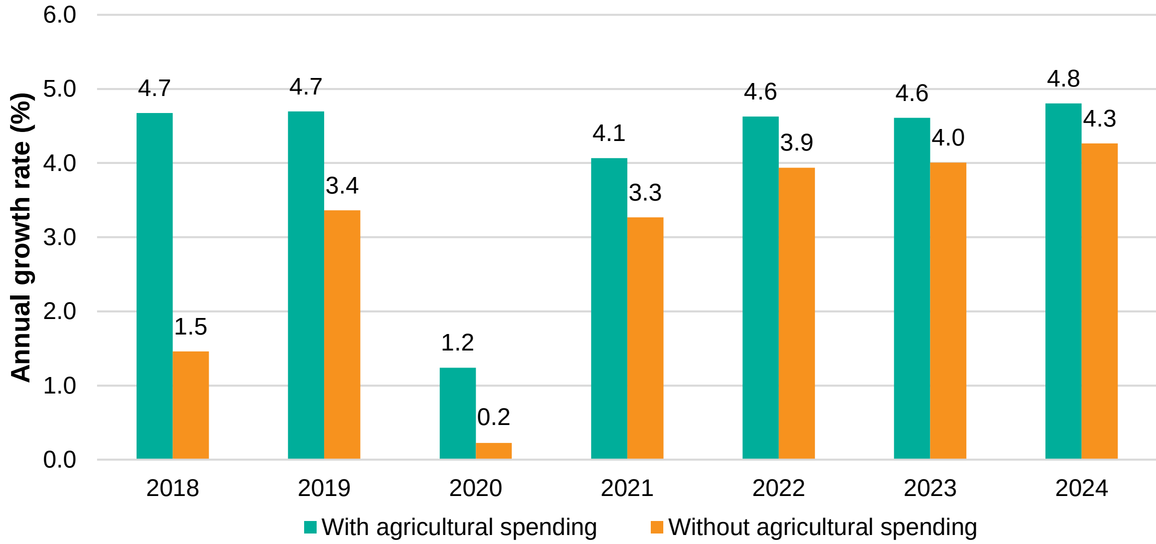


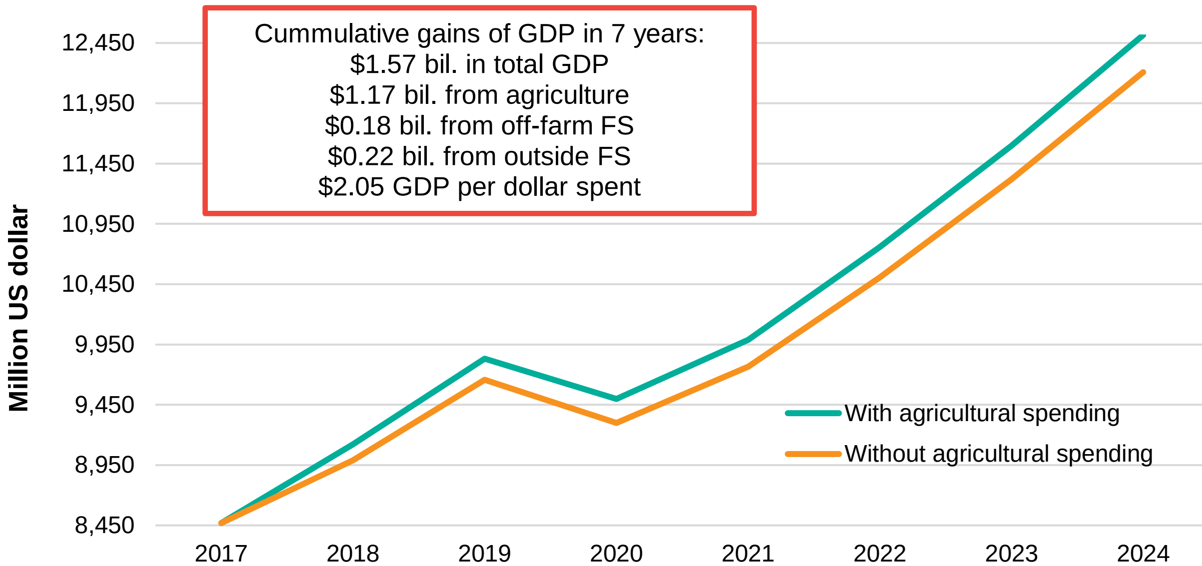
Figure 4c: Annual growth rate in agriculture GDP with and without $109 million in annual agricultural expenditures, 2018–2024



Source: Rwanda-RIAPA model.

Figure 5 measures the cumulative gains in GDP from the annual agricultural expenditure of $109 million. Over the seven years between 2018 and 2024, agricultural expenditures generate GDP gains of $1.57 billion. Of this, $1.17 billion (74.5 percent) is the gain within agriculture, $0.18 billion (11.5 percent) is from the off-farm part of the food system, and $0.22 billion (14.0 percent) is from the rest of the economy beyond the food system; thus almost 86 percent of the benefits are realized within the food system. Each dollar spent generates a $2.05 gain in GDP. Also, our simulation analysis properly picks up the kink in GDP growth trends that is caused by the COVID-19 pandemic in 2020 and 2021. Under the assumed growth trajectory, the economy achieves pre-pandemic levels of growth in 2022.

Figure 5: Level of GDP with and without $109 million in annual agricultural expenditures in 2018–2024, in constant (2017) US$ million



Source: Rwanda-RIAPA model.

Figure 5 reports the cumulative gains in GDP from $109 million in annual agricultural expenditure in 2018-2024, while 4able 4 splits the total gains by two periods: 2018-2021 for the already realized gains, and 2022-2024 for the expected gains.

Table 4: Cumulative gains in GDP in 2018-2021 and 2022-2024 from $109 million in annual agricultural expenditures, in constant (2017) US$ billion

GDP gains	2018-2021	2022-2024	2018-2024
Total GDP	0.73	0.84	1.57
Agricultural GDP	0.51	0.66	1.17
Off-farm food system GDP	0.08	0.10	0.18
GDP outside the food system	0.14	0.08	0.22

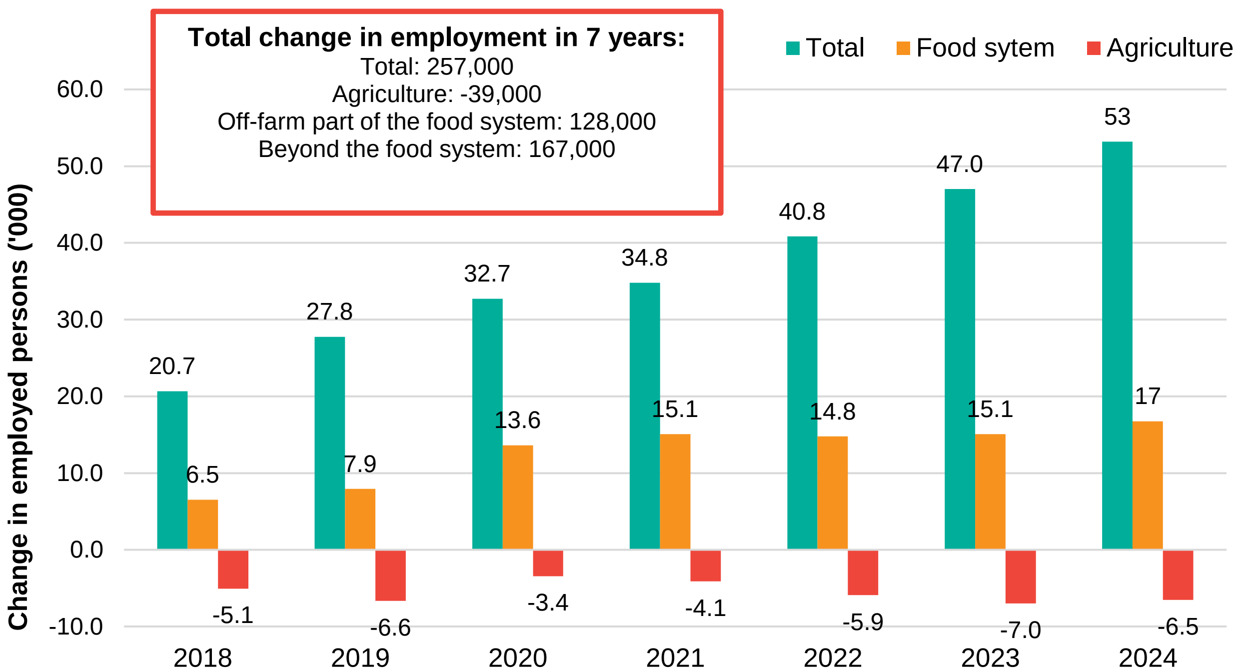
Source: Rwanda-RIAPA model.

Results in Table 4 indicate that during the first four years of PSTA 4 (i.e., 2018–2021), agricultural expenditures generated additional GDP of $0.73 billion. About $0.51 billion (70 percent) of the gains were within agriculture and $0.08 billion (10 percent) from the off-farm part of the food system, indicating that 80 percent of the benefits are realized within the food system. About $0.14 billion (20 percent) of the gains came from the rest of the economy beyond the food system.

For the remaining three years of PSTA 4 between 2022 and 2024, more GDP gains from the same amount of annual agricultural expenditures are expected, because early investments in 2018-2021 continue to contribute to GDP growth. GDP gains are expected to reach $0.84 billion in these three years, of which $0.66 billion (79 percent) are within agriculture, $0.10 billion (12 percent) from the off-farm component of the food system, and $0.08 billion (10 percent) from the rest of the economy. The food system benefits more in relatively longer terms because of the long-lasting effects of agricultural investments and R&D spending that directly and disproportionately benefit the agriculture sector.

Agricultural expenditures also contribute to employment opportunities, poverty reduction, and diet quality improvements. Figures 6a to 6c display the expected impact of agricultural expenditures on these development indicators in 2018-2024. To begin, Figure 6a shows that the same amount of agricultural expenditures each year could create 275,000 job opportunities during 2018–2024. All the jobs are created outside agriculture, within or outside the food system, while the number of people working in agriculture falls. Agricultural spending aims at improving agricultural productivity. At a higher level of agricultural productivity for the production of more agricultural products, fewer people need to work on-farm, and more are required off-farm within and outside the food system; this leads to transformation in the structure of rural employment.

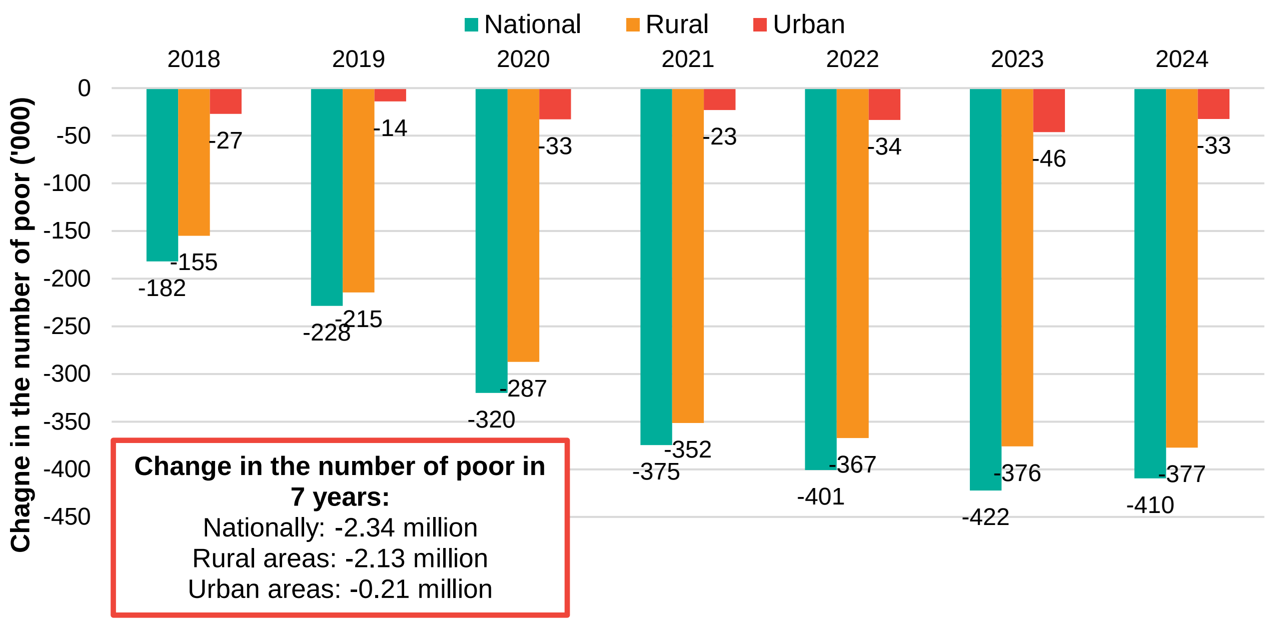
Figure 6a: Contribution of agricultural expenditure to employment, measured in terms of changes in the number of people employed, 2018–2024



Source: Rwanda-RIAPA model.

Agricultural expenditures also help reduce poverty. Figure 6b reports the change in the numbers of poor (national, rural, and urban) associated with the $109 million annual expenditure on agriculture. The poverty reduction effect is arguably stronger in rural areas since the majority of new nonfarm jobs are created in rural areas where the poverty rate is higher than in urban areas. Moreover, rural households benefit directly from a more productive agricultural sector, generating higher farm income. Together with more rural nonfarm opportunities, agricultural expenditures help to create diverse livelihood for many rural households. Consistent with more gains in GDP in the remaining years of PSTA 4 (Table 4), the rate of poverty reduction gradually increases over time. At national level, there will be 2.34 million fewer poor by the end of the PSTA 4. Most poverty reduction occurs in rural areas (91.0 percent), where 93 percent of the poor reside.

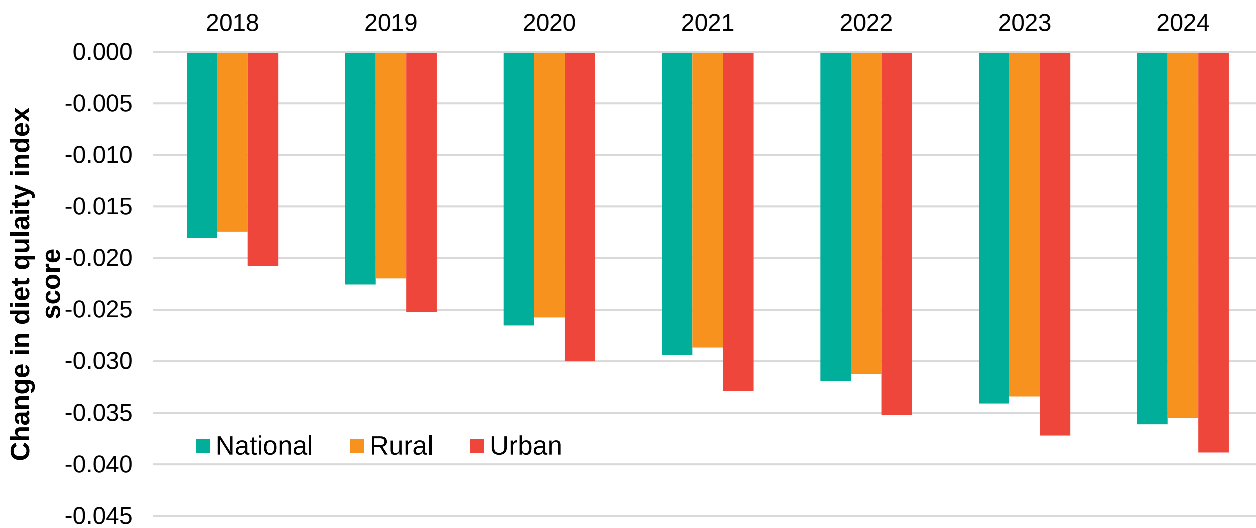
Figure 6b: Contribution of agricultural expenditures to poverty reduction, measured in terms of changes in the number of poor, 2018–2024



Source: Rwanda-RIAPA model.

The positive impact of agricultural expenditures on diet quality is also provided in these results. Figure 6c uses changes in diet quality index, which is a measure of the gap between actual and recommended diet structure which takes price structure into consideration. Declines in the index imply that gaps have narrowed—an indicator of improvement in diet quality. Figure 6c shows consistent declines in the diet quality index at the national level as well as for rural and urban households. Interestingly, diet quality improves more among urban than rural households. This is possibly due to urban households consuming more high diet-quality products like vegetables and animal-source foods, the prices of which falls with higher productivity. This indicates that the dominant source of agricultural expenditure to benefit urban households is through its price effect on high diet-quality products, while nonfarm employment opportunities created in urban areas through the linkage effects of increased agricultural expenditure further enhance such benefits through increases in urban household incomes.

Figure 6c: Contribution of agricultural expenditures to diet quality, measured in terms of changes in diet quality index scores, 2018–2024 (in which negative changes imply diet quality improvement)



Source: Rwanda-RIAPA model.

Decomposition of the contribution of agricultural public expenditures to growth and development

We next decompose the expenditures that are detailed above under the current PSTA 4 allocation, in order to assess the differential impacts of agricultural spending when grouped by sector and type of investment. The decomposition captures the scale of different expenditures and investments as well as the size of different agricultural sectors which, when decomposed, affect growth and rural development in different ways. More importantly, the decomposition captures the differences in the effectiveness of different types of expenditures and investments, which helps us consider reallocation impacts and serves as a guide for allocating additional public resources to maximize impacts.

We design 52 scenarios that capture a range of different combinations of spending; these include investment in irrigation and terracing combined with spending on input subsidies and crop extension services; livestock input subsidies combined with livestock extension services; spending on crop and livestock R&D; and investments in rural development including feeder roads, education, and electricity. By grouping the results of these 52 scenarios, we decompose the impacts of agricultural expenditures and investments from two different perspectives.

The first perspective relies on a grouping that is more focused on the agricultural sector; in this perspective, spending/investments are grouped by different crops, crop groups, and livestock, in addition to spending on crop and livestock R&D and three types of nonagricultural investments. We refer to this group as the “sector of investment” scenarios. This grouping generates 17 different spending options that fully cover the annual total spending of $109 million.

The second perspective groups the 52 scenarios by types of expenditure and investment. This grouping of scenarios is according to “type of investment”. Totally, there are seven types of investment: three of irrigation; two of terracing, crop, and livestock R&D, grouped together as agricultural R&D; and three types of rural infrastructural investment which are grouped together as nonagricultural investments, and which include rural roads, rural education, and rural electricity. Two scenarios related to coffee and tea and one scenario related to livestock are not related to investments in irrigation and terracing; we thus consider spending on coffee and tea and on livestock to be standalone spending types in the grouping, such that the second perspective includes a total of 9 types of investment.

For the decomposition of each perspective, we use eight figures to show the contribution of different spending (Figures 7–10 a & c), and eight figures to show the effectiveness of such spending (Figures 7–10 b & d). The contribution to growth is measured as a share of the increases in GDP in the total economy, in the food system, and in agriculture, while contributions to employment, poverty, and diet quality are measured by changes in their respective values. The different types of spending are ranked from high to low in terms of their effects on gains in GDP per dollar spent; we can thus connect the scale of the contributions of different types of spending with their rank in efficiency, as measured by increases in GDP per dollar of such spending.

We focus on the same four outcomes discussed in the previous subsection. Figure 7a shows specific contributions to the increase in GDP in the total economy, food system and agriculture from investments in crops, livestock, and infrastructure, measured by the shares of increased GDP in 2018–2024, while Figure 7b displays the increase in values of GDP, food system GDP and agricultural GDP per dollar spending on such crops, livestock, and infrastructure. Figures 7c and 7d turn to the contribution of different investment types; in those two figures, similar contribution shares and increases in GDP per dollar spent are measured for different types of investments.

Figures 8a to 8d report the contributions of spending to changes in employment, Figures 9a to 9d for poverty reduction, and Figures 10a to 10d for diet quality improvement. Specifically, Figures 8 to 10 follow the same order described for increases in GDP in Figures 7a to 7d, while the contributions are measured as changes in absolute numbers instead of shares. Spending is also measured per $1,000 instead of per dollar. Results reported in each of these figures are discussed below.

When the contributions of different agricultural sectors, R&D, and nonagricultural investments are ranked in order of per-dollar spending on each, a clear divergence is observed between the scale of contributions and the cost-effectiveness of the spending (Figure 7a-b). The scale of contribution captures the size of different agricultural sectors and the amount of investment in those sectors; that is, sectors with a larger share in agriculture, or on which more money is spent, generally have a higher contribution to GDP.

Consider Irish potatoes and vegetables as illustrative examples. In 2017, these two crops accounted for a similar share of national GDP, at 2.26 percent and 2.01 percent, respectively (Table A3). Spending on Irish potatoes and vegetables includes subsidies of inputs, extension services, and investment in irrigation and terracing for land allocated to these two crops. The spending on Irish potatoes is about 2.33 percent of the $109 million annual expenditure, while for vegetables it is 4.02 percent because more vegetables are covered by irrigation with greater use of modern inputs (Table A3). As a result, vegetables account for 13.0 percent of the increase in GDP that results from investments in the sector, while the contribution from spending on Irish potatoes is just 8.4 percent (Figure 7a).

Investing in the potato sector, however, is slightly more cost-effective (Figure 7b), yielding a $7.80 increase in GDP per dollar spent as compared to a $7.00 increase in GDP per dollar spent on vegetables. These two crops rank highest in terms of cost-effectiveness.

Spending on coffee and tea, by comparison, ranks third. The contribution of these two crops to the increase in GDP is only 2.1 percent (Figure 7a), since only 0.8 percent of the $109 million annual expenditure is on coffee and tea crops, which are assumed to not be cultivated on irrigated or terraced fields. The value-added shares of these two crops are also small, about 1.4 percent of total GDP in 2017 (Table A3).

Bean-related spending, on the other hand, ranks quite low in cost-effectiveness, with an increase in GDP of $1.50 per dollar spent. Beans, however, are a relatively large group of crops, accounting for 3.3 percent of GDP in 2017 (Table A3). Of the $109 million annual expenditure, 8.5 percent is related to beans (Table A3) in the form of input subsidies, irrigation, and terracing; however, this crop contributes only 6.0 percent to the increase in GDP.

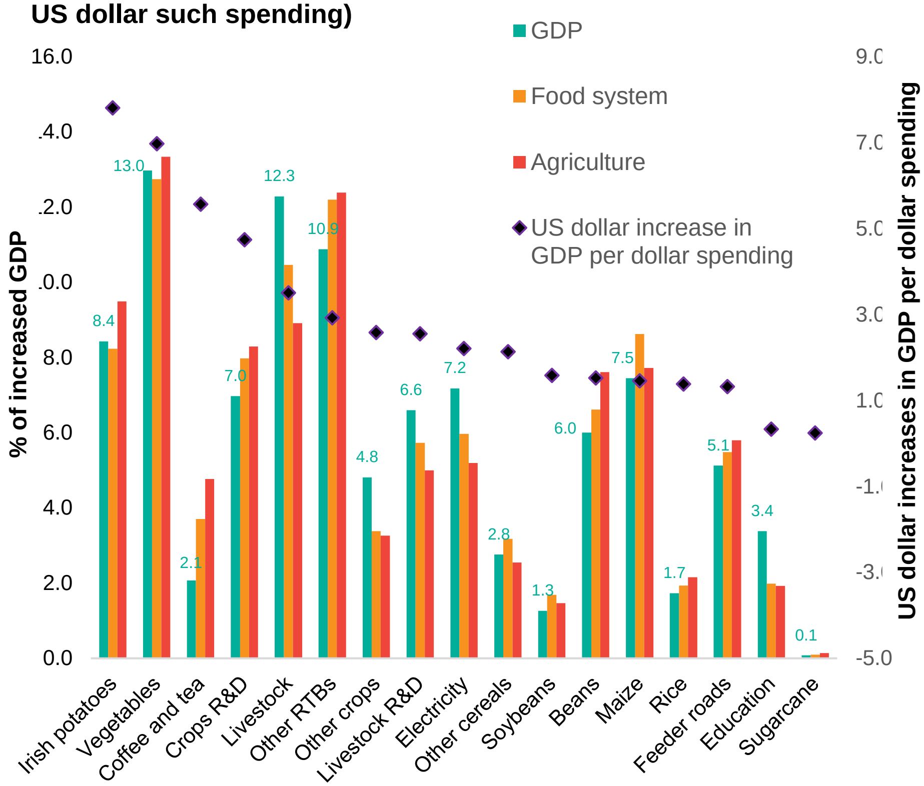
Sugarcane-related investments yield the lowest return, fetching only $0.30 in GDP gain per dollar spent (Figure 7b); they also have one of the lowest contributions to GDP at 0.1 percent (Figure 7a). The reason for the low return may be that a large share of sugarcane is primarily cultivated on irrigated marshland with a long growing season, making multiseason cultivation impossible once the irrigated field is allocated to sugarcane. This indicates that if the efficiency and effectiveness of agricultural expenditures are to be improved, sugarcane is a crop that may not deserve to be prioritized in budget allocations.

Putting Figures 7a and 7b together helps us understand that for more effective and efficient agricultural investments, both the size of an agricultural subsector in the economy as well as the returns to investment in that subsector must be taken into consideration. Our study also implies that crops with higher returns may not necessarily deserve more resources if their sectoral share is very small.

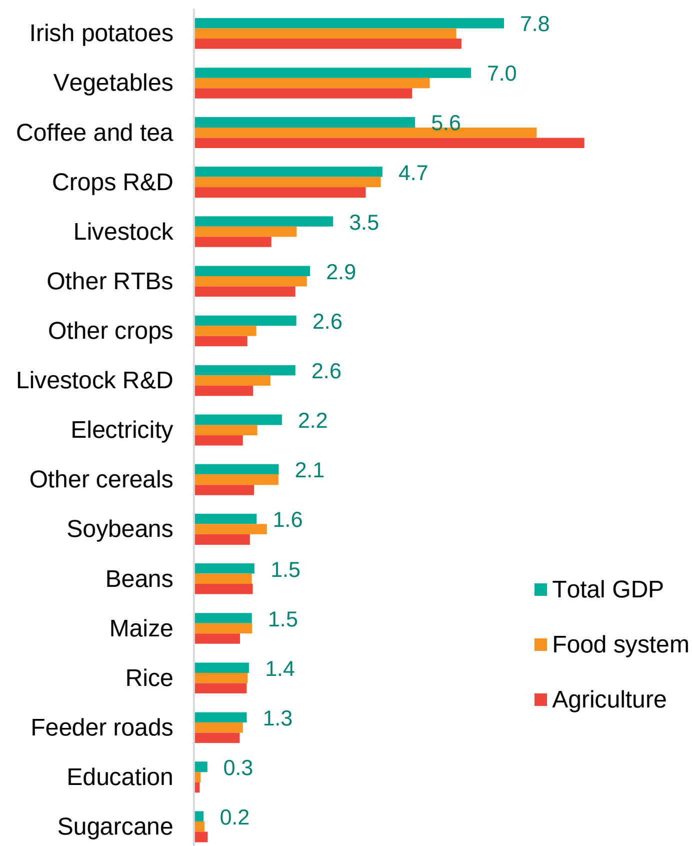
When contribution to growth is decomposed by investment type, small-scale irrigation has both the largest contribution to gains in GDP and the highest returns per dollar spent under the current PSTA 4 allocation. About 17 percent of the increase in GDP is related to investments in small-scale irrigation combined with the use of modern inputs and extension services; such investments generate $6.40 in GDP per dollar spent. Livestock spending is also cost-effective, ranking third in Figure 7d, however, its contribution to the increase in GDP is only 12.3 percent, which is smaller than that from investments in R&D, progressive terracing, and radical terracing (Figure 7c). While nonagricultural rural investments make the second-largest contribution to increases in GDP after small-scale irrigation, returns to such investments are lowest, with a $0.90 increase in GDP per dollar spent.

Figure 7a-7b: Contribution to total increases in GDP from public expenditures on crops, livestock, and infrastructure, and US dollar increases in GDP per dollar of such spending, 2018–2024

7a) Contribution to total increases in GDP from spending on crops, livestock, and infrastructure (percentage of total change in 2018-2024, ranking increases in GDP per US dollar such spending)



7b) US dollar increases in GDP per dollar of spending on crops, livestock, and infrastructure, 2018-2024

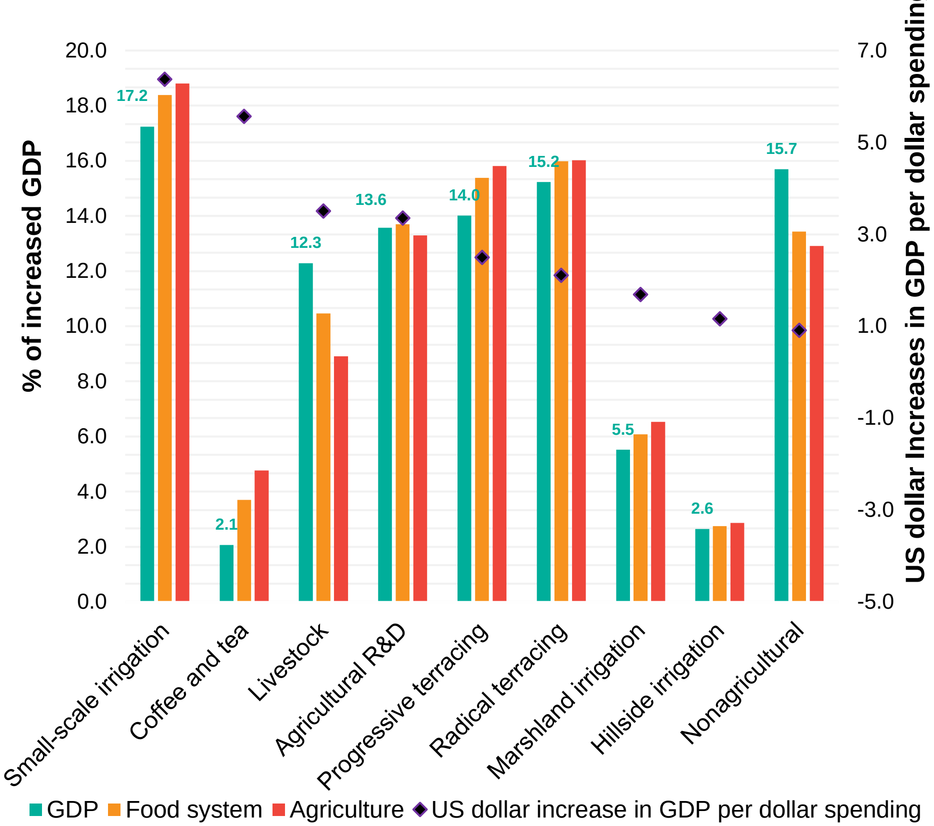


Source: Rwanda-RIAPA model.

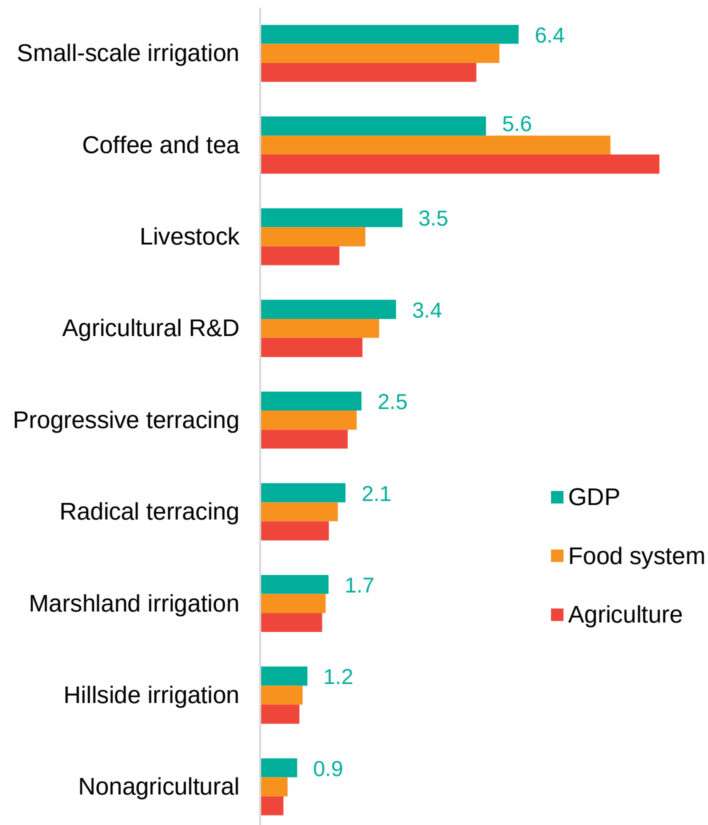
Note: Only the percentage of the increase in total GDP is labeled; labels for food system and agricultural GDP are omitted for purposes of readability. RTBs = roots, tubers, and bananas.

Figure 7c-7d: Contribution to total increases in GDP from different types of investment, and US dollar increases in GDP per dollar of such investment spending, 2018–2024

7c) Contribution to total increases GDP from different types of investment (percent of total GDP increase in 2018-2024, ranked by increases in GDP per US dollar of such spending)



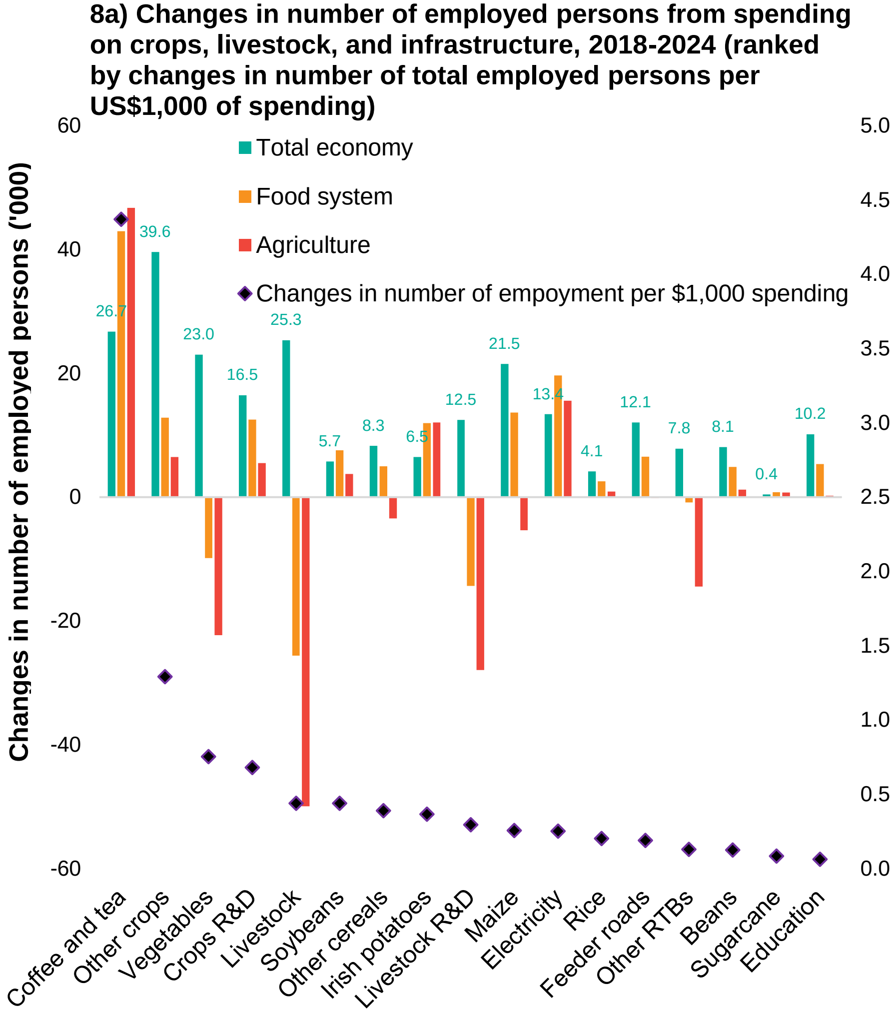
7d) US dollar increase in GDP per dollar of spending on different types of investment, 2018-2024

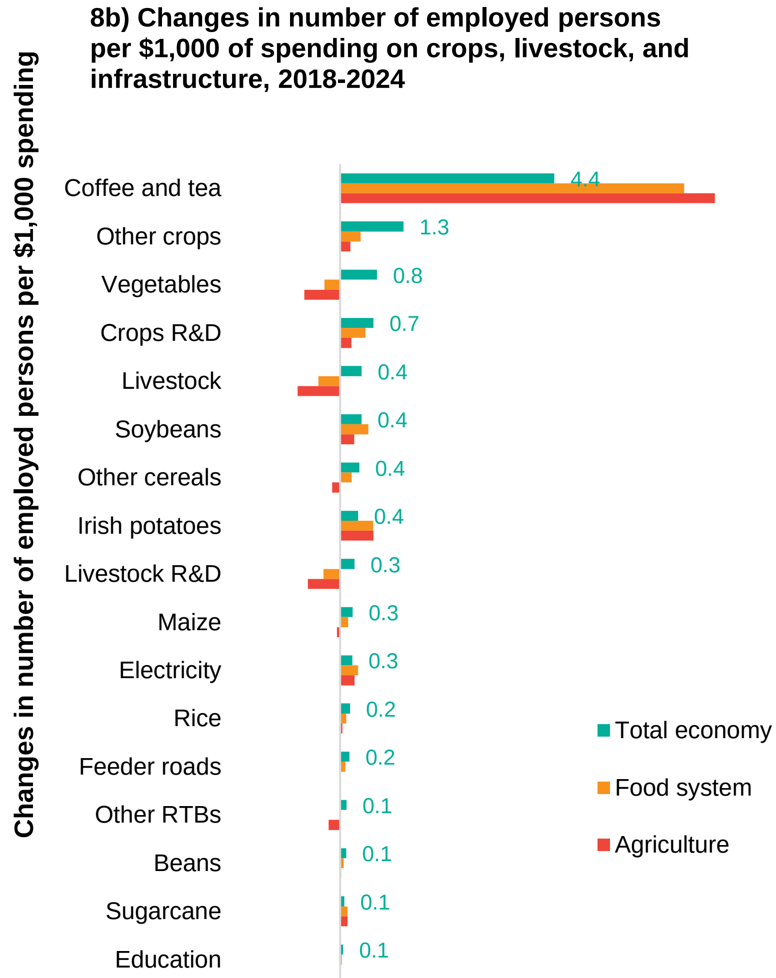


Source: Rwanda-RIAPA model.

Note: Only the percentage of the increase in total GDP is labeled; labels for food system and agricultural GDP are omitted for purposes of readability. RTBs = roots, tubers, and bananas; agricultural R&D refers to both crop and livestock R&D.

Figure 8a-8b: Changes in number of people employed resulting from public expenditures on crops, livestock, and infrastructure, and per US$1,000 of spending, 2018–2024

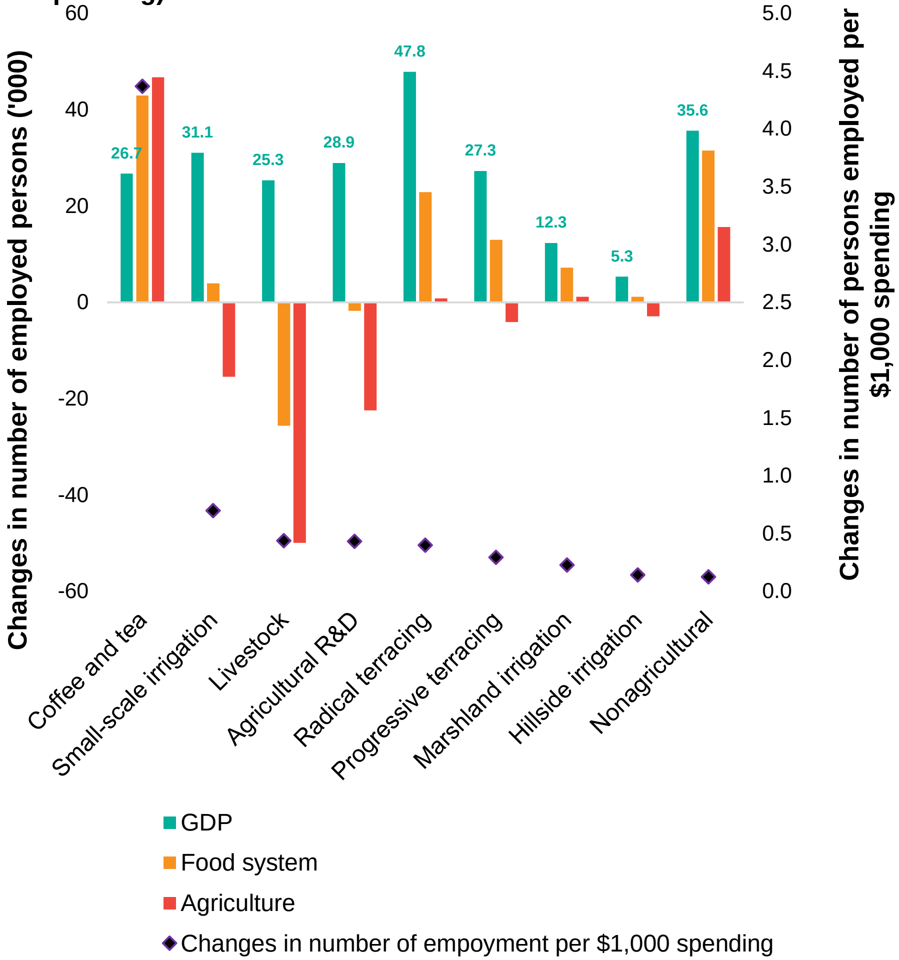




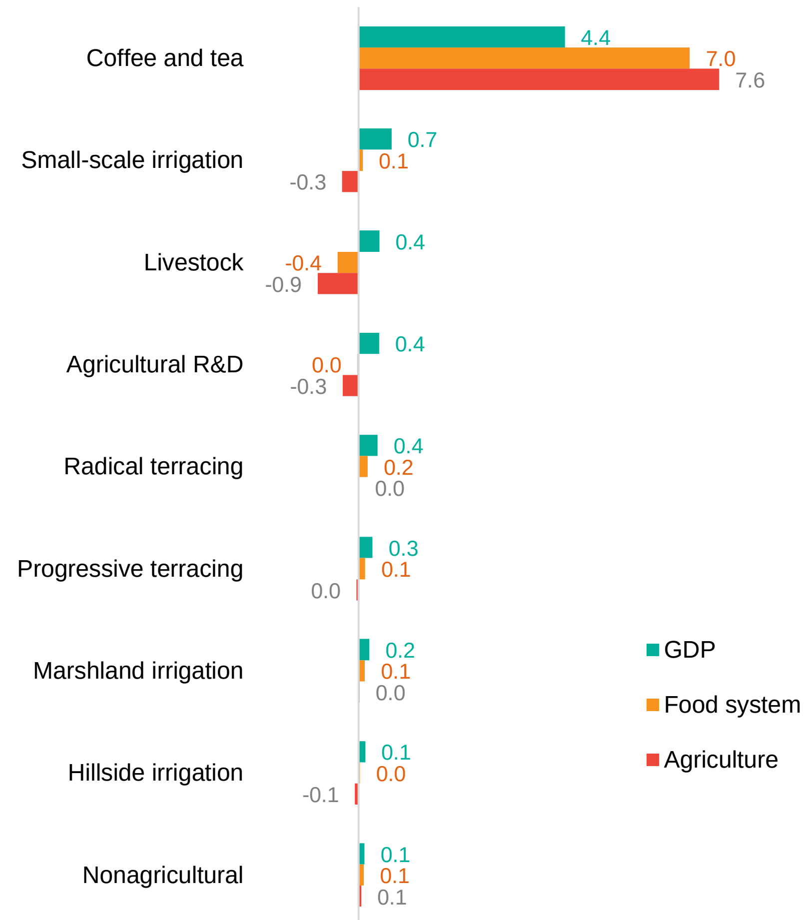
Source: Rwanda-RIAPA model.
Note: Only changes in the number of persons employed for the total economy is labeled; labels for the food system and agricultural sector are omitted to ensure readability. RTBs = roots, tubers, and bananas.

Figure 8c-8d: Changes in number of people employed resulting from different types of investment, and per US$1,000 of such investment spending, 2018–2024

8c) Changes in number of employed persons from different types of investment in 2018-2024 (ranked by changes in number of total employed persons per $1,000 of spending)



8d) Changes in number of employed persons per US$1,000 of spending on different types of investment, 2018-2024

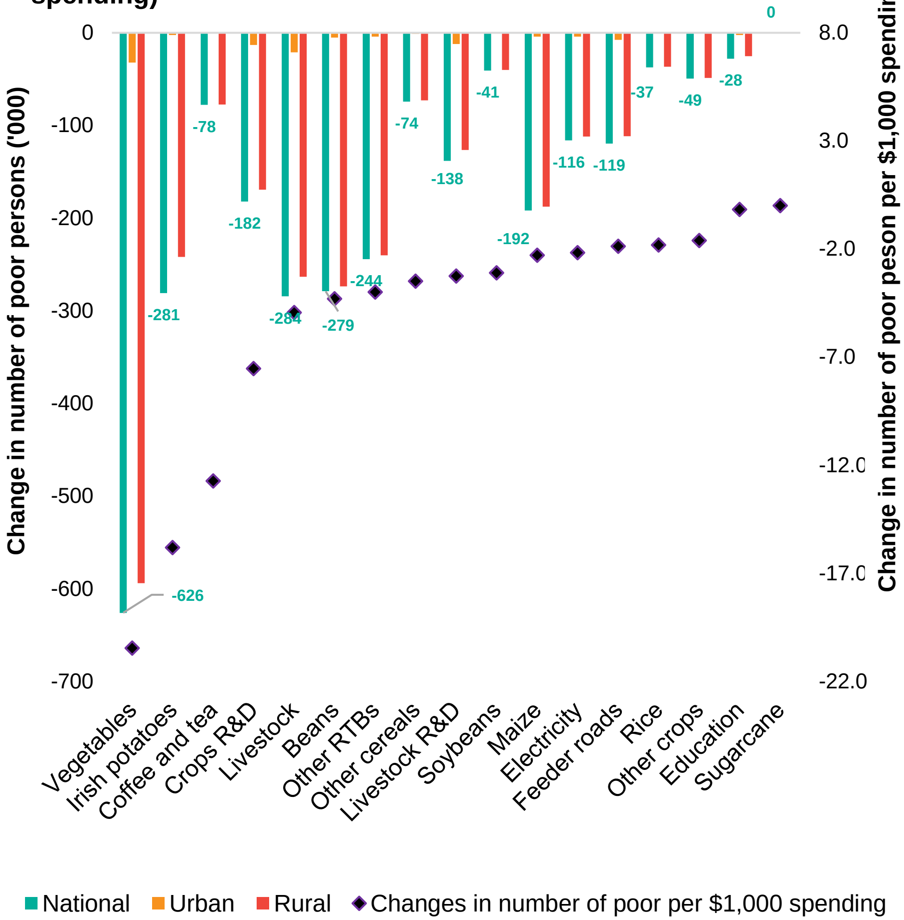


Source: Rwanda-RIAPA model.

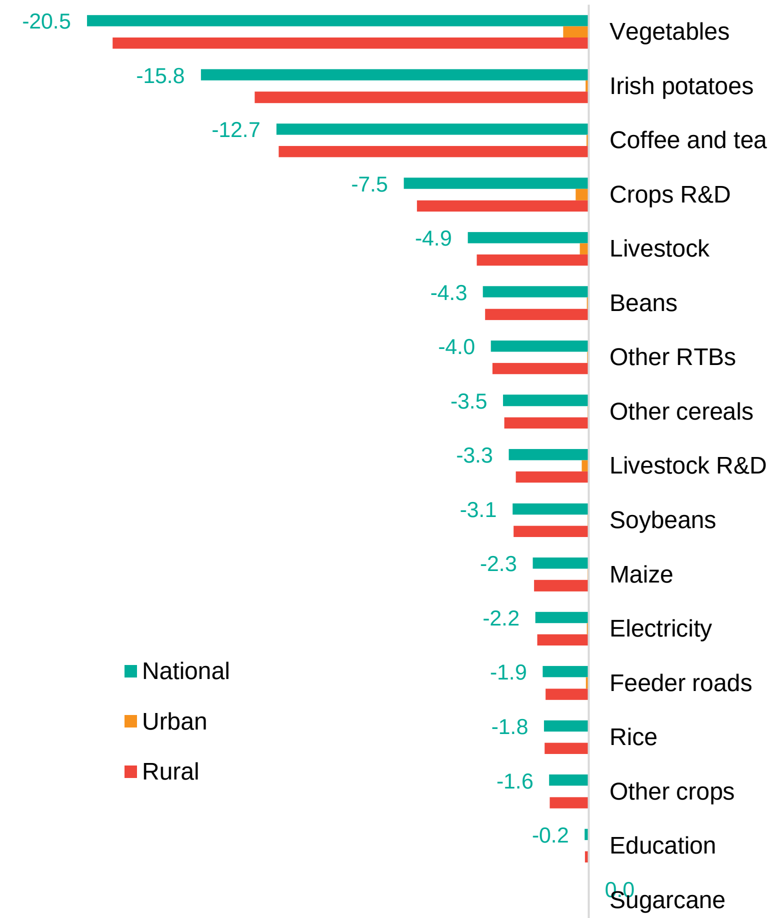
Note: Only changes in the number of persons employed for the total economy is labeled; labels for the food system and agricultural sector are omitted to ensure readability. Agricultural R&D refers to both crop and livestock R&D.

Figure 9a-9b: Changes in the number of poor from public expenditures on crops, livestock, and infrastructure, and per $1,000 of spending, in 2018-2024

9a) Change in the number of poor from spending on crops, livestock, and infrastructure, 2018-2024 (ranked by change in number of national poor per US$1,000 of spending)

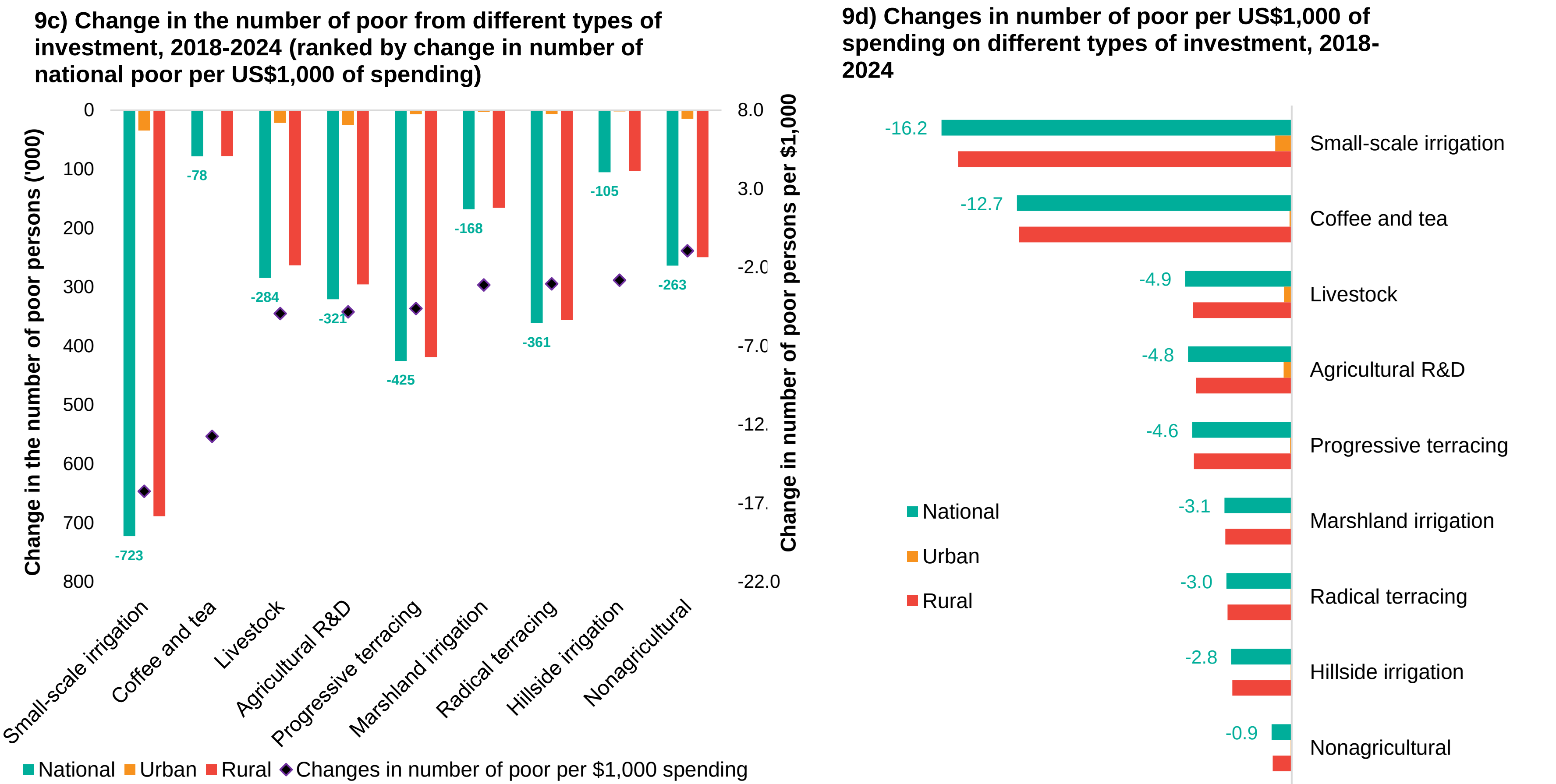


9b) Changes in the number of poor per US$1,000 of spending on crops, livestock, and infrastructure, 2018-2024



Source: Rwanda-RIAPA model.
Note: Only changes in the number of persons in poverty nationally labeled; labels for urban and rural numbers are omitted to ensure readability. RTBs = roots, tubers, and bananas.

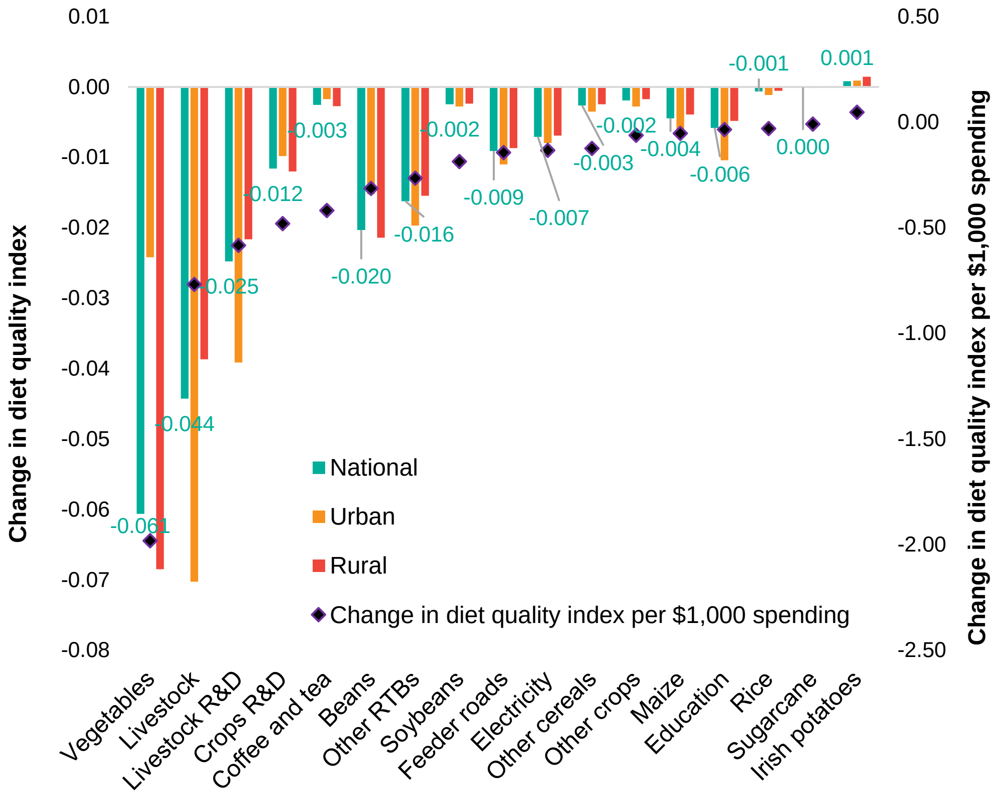
Figure 9c-9d: Changes in the number of poor from different types of investment , and per US$1,000 of such investment spending, 2018–2024



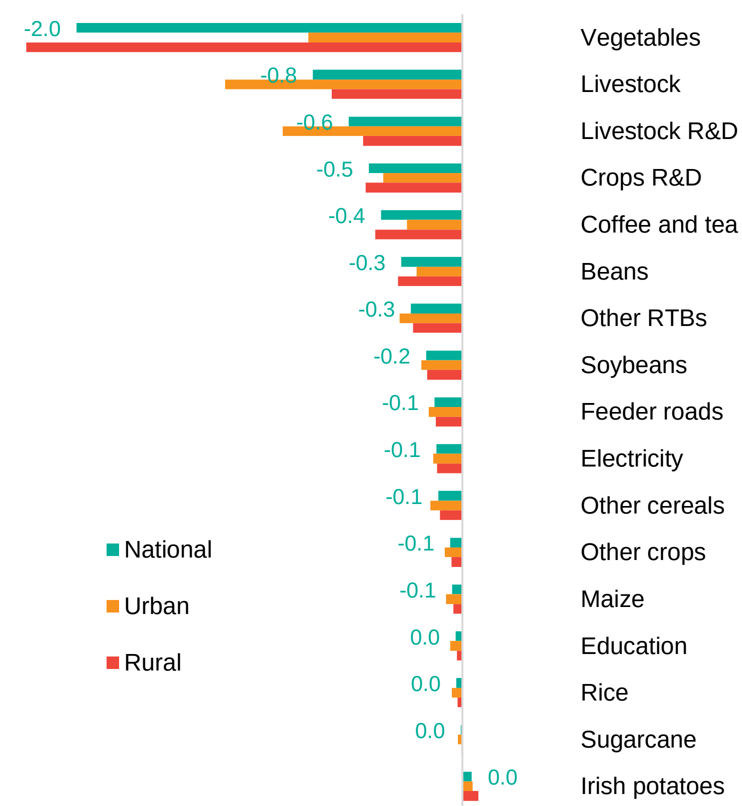
Source: Rwanda-RIAPA model.
Note: Only the change in the number of persons in poverty nationally is labeled; labels for urban and rural numbers are omitted to ensure readability. Agricultural R&D refers to both crop and livestock R&D

Figure 10a-10b: Changes in diet quality index resulting from public expenditures on crops, livestock, and infrastructure, and per $1,000 of such investment, 2018–2024

10a) Changes in diet quality index from spending on crops, livestock, and infrastructure in 2018-2024 (ranked by change in the national index per US$1,000 of spending)



10b) Changes in diet quality index per US$1,000 of spending on crops, livestock, and infrastructure

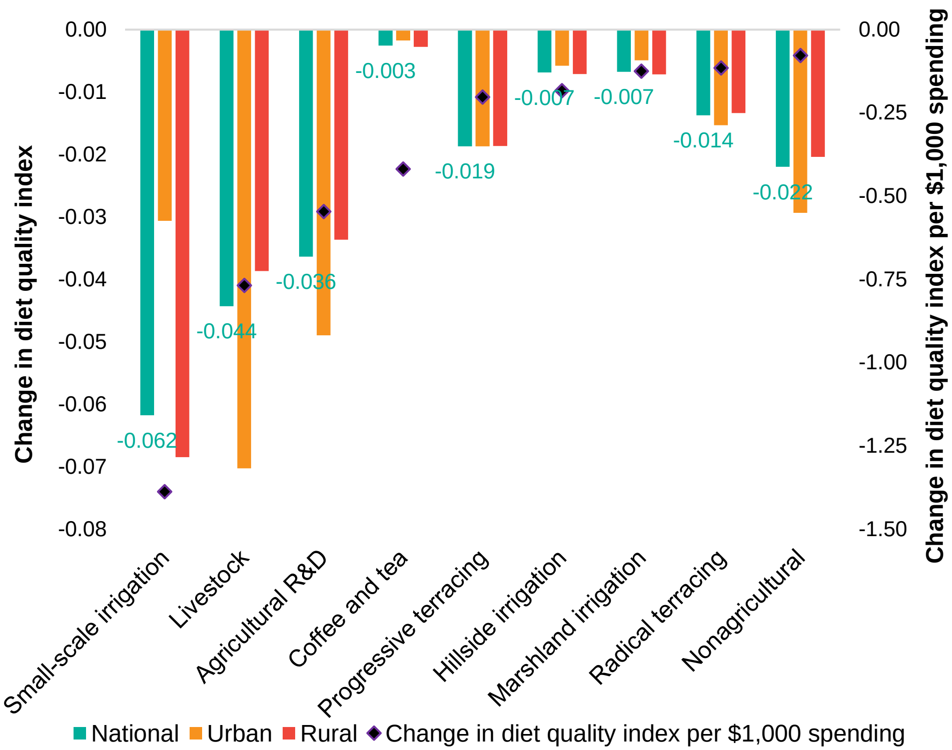


Source: Rwanda-RIAPA model.

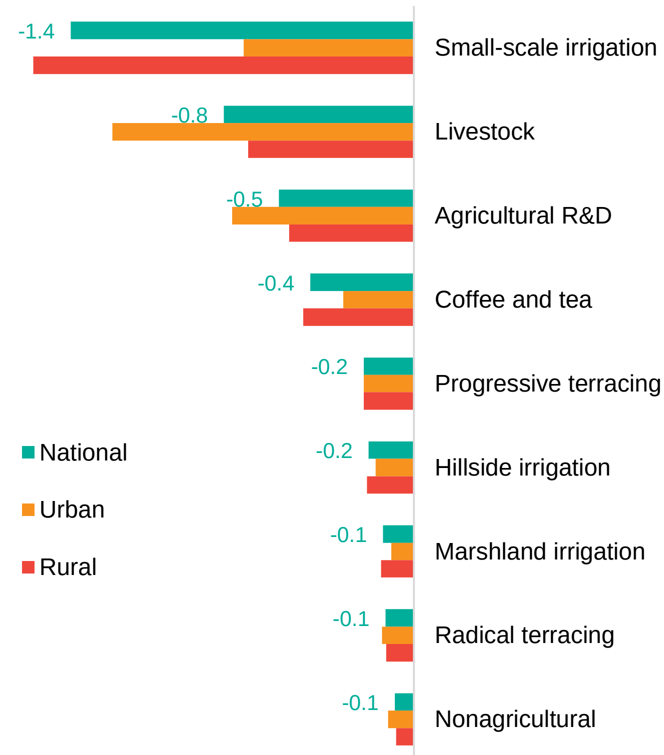
Note: Only the change in the diet quality index at the national level is labeled; labels for urban and rural numbers are omitted to ensure readability. RTBs = roots, tubers, and bananas.

Figure 10c-10d: Changes in diet quality index from different types of investment, and per US$1,000 of investment spending, 2018–2024

10c) Changes in diet quality from different types of investment, 2018-2024 (ranked by changes in the national index per US$1,000 of spending)



10d) Changes in diet quality index per US$1,000 of spending on different types of investment, 2018-2024



Source: Rwanda-RIAPA model.
Note: Only the change in the diet quality index at the national level is labeled; labels for urban and rural numbers are omitted to ensure readability. Agricultural R&D refers to both crop and livestock R&D

We next turn to employment results. Figures 8a to 8d show that spending on coffee and tea is the most efficient in terms of economywide employment generation. Its contribution to total employment creation is also significant, with 26,700 more people employed as a result of spending on coffee and tea under the current PSTA 4 allocation (Figure 8a). Spending on coffee and tea generates more employment in agriculture and in the food system than it does in the total economy, as indicated in Figure 8a by the two bars for the food system and agriculture.

Certain investments in the agricultural sector may generate more employment economywide, but jobs may not necessarily be created within agriculture. Livestock sector spending, for example, generates 25,300 jobs in the economy even while agricultural employment falls by almost 50,000; this drop causes a decline of 25,600 jobs within the food system, even though there is an overall increase in the off-farm part of the food system. Measured by type of investment, radical terracing has the largest effect on total employment, creating 47,800 more jobs economywide and 23,000 in the food system, though almost none of these are in agriculture (Figure 8c). In terms of efficiency of employment generation, however, radical terracing ranks lower than small-scale irrigation; that is, 0.4 new jobs are created per $1,000 spent on radical terracing while 0.7 new jobs are created per $1,000 spent on small-scale irrigation (Figure 8d).

Figures 9a and 9b report the poverty impact of investing in different crops, livestock, and infrastructure. The figure shows that vegetable-related investment/spending generates the highest poverty-reducing impact both in terms of the current allocations of PSTA 4 and per dollar spent. The number of poor people falls by 626,000 between 2018 and 2024, which is equivalent to 20.5 people per $1,000 spent. Figures 9c and 9d report the poverty impact of different investment types. We see that small-scale irrigation investment has the highest poverty-reducing impact both in the current allocation and per dollar spent. The number of poor people falls by 723,000 during the same period as noted above. In terms of cost-effectiveness, small-scale irrigation leads to 16.2 people coming out of poverty for every $1,000 investment.

Vegetable-related investments generate the largest impact on diet quality, both in terms of the change in the value of the diet quality index under the current allocation and per $1,000 spent (Figures 10a and 10b). Among different types of investments, small-scale irrigation generates the largest impact on diet quality both in the current allocation and per $1,000 spent (Figures 10c and 10d).

Broadly speaking, the decomposition analysis discussed here shows that the current budget allocation under PSTA 4 is overall effective in generating economic growth, employment, poverty reduction, and diet quality improvement. Investments that are more important in the budget allocation of PSTA 4 often have larger impacts on growth and development outcomes and they are also generally more efficient in terms of returns per dollar or per $1,000 spent. Among investments in different sectors, those related to vegetables and Irish potatoes often generate a large impact with relatively high returns per unit spent. The exception is the impact on employment, where investments in vegetables and Irish potatoes do not create more jobs when compared to investments in many other sectors. Investments in Irish potatoes also perform particularly badly in diet quality improvement. Among different types of investment, small-scale irrigation consistently shows the highest impact and high efficiency in returns per dollar spent.

In summary, the decomposition analysis shows that the impacts of different investments on different development outcomes often differ and are often accompanied by trade-offs between and among the development outcomes. Investments related to Irish potatoes rank high in GDP growth and poverty reduction, but low in diet quality improvement. Spending on coffee and tea is fairly efficient, but its impact on growth is relatively modest. The decomposition analysis also shows that many types of agricultural investments create jobs in the wider economy or in the off-farm part of the food system while at the same time agricultural employment falls; this suggests that agricultural spending plays an important role in rural transformation.

It must be kept in mind, however, that by grouping our expenditures and investments scenarios by crops, livestock, and infrastructure, and type of investment, we may be overlooking the potential for improvement in development outcomes that can follow from a reallocation of funds among different investments. As shown in Table 3b, for example, many food crops grown on progressive terraces did not use modern inputs or at least improved seed, which possibly lowers returns to such costly investments. In the next subsection, we provide a summary evaluation of public expenditures by generating a composite score that ranks expenditure options in terms of their contribution to achieving joint development outcomes. We are then able to investigate whether a modest reallocation of the current amount of agricultural expenditure can generate larger impacts.

Composite indexes for evaluating combined impacts of agricultural expenditures

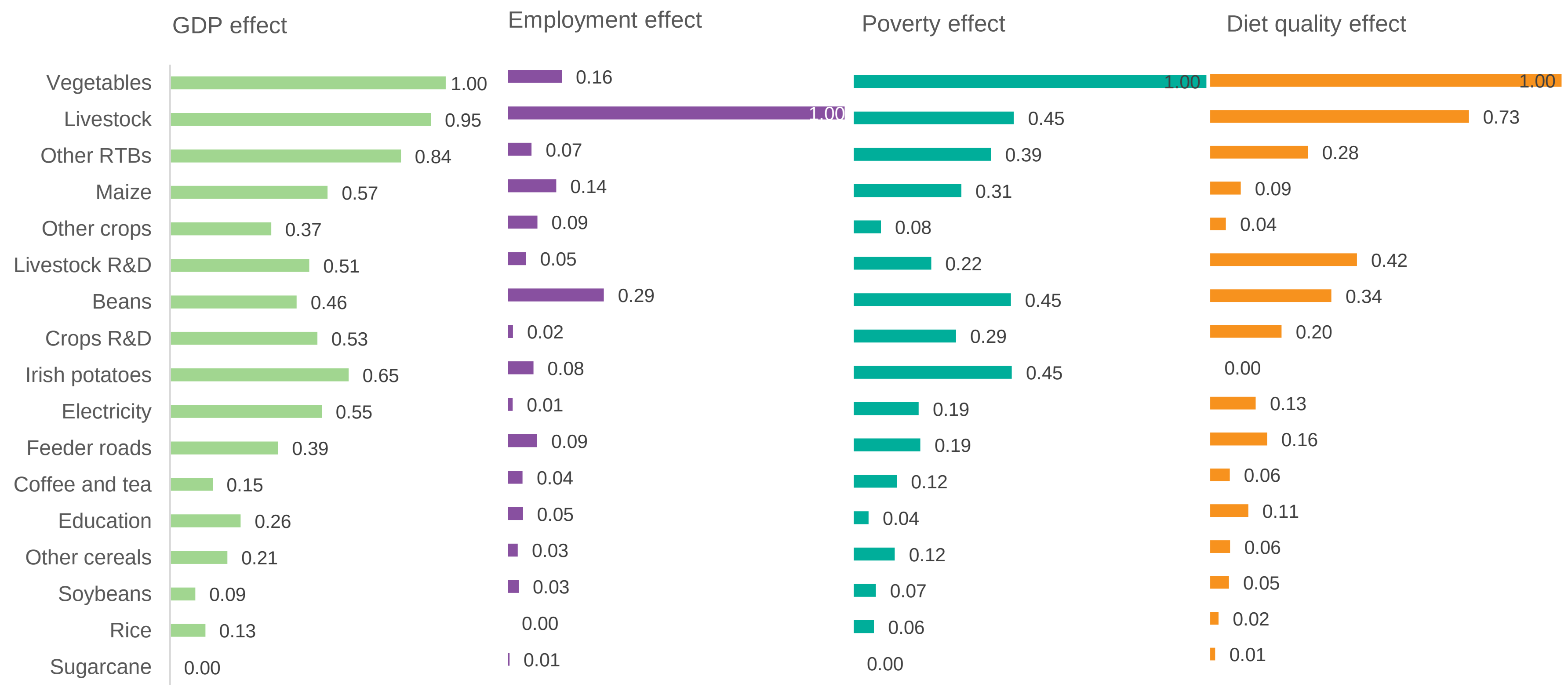
In this subsection, we develop composite indexes that combine the four development outcome indicators to measure the overall effect of different agricultural expenditures and investments. In designing these composite indexes, we again consider both the scale of contribution (effectiveness) corresponding to panels a and c in Figures 7 to 10, and the returns per dollar spent (efficiency) corresponding to panels b and d in Figures 7 to 10 in the previous section.

We first normalize the contribution of each development outcome across different investment options in Figures 11a and 11b. We then turn to the benefit-to-cost ratio of these investment options in Figures 12a and 12b for each development outcome. As in the previous section, investment options are grouped by crop/livestock sector and by investment type. The outcome indicators discussed in the previous section are all normalized individually, with scores ranging from 1 to 0, where 1 is for the most effective or efficient investment option and 0 is for the least effective or efficient investment option.

Figure 11a displays the ranking and scores for the four outcome indicators individually by the contribution of the expenditures associated with individual crops and livestock (plus several broad agricultural and rural investment categories). Figure 11b displays the scores for the four outcome indicators by investment type. In both figures, if an investment option offers the greatest contribution to GDP, employment, poverty reduction, or diet quality improvement, the score for this investment option is valued at 1.00. In Figure 11a, vegetables thus receive a score of 1.00 for GDP, poverty, and diet quality effects; this implies that investments related to vegetables contribute the most to GDP growth, poverty reduction, and diet quality improvement when compared with other options. Similarly, small-scale irrigation earns a score of 1.00 for GDP, poverty, and diet quality effects; this indicates that small-scale irrigation investment contributes the most to these three development outcomes when compared to other investment options.

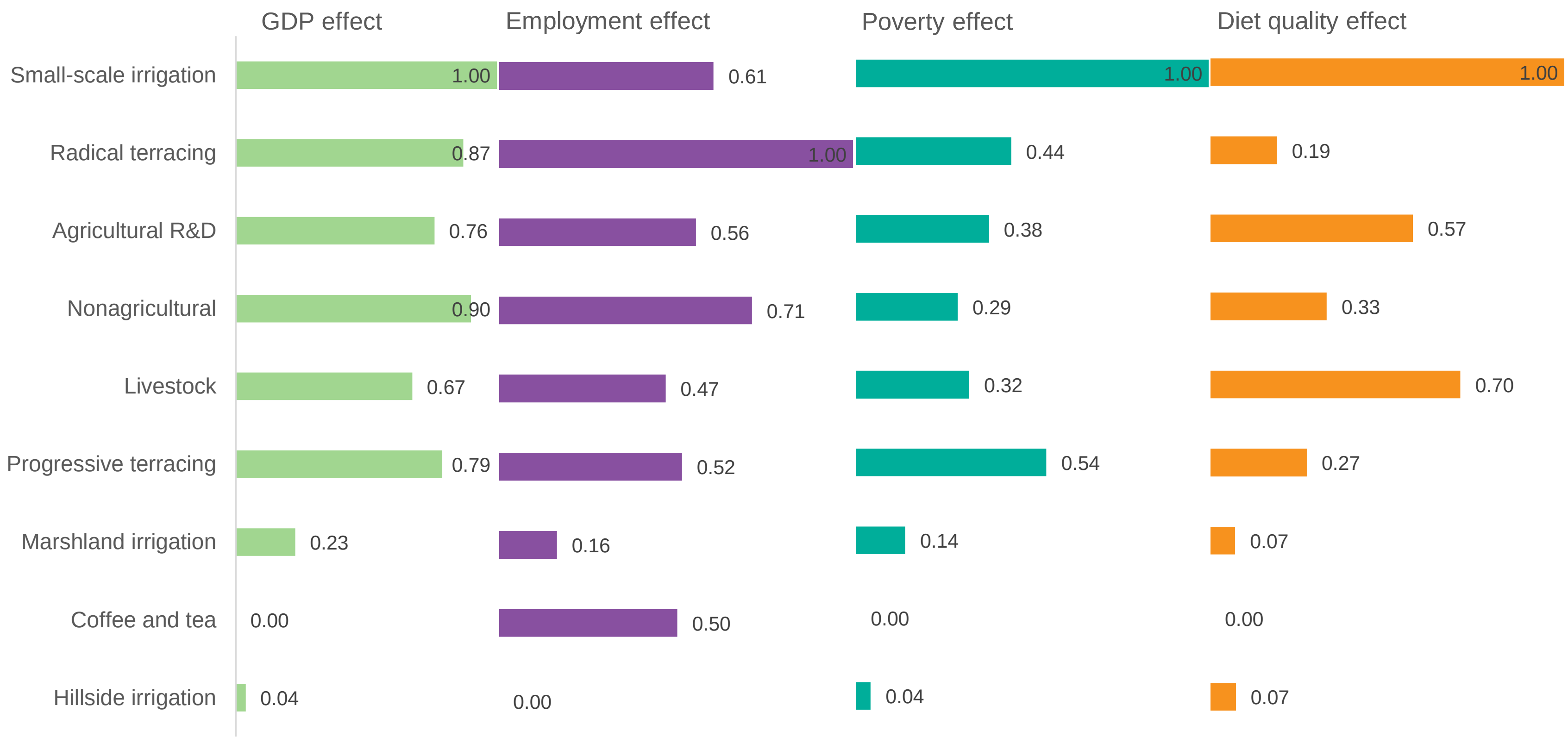
As discussed in the previous section, for any given investment option, the scale of its contribution to a development outcome is determined by the size of the associated sector and the scale of investment in that sector. A larger sector or a sector enjoying more investments usually makes a larger contribution to a development outcome. The normalized scores in Figures 11a and 11b reflect this fact. It is not always the case, however, that a large sector or a sector enjoying more investment consistently has the highest score for all four development outcomes. In Figure 11a, for example, vegetables earn the highest score in terms of GDP, poverty, and diet quality effects, but not in terms of employment effect; for the latter, livestock takes the top position. This is also the case for small-scale irrigation in Figure 11b, which ranks at the top for three of the four outcome indicators but not for employment effect; there, investment in radical terracing ranks highest.

Figure 11a: Normalized outcome scores by spending on crops, livestock, and infrastructure, based on their contribution to development outcomes



Source: Rwanda-RIAPA model.
Note: RTBs = roots, tubers, and bananas.

Figure 11b: Normalized outcome scores by investment type, based on contribution to development outcomes



Source: Rwanda-RIAPA model.
Note: Agricultural R&D refers to both crop and livestock R&D

Figures 12a and 12b turn to the normalized score of the four outcome indicators as returns per $1,000 that are spent on different investment options. Figure 12a displays the scores and rankings for the four individual outcomes by the efficiency of the expenditure or investment, that is, returns per $1,000 of spending. Figure 12b displays their scores for the different types of investment.

In Figure 12a, we observe that Irish potatoes rank at the top with a score of 1.00 for their GDP effect; this means that for each $1,000 spent, Irish potatoes increase GDP more than any other expenditure or investment on other crops, livestock, or broader agricultural and rural development activity. Meanwhile, coffee and tea rank highest, with a score of 1.00 for their employment effect; that is, for each $1,000 spent, coffee and tea create more jobs than other expenditures or investments. Similarly, in Figure 12b, small-scale irrigation ranks highest for both GDP and poverty effects, with a score value of 1.00; that is, small-scale irrigation investment is the most efficient per dollar spent in terms of increases in GDP and jobs when compared to other expenditure or investment options.

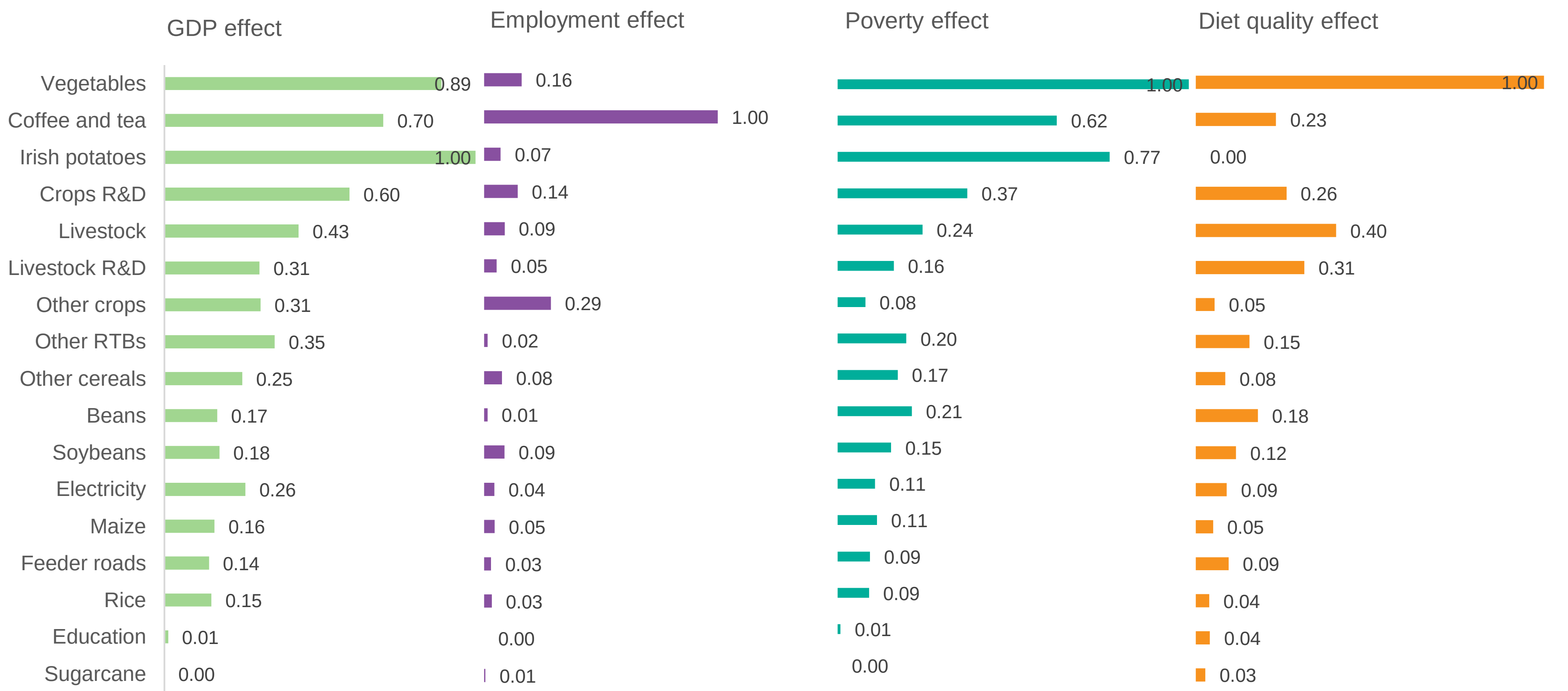
Consistent with our earlier discussion, Figures 12a and 12b reiterate the findings presented in the previous section. By sector, for example, vegetables are the most effective in reducing poverty and improving diet quality, achieving the highest score in Figure 12a. This sector is less effective in improving employment opportunity at the economywide level, however, with a score value of only 0.16; this can be attributed to the limited processing in the downstream sectors and the non-tradability of most vegetables, which result in labor shifting away from the sector itself as productivity improves. Coffee and tea rank highest in terms of their employment effect, while their impact on diet quality improvement is rather limited, with a score value of 0.23. As tradable crops, coffee and tea have strong employment effects; this suggests that promotion of export agriculture can be a potentially strong driver behind efforts to tackle unemployment. Investment or spending on sugarcane, by contrast, consistently ranks among the lowest across the four development indicators, indicating that spending associated with the sugarcane sector is possibly the least efficient investment available

Figure 12b reports the normalized scores and rankings of different investment types by their relative cost-effectiveness in jointly achieving the four development outcomes. Small-scale irrigation ranks at the top with the highest score for three of the four outcome indicators, although its employment effect is limited relative to other investment types. Investments in coffee and tea also take a top position, although their diet quality effects are relatively low. Livestock sector investments and agricultural R&D spending consistently rank high in terms of cost-effectiveness, with similar scores for each outcome indicator.

Figures 11a, 11b, 12a, and 12b demonstrate the differential effects of a given investment option on the four different development outcomes. By comparing Figures 11a and 11b with Figures 12a and 12b, we observe a clear divergence between the effectiveness and efficiency of a given investment option in terms of its joint development outcomes. While an investment option can show a strong effect on one outcome in terms of either effectiveness or efficiency, there is no single investment option that generates the highest effect for all four development outcomes. This is a basic illustration of the trade-offs that commonly exist across different development outcomes that are targeted by a given investment choice or a portfolio of investment choices.

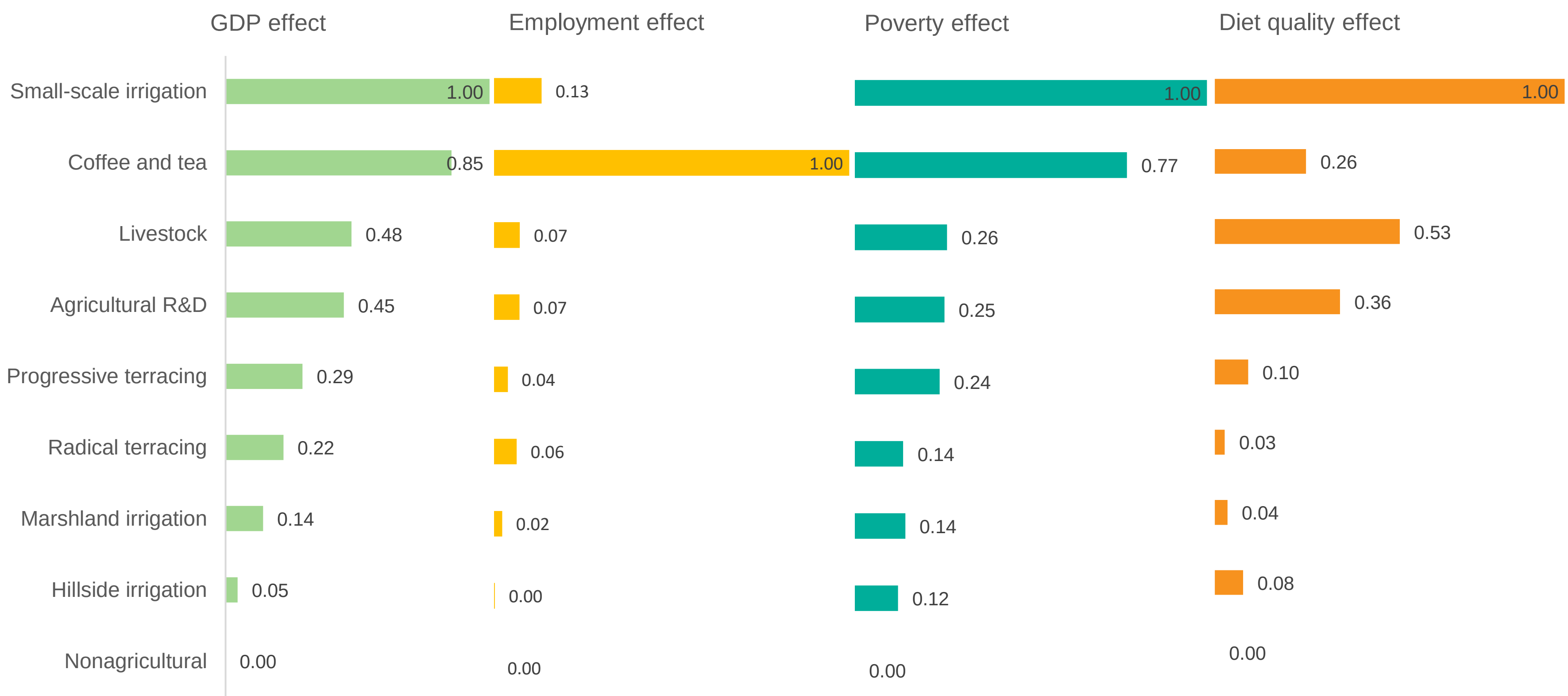
It seems unlikely for an investment option to be simultaneously dominant in both effectiveness and efficiency in terms of achieving our four development outcomes; policymakers are nonetheless required to make an investment decision that aims to achieve the maximum possible impact. For this purpose, it may be useful to have a single composite index that combines the different development outcome indicators. Based on the normalized scores provided in Figures 11 and 12, we develop two composite indexes to combine the scores generated for the four development outcomes; in doing so, we assign equal weights to the outcomes. Of course, the weights can also be adjusted to create alternative composite indexes, depending on the preferences of policymakers.

Figure 12a: Normalized outcome scores by spending on crops, livestock, and infrastructure, based on the benefit-to-cost ratio



Source: Rwanda-RIAPA model.
Note: RTBs = roots, tubers, and bananas.

Figure 12b: Normalized outcome scores by type of investment, based on the benefit-to-cost ratio

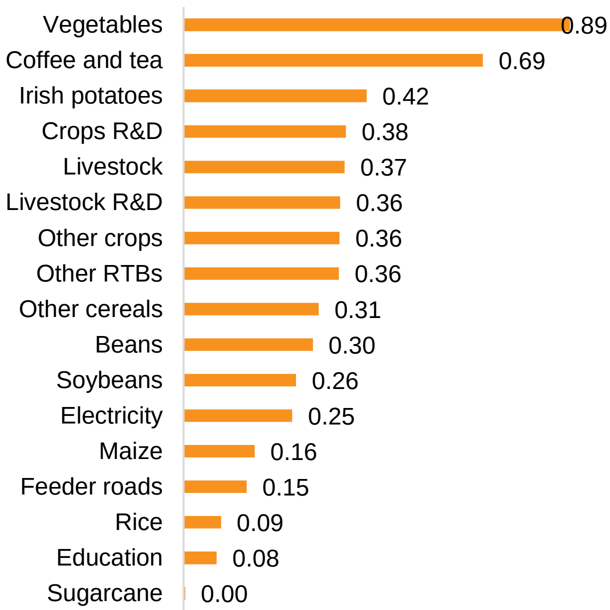


Source: Rwanda-RIAPA model.
Note: Agricultural R&D refers to both crop and livestock R&D.

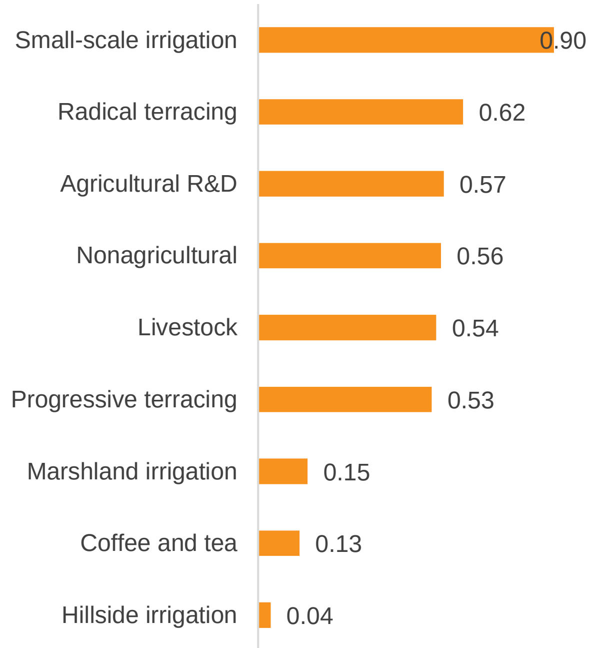
In Figure 13 the composite scores combining the four development outcomes are reported for different investment options, while Figure 14 provides these composite scores of investment options in terms of efficiency in the benefit-to-cost ratio. For each figure, there are two panels: (a) ranking by spending on crops, livestock, and infrastructure, and (b) ranking by investment type.

Figure13: Composite scores combining the four development outcome indicators from different investment options (equal weight for each outcome indicator)

13a) Ranking by spending on crops, livestock, or infrastructure



13b) Ranking by investment type



Source: Rwanda-RIAPA model.
Note: RTBs = roots, tubers, and bananas; agricultural R&D refers to both crop and livestock R&D.

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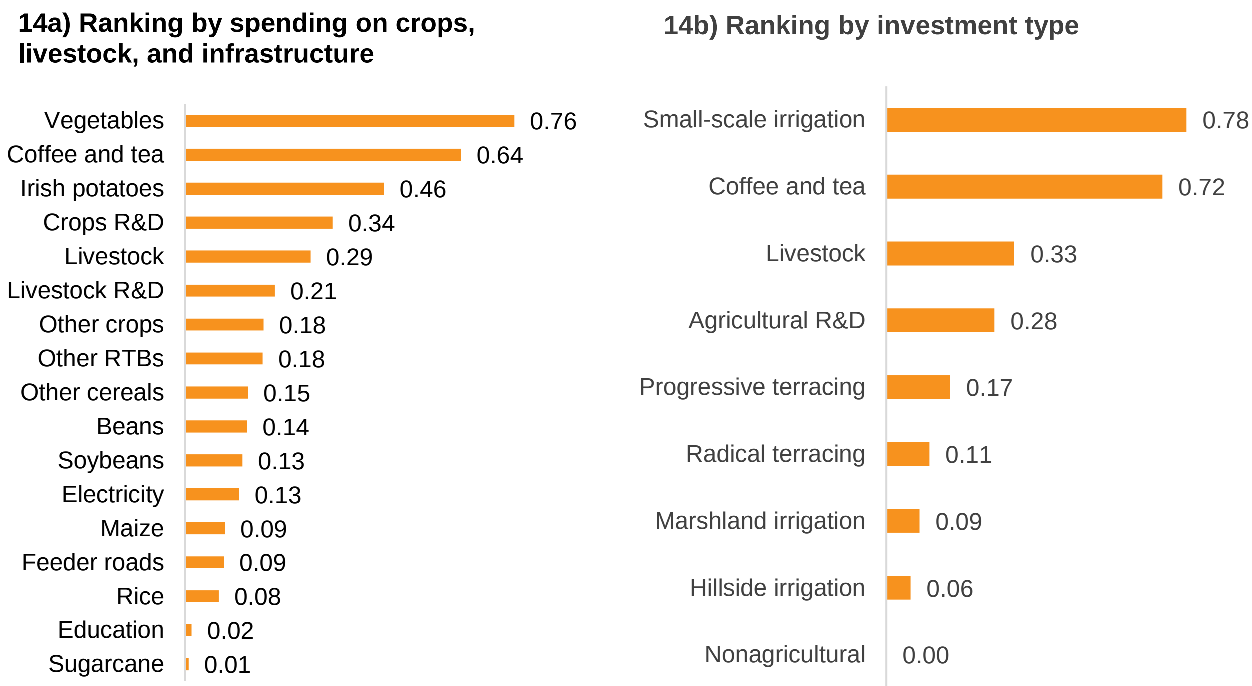
Figure 14: Composite scores combining the four development outcome indicators from different investment options' benefit-to-cost ratios (equal weight for each outcome indicator)



Source: Rwanda-RIAPA model.
Note: RTBs = roots, tubers, and bananas; agricultural R&D refers to both crop and livestock R&D.

The first and most obvious finding here is that there is no single investment option with a score of 1.00 in either Figure 13 or Figure 14; this indicates that none of the investment options have a clearly dominant contribution to all the four development outcomes.

The second finding is that the ranking is consistent for Figure 13a and Figure 14a, but not for Figure 13b and Figure 14b. We start by examining the "a" panel in both figures. Our results indicate that investments associated with vegetables generate the highest score in figures. While investments associated with coffee and tea are relatively low in terms of public spending, they rank the second largest and the most efficient outcomes in both figures, followed by investments associated with Irish potatoes in the third position. These three top-ranked crops are highly tradable high-value products in domestic or export markets, indicating the importance of developing value chains for high-value agriculture in public investment prioritization.

Spending on crop R&D, livestock inputs and extension (combined), and livestock R&D rank fourth, fifth, and sixth, after these three high value crops. This indicates the importance of R&D spending and livestock sector development to the achievement of broad development outcomes. Sugarcane consistently ranks at the bottom in Figures 13a and 14a, while rice is positioned at third from the bottom. These two crops dominate investments in irrigated marshland development, and both are targeted by the country's agricultural import substitution strategy; however, their contribution to development outcomes and their investment efficiency are not particularly encouraging when compared to other options because of the high unit cost in marshland development.

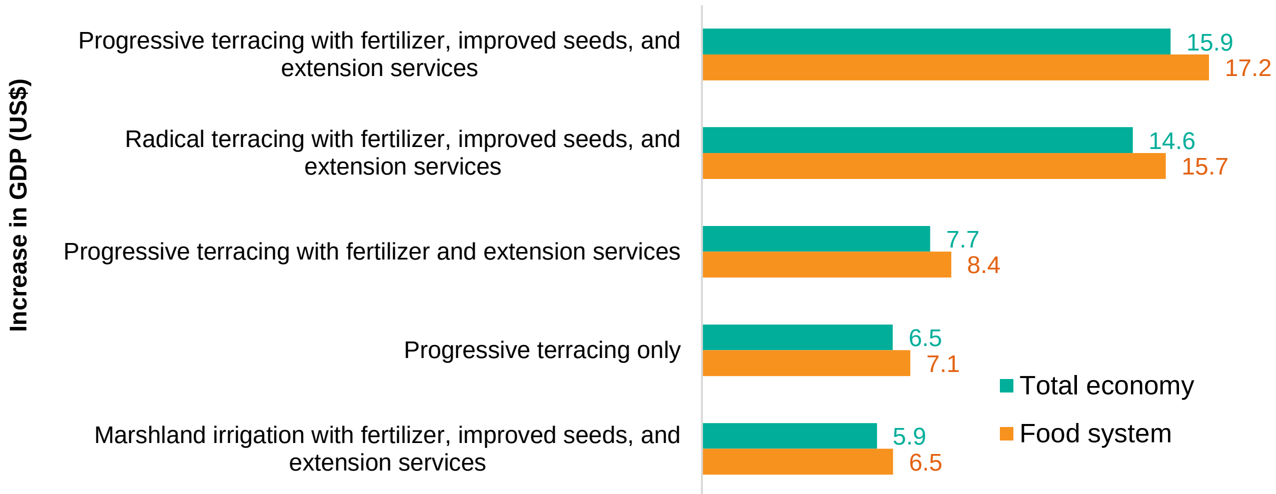
We next examine Figures 13b and 14b. Results shown in these two figures are not consistent in terms of how they rank the different types of investment. Small-scale irrigation consistently ranks highest in both figures, with a score value much higher than the investment option just below it in second place. This is most visible in Figure 14b, indicating that small-scale irrigation investments are clearly important to the achievement of broad development outcomes relative to other options. On the other hand, hillside irrigation ranks either at the bottom (Figure 14b) or near the bottom (Figure 13b), alongside marshland irrigation. The contrasting position in the ranking found in Figures 13b and 14b between small-scale irrigation and marshland/hillside irrigation should not necessarily indicate that the latter investments are undesirable; rather, they highlight the importance of looking for lower-cost approaches in developing irrigation systems. The same is true for investments in terracing. Indeed, investments in both irrigation and terracing are important to Rwanda in the long run for the purposes of sustainable agricultural development, environmental protection, and resilience to climate change. Experiences with lower-cost solutions in irrigation and terracing from other countries, particularly Asian countries with similar geographies and agroclimatic conditions, may be instructive.

Budget reallocation for improving effectiveness of agricultural expenditures

More than 60 percent of Rwanda's farmland is located on fragile hillsides. In such environments, terracing is possibly one of the most important interventions in soil, water, and land management. It is effective not only in improving on-farm productivity in the short run; in the longer run, it can also control soil erosion and protect against environmental degradation. Two types of terracing have been promoted in Rwanda: progressive and radical. The public investment cost of progressive terracing is much lower than that of radical terracing; as such, more than 900,000 hectares (ha) of farmland are under progressive terracing in the country, as compared to only about 100,000 ha under radical terracing. In the context of information drawn from seasonal agricultural surveys and EICV5, this indicates that, for many crops, farmland under progressive terracing exceeds farmland on which modern inputs (particularly improved seeds) are in use. As shown in Table 3b, farmland on which inorganic fertilizer and improved seeds are being used and where the farmer has access to extension services accounts for about 42 percent for maize, but is as low as 5 percent for beans, and 27 percent for Irish potatoes, with the figures for many other crops falling within this range. We observe from our data synthesis that 38.5 percent of maize farmland that is under progressive terracing is cultivated without the use of modern inputs, and more than 50 percent of Irish potato farmland under progressive terracing does not jointly use inorganic fertilizer and improved seeds, or even fertilizer alone. For crops such as soybeans, coffee, and tea, which are not cultivated on progressive or radical terraces, inorganic fertilizer use exceeds use of improved seeds.

In this subsection, we take these situations as examples to assess whether budget reallocation at the margins can help improve the effectiveness of overall public spending on agriculture. Specifically, without increasing total agricultural spending, we consider the impact of encouraging farmers on a range of options, including the use of modern inputs on all progressive terraces, the cultivation of soybeans, and the use of modern inputs in the cultivation of coffee and tea.

Figure 15: Increases in total and food system GDP per US$ spent on Irish-potato-related investments

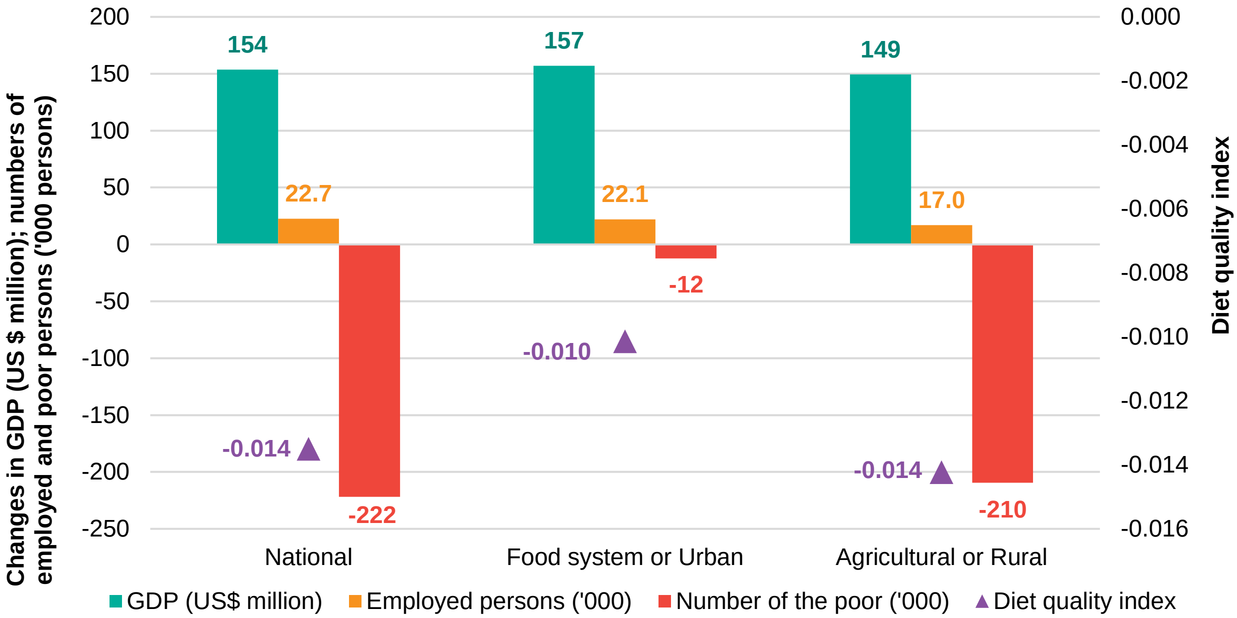


Source: Rwanda-RIAPA model.

Figure 15 uses Irish potatoes as an example to indicate the current gap between progressive terracing with and without modern inputs. This study considers five investment scenarios for Irish potatoes, which are grouped together as Irish-potato-related spending in the previous subsections. Other crops are also explored with multiple scenarios that vary according to the applicability of terracing and irrigation investments. Figure 7b shows that the increases in total GDP and food system GDP are $7.80 and $6.70, respectively, per dollar spent on Irish-potato-related investments. These GDP gains, as reported in Figure 7b, are averaged from the five scenarios shown in Figure 15 and simulated in the model. Figure 15 indicates that gains in GDP from each dollar spent on a combination of progressive terracing and subsidies of modern inputs, together with extension services, are the highest among the five simulations; it further shows that they are much higher than progressive terracing without modern inputs or without improved seeds. A similar situation is true for other crops. Thus, by promoting the combination of modern input use and progressive terracing, returns are expected to increase even with the same level of agricultural expenditure.

Figure 16 shows results from a marginal reallocation of the current budget. The reallocation without increasing total spending focuses on input subsidies targeting the crops grown on already developed progressive terracing but with less adoption of modern inputs, particularly improved seeds. The reallocation also considers soybeans and for coffee and tea, which are not normally grown on terraced land; that is, farmers are encouraged to combine the use of fertilizer with improved seeds through the reallocation.

Figure 164: Gains from a marginal reallocation of current agricultural expenditures, 2018-2024



Source: Rwanda-RIAPA model.

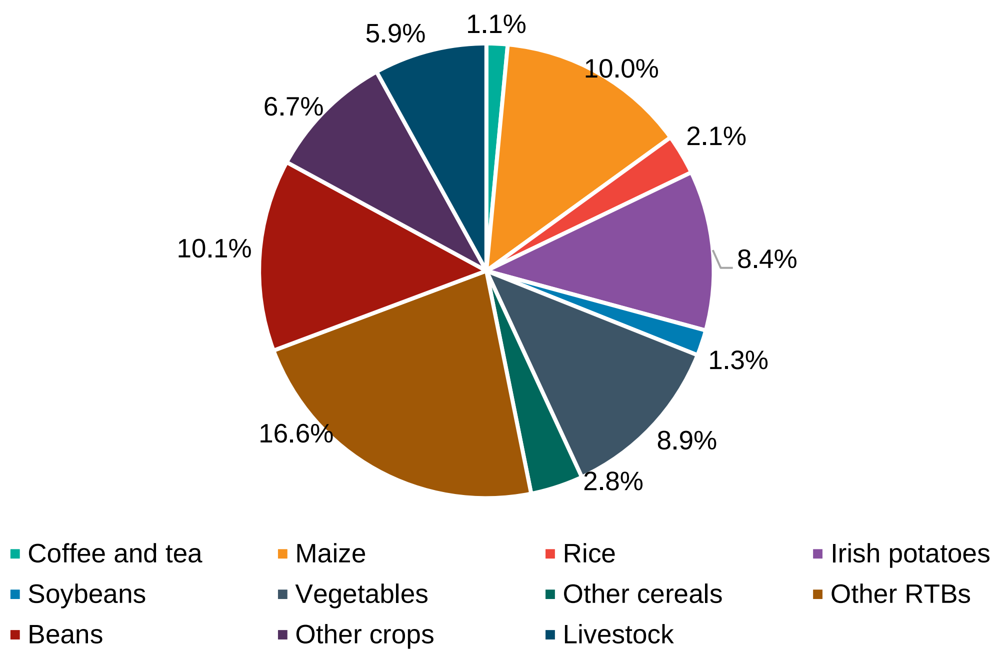
As shown in Figure 16, with just a modest reallocation of current spending, significant benefits are expected to be generated for all four development outcomes. Over the seven years between 2018 and 2024, GDP is expected to be $154 million higher for the national economy, $157 million higher for the food system, because the reallocation seems to benefit the food system more than it does the rest of the economy, particularly for agriculture with the sector's GDP expected to be $149 million higher than under the current allocation in the period of 2018-2024. During the same period, employment is expected to increase by 22,700 jobs for the total economy and 17,000 for agriculture. It is projected that, nationally, the number of poor will be 222,000 less than under the current allocation; of this total, 210,000 rural poor and 12,000 urban households will be lifted out of poverty. Diet quality also improves, particularly among rural households. These encouraging results indicate that there is room to increase returns with only limited expenditure of public resources. Figure 16 is just an example of such reallocation, demonstrating the Rwanda-RIAPA model's capacity for handling multiple expenditure reallocation scenarios.

If the marginal reallocation is implemented only in the remaining three years of PSTA 4 in 2022-2024, GDP is expected to gain $79 million in 2022–24 when compared to a situation without such reallocation. Approximately 11,000 new jobs would be created in the economy, and 103,000 people would be lifted out of poverty.

Increasing agricultural expenditures under a new allocation portfolio to maximize impact

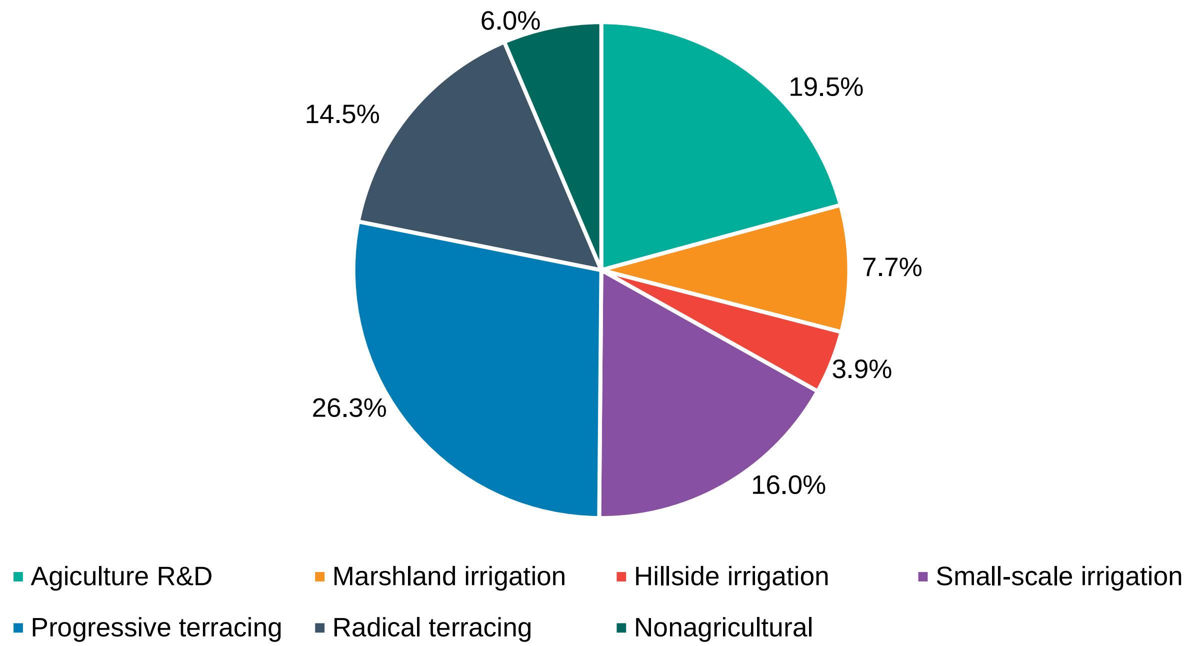
During the first half of the implementation period of PSTA 4 in 2018-2021, budget allocations to MINAGRI have been largely stagnant. The previous subsections, however, emphasize the importance of agricultural expenditure for economic growth and for job creation beyond agriculture, as well as for poverty reduction and diet quality improvement for both rural and urban households. Clearly, an increase in agricultural spending is important for realizing Rwanda's longer-term development goals. In this subsection, we consider a scenario in which agricultural expenditures under PSTA 4 grow by 5 percent annually, implying an additional $170 million in total agricultural spending over the 2018 to 2024 period. We also consider the new allocation for the total budget that is different from the current PSTA 4 allocation. The new allocation emphasizes support for agricultural R&D; investment in small-scale irrigation; promotion of targeted modern inputs for already developed terraces as a package; and increased adoption of new varieties of coffee and tea combined with greater use of inorganic fertilizer and extension services. Figures 17a and 17b present the allocation of the additional agricultural expenditures of $170 million in this scenario, in which, similar to the analysis in the previous subsections, we consider two different perspectives on the new allocation: impacts by crops, livestock, and infrastructure, and by type of investment.

Figure 17a: Allocation of an additional $126 million agricultural budget by crop and livestock production (percent of the total)



Source: Rwanda-RIAPA model.
Note: The remaining $44 million of the $170 million is allocated to agricultural R&D and to nonagricultural rural investments. RTBs = roots, tubers, and bananas.

Figure 17b: Allocation of additional $158 million agricultural budget by investment types (percent of total)



Source: Rwanda-RIAPA model.
Note: The remaining $12 million of the $170 million is for coffee and tea and livestock support, which are not covered by the seven types of investments listed here. Agricultural R&D refers to both crop and livestock R&D.

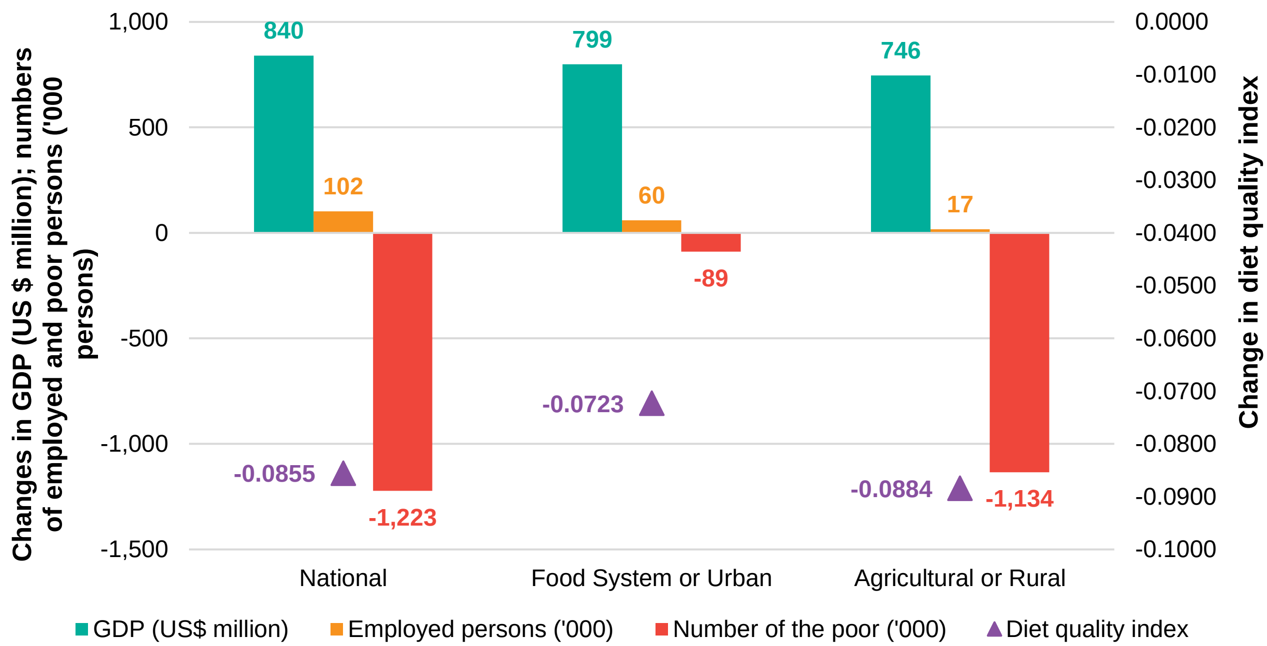
As shown in Figure 17b, 19.5 percent of the additional funds are allocated to crop and livestock R&D, while agricultural R&D accounts for only 8.7 percent of PSTA 4 under the current allocations. Moreover, allocations to small-scale irrigation (16.0 percent) and progressive terracing, with the combination of modern inputs and extension services as a package (26.3 percent), are much more than their current allocations of 5.8 percent and 12.1 percent, respectively. Only limited amounts of additional funds are allocated to the three types of nonagricultural rural development (6.0 percent), while in the current allocation they account for 37 percent.

The preceding sections indicate that returns on investments that benefit vegetables and Irish potatoes are higher than those from many other crops. Under the simulated new allocation with the additional budget, these two crops are further benefited through investments in small-scale irrigation and terracing. About 8.9 percent and 8.4 percent of the additional budget, respectively, are vegetable- and Irish potato-related, while the budget shares under the current allocation are only 4.0 percent and 2.3 percent, respectively. Other RTBs also benefit from the new allocation, which more than doubles their 8.0 percent share in the current PSTA 4 allocation.

Figures 18 to 21 show the impacts of the additional budget with the new allocation on the four development outcomes. Figure 18 highlights the impacts on GDP and employment (for the overall economy, the food system, and for agriculture) as well as reductions in poverty and improvements in the diet quality index during the 2018–2024 period. As shown in Figure 18, following the more efficient allocation suggested in this scenario, the 5 percent additional annual growth in total agricultural expenditures would lead to $840 million additional GDP over the same period than it would be without both the growth in agricultural expenditure and the adjusted budget allocation. Most GDP gains occur within the food system ($799 million), particularly within agriculture ($746 million). Over 102,000 new jobs are expected to be created, of which about 60,000 are within the food system and the other 40,000 are outside of the food system in the rest of the economy. With agriculture becoming more productive—supported by increased and more efficient agricultural spending—only 17,000 new jobs are created within agriculture for an additional $746 million in agricultural GDP.

The poverty reduction effect is impressive over this period, with the number of poor falling by 1.2 million, of which 1.1 million are accounted for by a reduction in the rural poor. The improvement in the diet quality index is also significant in both urban and rural households. Compared with the current allocation, the 5 percent annual growth in agricultural expenditures under the new allocation could help achieve almost 50 percent of the diet quality impact of PSTA 4's total budget, the total of which is more than four times the additional budget.

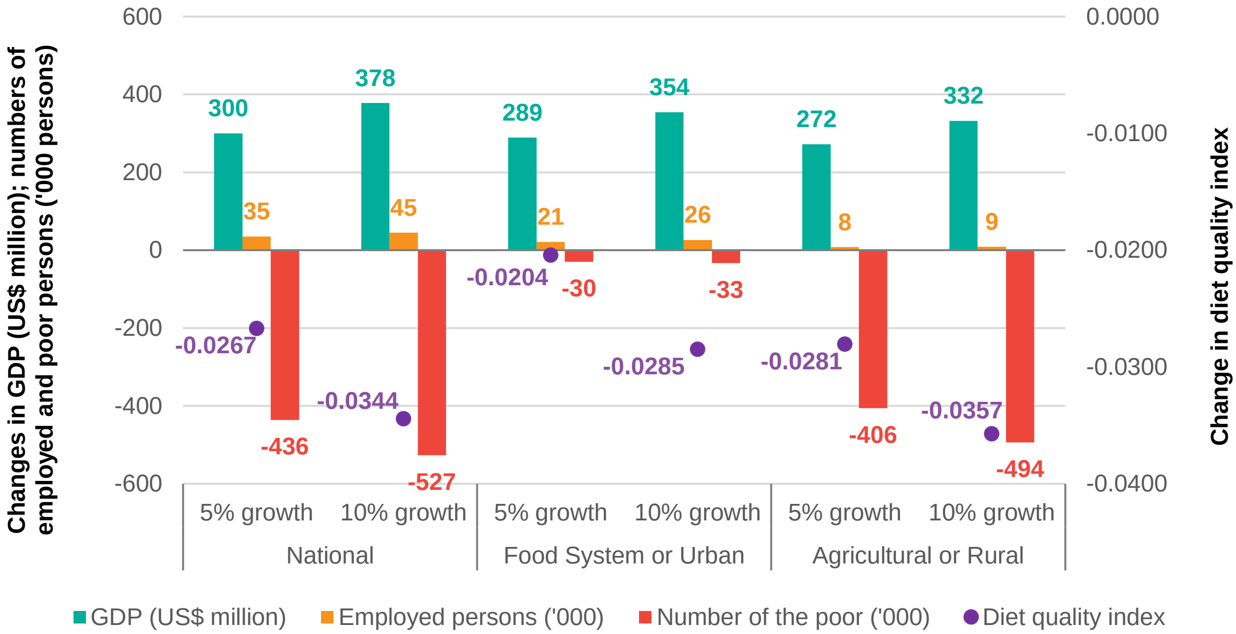
Figure 185: Gains in GDP and employment in the total economy, in the food system, and in agriculture, as well as poverty reduction and diet quality improvement in national, urban, and rural households following from an increase of $170 million in agricultural spending in a new allocation, 2018–2024



Source: Rwanda-RIAPA model.

If the 5 percent annual growth in agricultural expenditures occurs only in the remaining three years of PSTA 4, the increased budget is only about $34 million in 2022-2024. However, gains in GDP are expected to be $300 million in the same period. If annual growth rate in agricultural expenditures rises to 10 percent in these three years, the additional total expenditures amount about $70 million while GDP gains are about $380 million. Other development outcomes are also benefited in 2022-2024 (Figure 19).

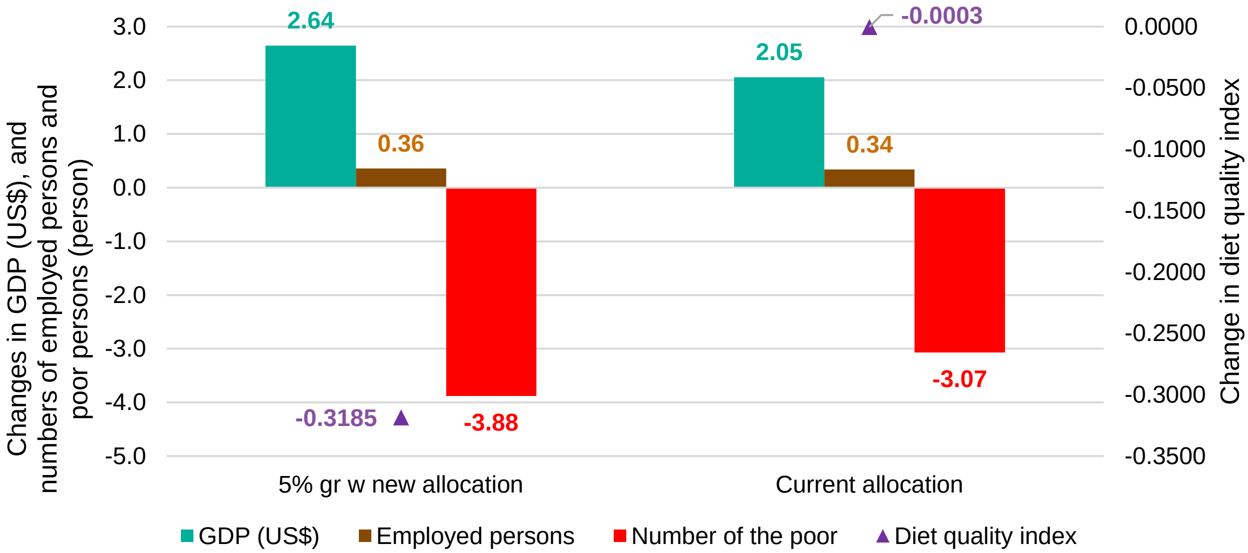
Figure 19: Gains in GDP and employment in the total economy, in the food system, and in agriculture, as well as poverty reduction and diet quality improvement in national, urban, and rural households following from an increase of $34 million and $70 million agricultural expenditures with the new allocation, 2022–2024



Source: Rwanda-RIAPA model

Figure 20 compares the gains in GDP per dollar of spending and the changes in employment, poverty, and diet quality per $1,000 of spending under the current and new allocation. The comparison in Figure 19 indicates a significant improvement in the efficiency of budget allocations. The same amount of spending is expected to generate more impacts on the focal development outcomes. This finding indicates the importance of prioritizing budget allocations to maximize impacts when public resources are limited.

Figure 20: Benefit-to-cost ratios for the 5 percent annual growth in total agricultural expenditures with a new budget allocation vs. the current level of agricultural expenditures and allocation: Increases in US dollar GDP per dollar spent and changes in employment, poverty, and diet quality per $1,000 of spending, 2018–2024



Source: Rwanda-RIAPA model.
Note: '5% gr w new allocation' refers to 5 percent of annual growth in total agricultural expenditure with the new allocation in 2018-2024.

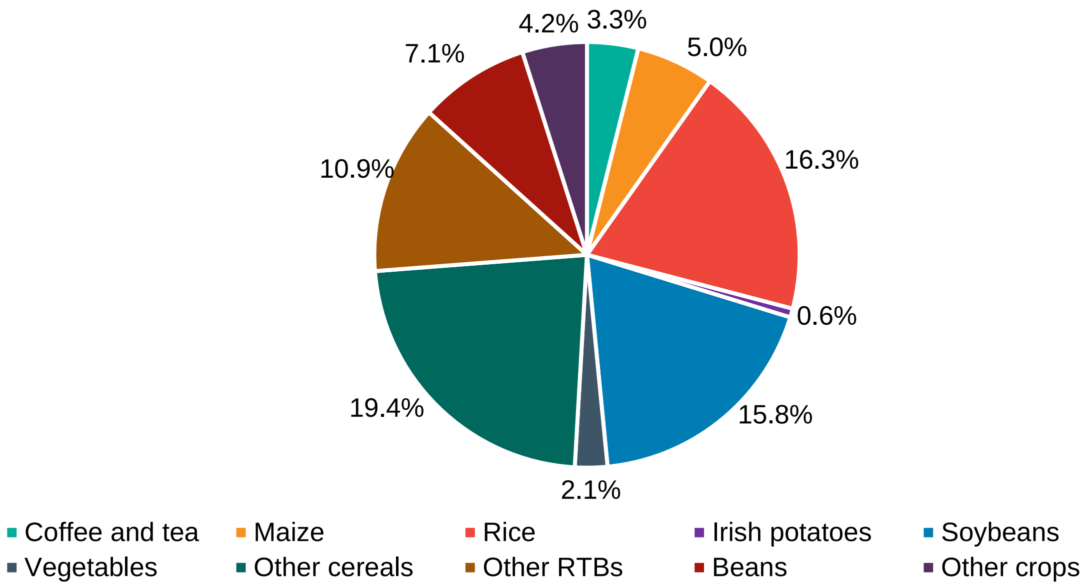
Figures 21 and 22 further measure the impacts of different types of investments on growth and poverty reduction. Specifically, Figures 21a and 21b illustrate the growth effect, while Figures 22a and 22b illustrate the poverty reduction effect.

As indicated in Figure 21b, the largest GDP gains come from additional investment in the promotion of a combination of modern input uses and progressive terracing; this gain in GDP is about 43 percent of total gains, and the expansion of small-scale irrigation accounts for the other 22 percent gain. Recall that in Figure 15a, the investments promoting a combined use of modern inputs with progressive terracing and expansion of small-scale irrigation account for 26.3 percent and 16.0 percent of the new investment, respectively. Figures 17a and 21b jointly indicate the importance of these two types of investment to the stimulation of growth. The new investment in crop and livestock R&D generates more than 13 percent of total GDP gains, which gives it a rank of third in contribution to GDP growth.

In Figure 21a, gains in GDP from additional investments are broken down into their associated crops and livestock production. As expected, Irish potatoes and vegetables are two crops with higher contribution shares in GDP gains. Moreover, putting Figures 17b and 21a together, investments associated with these two crops are highly effective, as such investments account for 8.4 percent and 8.9 percent of total increased investments in Irish potatoes and vegetables, respectively, while generating 16.3 percent and 15.8 percent of total gains in GDP, respectively. Investments associated with other RTBs have the largest share both in the increased budget (16.6 percent, see Figure 17b) as well as the total gains in GDP (19.4 percent, see Figure 20a).

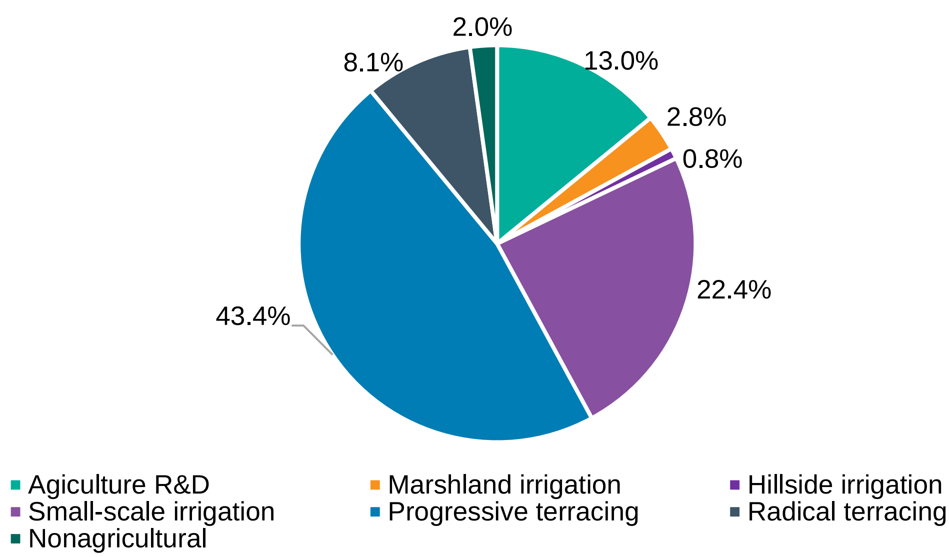
Figures 22a and 22b turn to the contribution of additional expenditures on crops and livestock to the reduction of poverty, with a breakdown by investment type. Again, investments associated with Irish potatoes and vegetables consistently rank at the top on their poverty reduction effects, and this effect is generally stronger for vegetable-related investment (Figure 22a). Similarly, the contribution to GDP from the promotion of a combination of modern inputs, progressive terracing, and expansion of small-scale irrigation consistently ranks at the top, while agricultural R&D ranks third (Figure 22b).

Figure 21a: Contributions to a GDP gain of US$690 million from additional investments in various crops and in livestock production, 2018–2024



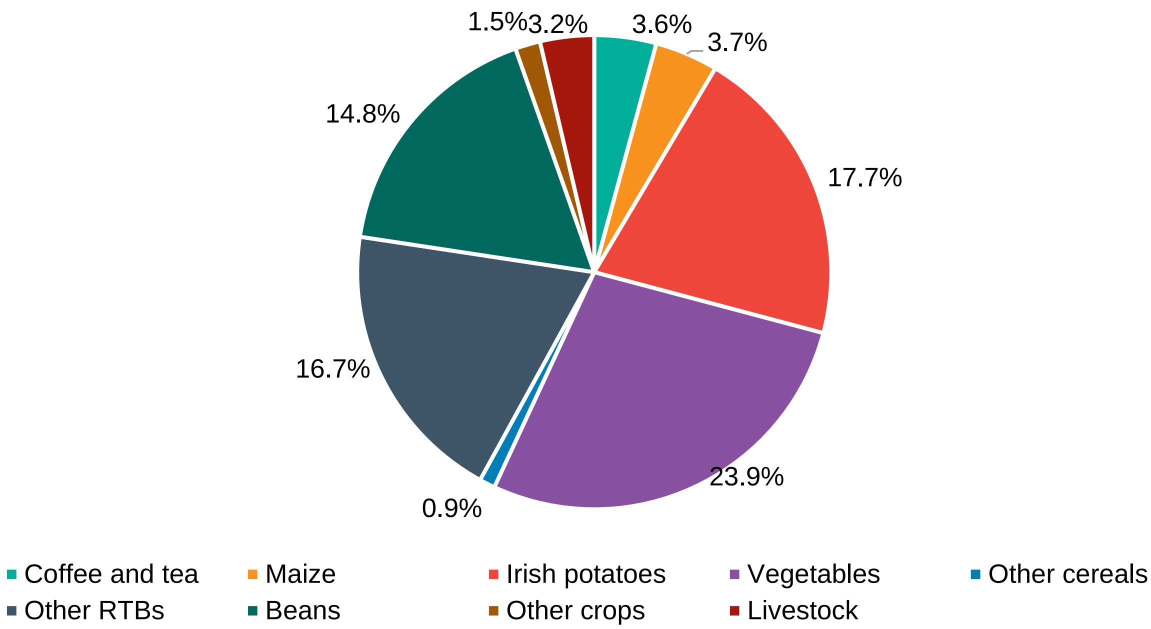
Source: Rwanda-RIAPA model.
Note: The remaining $150 million GDP gain is associated with agricultural R&D and rural nonagricultural investments. RTBs = roots, tubers, and bananas.

Figure 21b: Contribution to GDP gains of US$ 752 million from different types of additional investments, 2018–2024



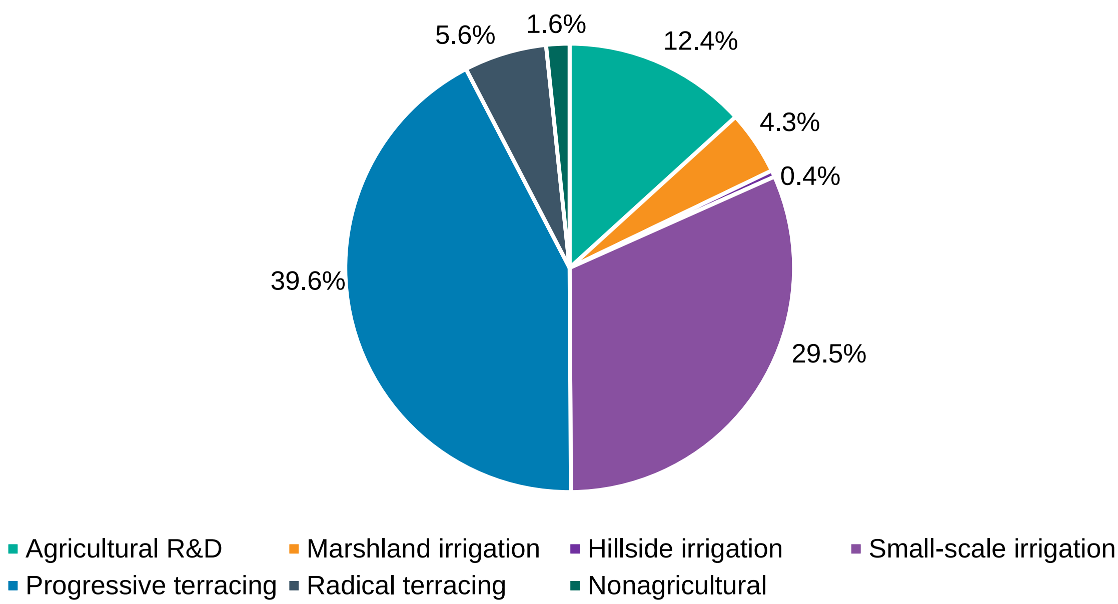
Source: Rwanda-RIAPA model.
Note: The remaining $90 million GDP gain is associated with livestock expenditures and with coffee and tea expenditures that are not covered by the seven types of expenditures shown in the graph. RTBs = roots, tubers, and bananas; agricultural R&D refers to both crop and livestock R&D.

Figure 22a: Contribution to a 1.15 million persons decline in poverty reduction from additional investments associated with different crops and livestock production, 2018–2024



Source: Rwanda-RIAPA model.
Note: The additional 90,000 decline in the number of poor persons is associated with agricultural R&D and rural nonagricultural investments. RTBs = roots, tubers, and bananas.

Figure 22b: Contribution of different types of additional investments to poverty reduction, 2018–2024



Source: Rwanda-RIAPA model.
Note: RTBs = roots, tubers, and bananas; agricultural R&D refers to both crop and livestock R&D.

CONCLUSIONS AND FUTURE DIRECTIONS

Public investment prioritization is always challenging when governments design ambitious agricultural strategies and then allocate limited public resources. As such, data-driven and evidence-based approaches to public policy, investment, and expenditure prioritization are critical to making informed decisions about development plans in a constrained fiscal environment. By focusing on economic growth, employment creation, poverty reduction, and diet quality improvement—all of which are central to the economic transformation process—the modeling exercise conducted here generates new insights into alternative scenarios, tradeoffs, and synergies that are designed to achieve optimal outcomes under constrained conditions. The aim of this exercise is to assist the Government of Rwanda and its development partners in prioritizing limited public resources in order to maximize the realization of national development goals.

Among the different types of public investments and expenditures, returns often differ not only in terms of cost-effectiveness, but also in terms of their impacts on multiple development outcomes. By linking growth and development outcomes with different types of agricultural investments and expenditures across different agricultural sectors or broad categories of intervention, the RIAPA model results provide options to the government's decision-making processes in terms of its immediate and longer-term agricultural budget allocations.

The simulation analysis shows that each US dollar of agricultural spending is associated with a $2.05 gain in GDP in 2018–2024. The total gains in seven years are $1.57 billion, of which, $1.17 billion is gain in agricultural GDP while $0.18 billion and $0.22 billion are gains in off-farm economic activities that are situated within and outside the food system, respectively. According to the RIAPA model, agricultural expenditures are expected to contribute an additional 1.6 percentage points of GDP growth in 2018 and an additional 0.4 percentage points of growth in 2019. These expenditures contribute significantly to the food system and to agricultural GDP growth in both years. In 2020, as GDP declines due to the unprecedented shocks from the COVID-19 pandemic, agricultural expenditures help ease some of the difficulties faced by the economy, making the fall in GDP growth less than it would have been without the agricultural expenditures.

Agricultural spending also creates jobs that are mainly outside agriculture while reducing the number of on-farm rural workers when agricultural productivity increases, allowing many rural workers to move into nonfarm activities without lowering agricultural production. This is an important factor in the transformation of the rural economy. Agricultural expenditures under PSTA 4 are also seen to have a strong poverty reduction impact, lowering the number of poor by 2.34 million in 2018–2024. The agricultural expenditures can improve diet quality, with diet quality impact being particularly strong among urban households.

The analysis of the decomposition of agricultural expenditures aims at identifying more effective or efficient types of spending on different agricultural sectors or types of investments. The analysis clearly shows the existence of trade-offs between effectiveness and efficiency in the allocation of agricultural expenditures. The larger sectors that received more support in terms of government spending or that benefited more from investment in irrigation or terracing generally make a larger contribution to economic growth and other development outcomes. Investing in these sectors, however, is not necessarily more efficient, while investments in some small sectors can be highly efficient even though they are unlikely to contribute significantly to growth and development outcomes. Allocation of limited public resources needs to consider both these factors.

The decomposition analysis also finds that the current budget allocation under PSTA 4 is generally effective for economic growth, employment, poverty reduction, and diet quality improvement. Investments that are more important in the budget allocation of PSTA 4 often have larger impacts on growth and other development outcomes; many of these investments are also generally more efficient in terms of returns per unit of spending. Investments that specifically target vegetables and Irish potatoes often have large impacts with relatively high returns per unit spent. An exception to this is the impact on employment, with investments in vegetables and Irish potatoes showing a smaller effect on employment than do investments targeting many of the other sectors. Investment in Irish potatoes performs particularly badly on diet quality improvement. Sugarcane is a sector with less-efficient investments because of its dependency on irrigation and its long growing period. These make scarce irrigated land much less efficient than if other crops are grown there which have multiple growing seasons per year. Among different types of investments, small-scale irrigation consistently generates a larger impact and higher efficiency in terms of returns per dollar spent.

The decomposition analysis by different types of investments/spending is grouped at the agricultural sector level or by type of investment; this potentially overlooks the improvements that may come from allocating investment within a sector. Many food crops grown on progressive terraced farmland still did not use modern inputs or even improved seeds, which possibly lowers returns from costly infrastructural investments. Modest reallocation of given public resources is expected to generate larger impacts.

Progressive terracing has already covered a large portion of hilly farmland. Terracing is an important investment, not just for increasing yield in the short term but also for controlling soil erosion and protecting the environment for sustainable agricultural practices and growth in the longer term. Not all terraced land uses modern inputs, however, particularly improved seeds. Since the country has already invested in terracing, subsidies targeting farmers to apply improved seeds together with fertilizer for crops grown on already developed terracing land are expected to improve returns from terracing investment. This is also true for crops such as soybeans that are not suitable for hilly land or crops such as coffee and tea that are not beneficiaries of terracing investment, where the rate of adoption of improved seeds and modern varieties is lower than the adoption rate of fertilizer. Fertilizer subsidies combined with interventions encouraging farmers to adopt improved seeds could improve the returns to the spending. By an adjustment at the margins of current spending allocation, the simulation analysis shows that the current level of budget spending can significantly improve its effectiveness. GDP can increase by $154 million nationwide over 2018–2024, with an even higher rate of growth in the food system than in the country overall. Employment also increases by 22,700 for the total economy and by 17,000 for agriculture. Nationally, the number of poor is expected to be 222,000 less than under the current allocation, with most additional poverty reduction occurring in rural areas. The reallocation at the margins also improves diet quality, particularly among rural households. If the reallocation occurs in the remaining three years of PSTA 4, the gains in GDP are expected to be $79 million in 2022-2024.

The modeling results show that no single expenditure option is the most effective or efficient in achieving all four development outcomes, and trade-offs commonly exist across different development targets. To help policymakers identify options for achieving marked progress across all outcomes jointly, a single composite index is generated to combine scores with equal weights for the four outcome indicators. Of the sectors analyzed, the high value crops (including vegetables, coffee and tea, and Irish potatoes) rank at the top with the highest composite scores; this suggests that supporting high value agriculture through increased investments in value chain development would help the country achieve broad development outcomes faster than focusing on many agricultural value chains. From the angle of type of investment, small-scale irrigation ranks at the top, with the highest composite score both in its contribution to development outcomes and in the cost-effectiveness of the investment. Hillside irrigation and marshland development, on the other hand, rank close to the bottom, with lower scores than many other types of investment. The contrast between small-scale irrigation investment and marshland/hillside irrigation investment in terms of the ranking of their respective contributions to development outcomes and their cost-effectiveness indicates how important it is for Rwanda to search for low-cost irrigation investment approaches to achieving larger impacts when public resources are limited. This is also true for terrace investment.

The budget reallocation analysis considers a marginal redistribution of the current budget across the modeled spending options. It indicates that there is room for increasing returns from the existing budget under public resource constraints. The Rwanda-RIAPA model is a useful tool that can be used by MINAGRI and by other government ministries; it can help to further improve resource allocation in a constrained economic environment in order to achieve better development outcomes, and it can assess areas of focus for agricultural investment when funds are scarce and when new monies are available.

This paper emphasizes the importance of agricultural expenditure for growth and job creation beyond agriculture, and poverty reduction and improvements in diet quality both for rural and urban households Agricultural budget allocations are particularly important during the current 2018–2024 PSTA 4 period as total allocations to MINAGRI have been stagnant—and even declined—when measured in constant prices. Increasing agricultural expenditures is important to the Government of Rwanda's achievement of its longer-term development goals. Our estimates indicate that if agricultural expenditures can grow 5 percent per year and when additional public funds are disproportionately allocated to key priorities, higher returns can be realized than with the current level of spending with the current allocation portfolio in terms of key development outcomes. Priority areas include crop and livestock R&D; small-scale irrigation; terracing with the adoption of modern inputs and extension services as a package; and improved coverage of coffee and tea production with modern inputs and extension services. With agricultural expenditures growing 5 percent annually, total expenditures would be $170 million more than current budget in 2018–2024. Together with a reallocation of the spending, the additional GDP could be as high as $840 million in 2018-2024. Each US dollar of agricultural spending is expected to generate $2.64 in GDP under the new allocation, while in the current allocation portfolio the GDP gains are only $2.05. If the 5 percent of growth in agricultural expenditures occur in the remaining three years of SPTA 4, GDP gains are $300 million against just $34 million additional spending in 2022-2024. If the growth rate rises to 10 percent in the spending and increased spending is about $70 million, GDP gains are about $380 million in 2022-2014.

Ultimately, this exercise also demonstrates how the Rwanda-RIAPA model can be used for future planning of public resource allocations. This includes covering several topics not addressed directly in the current exercise, for example the potential impacts of specific policy reforms that are designed to make public spending more efficient. More importantly, policy reforms aimed at improving the enabling environment for the private sector can increase incentives for private sector investing in, and for, agriculture, including investments by farmers. Thus, in future studies of policy impacts, the RIAPA model can be used to investigate the synergy between policy reforms and public spending and to assess the viability of alternative budget allocations to maximizing impacts.

Looking to the future, there is scope to further strengthen and expand the application of the economywide modeling tool described here. Better data on coverage, costs, and other key parameters for Rwanda will enable continuous improvement of estimated impacts. Design and exploration of alternative allocation scenarios will inform future planning efforts. Taken together, these efforts will enable the government and its development partners to address many of the pressing questions and difficult decisions they face in prioritizing public policies, investments, and expenditures for a sustainable and inclusive agricultural transformation in Rwanda.

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APPENDIX

Table A1: Sectoral classification in the 2017 Rwanda social accounting matrix (SAM)

Agriculture (29)	Industry (23)	Services (11)
Maize	Natural gas	Wholesale and retail trade
Sorghum	Other mining and quarrying	Transport and postal services
Rice	Meat and meat products	Hotels and restaurants
Wheat	Prepared and preserved vegetables	Telecommunications
Other cereals	Animal and vegetable oils and fats	Financial services
Beans	Dairy products	Rental and other real estate
Groundnuts	Grain mill products	Other business services
Cassava	Other manufactured food products	Public administration and defense
Irish potatoes	Soft drinks and alcoholic drinks	Education
Sweet potatoes	Tobacco products	Human health activities
Other roots and tubers	Textiles, clothing, and leather products	Other service activities
Vegetables	Wood, paper, and related products	
Sugarcane	Coke and refined petroleum products	
Tobacco, raw	Chemicals and chemical products	
Soybeans	Pharmaceutical products	
Bananas	Nonmetallic mineral products	
Fruits	Metals and metal products	
Tea	Machinery and equipment	
Coffee	Transport equipment	
Pyrethrum	Other manufacturing	
Other crops	Electricity, gas, and steam	
Cattle	Water collection, treatment, and supply	
Milk	Construction	
Poultry		
Eggs		
Small ruminants		
Other livestock		
Forestry		
Fishery products		

Source: Social accounting matrix developed jointly by IFPRI, MINECOFIN, and NISR. See Aragie (2021b) for details.

Table A2: Budget allocation under PSTA 4, 2018–2024

Budget item	US$ million	Share of identified allocation (percent)
Fertilizer subsidy	7.0	6.3
Seed subsidy	1.9	1.7
Crop extension	8.1	7.4
Artificial Insemination and animal breeding	2.8	2.6
Animal health	2.2	2.0
Animal feed	0.2	0.1
Livestock extension	3.1	2.8
Crop R&D	3.5	3.2
Livestock R&D	6.1	5.5
Marshland irrigation	5.9	5.4
Hillside irrigation	4.7	4.3
Small-scale irrigation	5.9	5.4
Progressive terracing	4.6	4.2
Radical terracing	13.4	12.3
Feeder roads	9.1	8.3
Rural education	23.7	21.7
Rural electricity	7.6	7.0
Others	18.4	
Total identified allocation	109.5	100.0
Total	127.9	

Source: Authors' calculation from MAFAP's public expenditure data on Rwanda (MAFAP 2021). Where appropriate, the expenditure data is computed as a three-year average (2016-2018) to avoid outlier values and create a "stable" baseline. The budget on rural education is estimated using data from the Ministry of Education on the number of students (primary) (Rwanda, Ministry of Education 2019) and data from the World Bank (2021b) on education expenditure per student. The budget on rural electricity is estimated using World Bank data on new households with electricity per year (World Bank 2021b) and from the Ministry of Infrastructure (Rwanda, Ministry of Infrastructure 2018) on unit cost per on-grid new connection. Since the budget data is compiled from various sources and constitute budget lines beyond the responsibility of MINAGRI, the data in Table A2 may deviate from MINAGRI's own figures.

Table A3: Share of GDP and budget allocation across crops under PSTA, 2018–2024

Crop	Share of GDP 2017 (Percent)	Budget allocations	
		US$ million	Share of US$109 million (Percent)
Maize	1.34	11.98	10.9
Rice	0.79	2.92	2.7
Irish potatoes	2.26	2.77	2.5
Soybeans	0.04	1.87	1.7
Vegetables	2.01	4.37	4.0
Sugarcane	0.10	0.73	0.7
Coffee and tea	1.36	0.78	0.7
Other cereals	0.65	3.04	2.8
Other roots, tubers, and bananas	3.95	9.12	8.3
Beans	3.34	9.55	8.7
Other crops	4.58	4.38	4.0
Total crops	20.43	51.51	47.0

Source: Authors' calculation based on 2017 Rwanda SAM (Aragie 2021b) and data from MINAGRI (Rwanda, Ministry of Agriculture and Animal Resources 2018).

Table A4: Rwanda-RIAPA model scenarios

Scenario name	Sectors Targeted
Marshland irrigation with fertilizer, seeds, and extension services (maize)	Maize
Hillside irrigation with fertilizer, seeds, and extension services (maize)	Maize
Small-scale irrigation with fertilizer, seeds, and extension services (maize)	Maize
Progressive terracing only (maize)	Maize
Progressive terracing with fertilizer, seeds, and extension services (maize)	Maize
Radical terracing with fertilizer, seeds, and extension services (maize)	Maize
Marshland irrigation with fertilizer, seeds, and extension services (rice)	Rice
Marshland irrigation with fertilizer, seeds, and extension services (other cereals)	Other cereals
Hillside irrigation with fertilizer, seeds, and extension services (other cereals)	Other cereals
Small-scale irrigation with fertilizer, seeds, and extension services (other cereals)	Other cereals
Progressive terracing only (other cereals)	Other cereals
Progressive terracing with fertilizer, seeds, and extension services (other cereals)	Other cereals
Radical terracing with fertilizer, seeds, and extension services (other cereals)	Other cereals
Hillside irrigation with fertilizer, seeds, and extension services (beans)	Beans
Small-scale irrigation with fertilizer, seeds, and extension services (beans)	Beans
Progressive terracing only (beans)	Beans
Progressive terracing with fertilizer and extension services (beans)	Beans
Progressive terracing with fertilizer, seeds, and extension services (beans)	Beans
Radical terracing with fertilizer, seeds, and extension services (beans)	Beans
Marshland irrigation with fertilizer, seeds, and extension services (potatoes)	Irish potatoes
Progressive terracing only (potatoes)	Irish potatoes
Progressive terracing with fertilizer and extension services (potatoes)	Irish potatoes
Progressive terracing with fertilizer, seeds, and extension services (potatoes)	Irish potatoes
Radical terracing with fertilizer, seeds, and extension services (potatoes)	Irish potatoes
Hillside irrigation with fertilizer, seeds, and extension services (other RTBs)	Other RTBs
Small-scale irrigation with fertilizer, seeds, and extension services (other RTBs)	Other RTBs
Progressive terracing only (other RTBs)	Other RTBs
Progressive terracing with fertilizer and extension services (other RTBs)	Other RTBs
Progressive terracing with fertilizer, seeds, and extension services (other RTBs)	Other RTBs
Radical terracing with fertilizer, seeds, and extension services (other RTBs)	Other RTBs

Table A4 (continued)

Scenario name	Sectors Targeted
Marshland irrigation with fertilizer, seeds, and extension services (vegetables)	Vegetables
Hillside irrigation with fertilizer, seeds, and extension services (vegetables)	Vegetables
Small-scale irrigation with fertilizer, seeds, and extension services (vegetables)	Vegetables
Progressive terracing only (vegetables)	Vegetables
Progressive terracing with fertilizer, seeds, and extension services (vegetables)	Vegetables
Radical terracing with fertilizer, seeds, and extension services (vegetables)	Vegetables
Marshland irrigation with fertilizer, seeds, and extension services (sugarcane)	Sugarcane
Fertilizer and extension only (soybeans)	Soybeans
Small-scale irrigation with fertilizer, seeds, and extension services (soybeans)	Soybeans
Marshland irrigation with fertilizer, seeds, and extension services (maize)	Maize
Hillside irrigation with fertilizer, seeds, and extension services (maize)	Maize
Fertilizer and extension services only (coffee and tea)	Coffee and tea
Fertilizer, seeds, and extension services (coffee and tea)	Coffee and tea
Marshland irrigation with fertilizer, seeds, and extension services (other crops)	Other crops
Hillside irrigation with fertilizer, seeds, and extension services (other crops)	Other crops
Progressive terracing with fertilizer, seeds, and extension services (other crops)	Other crops
Radical terracing with fertilizer, seeds, and extension services (other crops)	Other crops
Progressive terracing with fertilizer and extension services (other crops)	Other crops
Livestock extension services, health, and breeding	All livestock
Crop R&D	All crops
Livestock R&D	All livestock
Feeder roads	All agriculture
Education	Agri-food systems
Electricity	Farm and processing

Note: RTBs = roots, tubers, and bananas.

Table A5: Rwanda-RIAPA model scenarios

	Unit cost ($/hectare)	Subsidy rate (percent)	Discount rate (percent)	Unit cost ($/hectare)	Subsidy rate (percent)
	Inorganic fertilizer			**Improved seed**	
Maize	134.3	33.6	100.0	71.7	69.5
Rice	253.5	19.7	100.0	57.4	69.5
Irish potatoes	134.3	15.1	100.0	57.4	61.8
Soybeans	253.5	33.6	100.0	57.4	61.8
Vegetables	253.5	15.1	100.0	57.4	61.8
Sugarcane	253.5	33.6	100.0	57.4	61.8
Coffee and tea	253.5	33.6	100.0	57.4	61.8
Other cereals	134.3	33.6	100.0	71.7	69.5
Other RTBs	253.5	33.6	100.0	57.4	69.5
Beans	134.3	33.6	100.0	57.4	69.5
Other crops	253.5	33.6	100.0	57.4	69.5
	Crops			Livestock (per head)	
Extension	30.0	100.0	33.4	10.9	100.0
	Marshland			Hillside	
Irrigation	3,000.0	98.9	5.0	5,600.0	98.9
	Small-scale				
	237.1	74.0	15.0		
	Progressive			Radical	
Terracing	404.2	98.9	15.0	1,682.6	98.9

Note: Unit costs for inorganic fertilizer and improved seeds are calculated by multiplying their prices by the applied quantities per hectare. Unit costs for extension services are calculated from budget data provided by MAFAP and divided by total cultivated areas. Unit costs for irrigation and terracing are calculated using total investment expenditures divided by the number of hectares targeted by the investments. Unit costs and subsidy rates for maize, rice, Irish potatoes, and soybeans are calculated using information from World Bank (2021a), while unit costs and subsidy rates for other crops are calculated based on these crops. Discount rates for inorganic fertilizer and improved seeds are assumed to be 100 percent, as they need to be applied every year. The knowledge from extension services is assumed to last for three years; the discount rate for extension services is therefore 33.4 percent. The tiny portions of marshland and hillside irrigation investments, as well as terracing investments, are assumed to be conducted by the private sector (1.1 percent), while 26 percent of small-scale irrigation investment is assumed to come from local communities and farmers. Discount rates for marshland and hillside irrigation systems and radical terracing are assumed to be 5 percent, which is based on assumptions about their maintenance cost as a percentage of their investments; small-scale irrigation and progressive terracing, on the other hand, are assumed to have lifespans one-third shorter and hence have a discount rate of 15 percent. RTBs = roots, tubers, and bananas.

Table A6: Estimates of productivity gains of inorganic fertilizer and improved seed adoption from data of 2017–2019 Seasonal Agricultural Surveys (SAS)

Dependent variable: log (output per hectare)	(1) Maize	(2) Rice	(3) Irish potatoes	(4) Soybeans	(5) Vegetables	(6) Sugarcane	(7) Coffee and tea	(8) Other cereals	(9) Other RTBs	(10) Beans	(11) Other crops
Fertilizer dummy	0.26***	0.03	0.33***	-0.14**	0.32***	0.04	0.14	0.15***	-0.14***	-0.05***	-0.04
	(0.028)	(0.057)	(0.033)	(0.064)	(0.074)	(0.291)	(0.095)	(0.043)	(0.022)	(0.016)	(0.044)
Seeds dummy	0.40***	-0.41***	0.10	0.42*	0.21**	1.48***	0.08	0.55***	0.59***	0.07	0.74***
	(0.023)	(0.081)	(0.325)	(0.255)	(0.101)	(0.523)	(0.075)	(0.100)	(0.085)	(0.080)	(0.196)
Observations	27,273	2,230	9,174	4,789	3,345	305	1,317	9,013	50,213	34,945	11,861
Number of fertilizer dummy = 1	7,335	2,187	4,926	516	2,063	107	356	898	5,479	6,051	1,997
Number of seeds dummy = 1	7,899	815	150	37	1,407	29	426	223	315	239	165
R-squared	0.327	0.255	0.547	0.135	0.418	0.465	0.215	0.275	0.268	0.188	0.523

Source: Authors, based on data from NISR (2017-2019)

Notes: Pooled ordinary least squares regression with year fixed effect. Observations are at the crop level; robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. RTBs = roots, tubers, and bananas.

Table A7: Estimates of productivity gains of adoption of inorganic fertilizer and seeds and other agricultural interventions, using 2017–2019 Seasonal Agricultural Survey (SAS) data

Dependent variable: log (output per hectare)	(1) Maize	(2) Rice	(3) Irish potatoes	(4) Soybeans	(6) Vegetables	(7) Sugarcane	(8) Coffee and tea	(9) Other cereals	(10) Other RTBs	(5) Beans	(11) Other crops
Fertilizer (log values of kg/ha)	0.09***	0.04*	0.05***	-0.04***	0.07***	0.05	0.06**	0.03*	-0.04***	-0.00	-0.01
	(0.007)	(0.024)	(0.006)	(0.016)	(0.014)	(0.066)	(0.026)	(0.015)	(0.005)	(0.004)	(0.010)
Seeds dummy	0.45***	0.54***	0.03	0.27	0.22**	1.48**	0.13	0.60***	0.60***	0.15	1.03***
	(0.031)	(0.202)	(0.262)	(0.367)	(0.105)	(0.690)	(0.161)	(0.152)	(0.117)	(0.101)	(0.350)
f+s dummy	0.12***	-0.55***	0.26	-0.07	-0.12	0.34	-0.11	-0.30*	-0.02	-0.27	-0.15
	(0.044)	(0.193)	(0.278)	(0.447)	(0.108)	(0.632)	(0.291)	(0.176)	(0.267)	(0.174)	(0.387)
Irrigation dummy	-0.04	-0.06	-0.05	-0.17	0.15**	-0.09	-0.87	0.07	0.20***	-0.17**	0.33*
	(0.080)	(0.143)	(0.110)	(0.172)	(0.065)	(0.599)	(0.670)	(0.130)	(0.057)	(0.086)	(0.195)
Terracing dummy	0.00	0.25	-0.15***	-0.02	0.06	0.67	-0.32	-0.06	-0.18***	-0.10***	-0.10**
	(0.027)	(0.170)	(0.033)	(0.060)	(0.080)	(0.467)	(0.201)	(0.048)	(0.024)	(0.018)	(0.048)
Observations	13,707	274	6,499	2,417	2,712	156	389	2,601	23,788	17,847	4,858
Number of seeds dummy = 1	7,899	815	150	37	1,407	29	426	223	315	239	165
Number of f+s dummy = 1	4,386	791	143	21	804	16	135	106	24	98	86
Number of irrigation dummy = 1	180	2,139	105	21	1,234	19	4	23	375	130	132
Number of terracing dummy = 1	4,326	5	2,434	727	438	27	110	1,993	6,248	6,170	2,185
R-squared	0.330	0.267	0.590	0.135	0.450	0.468	0.214	0.277	0.269	0.193	0.525

Source: Authors, based on data from NISR (2017-2019)

Notes: Pooled ordinary least squares regression with year fixed effect. Observations are at the crop level; robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. RTBs = roots, tubers, and bananas.

Table A8: Estimates of productivity gains of adoption of inorganic fertilizer and seeds using the Fifth Integrated Household Living Conditions Survey 2016/17 (EICV5) data

Dependent variable: log (output per hectare)	(1) Maize	(2) Rice	(3) Irish potatoes	(4) Soybeans	(5) Vegetables	(6) Sugar cane	(7) Coffee and tea	(8) Other cereals	(9) Other RTBs	(10) Beans	(11) Other non-cereals
Fertilizer dummy	0.21***	0.14	0.32***	0.03	0.46***	0.17	0.24*	0.09*	0.09***	0.08**	0.09***
	(0.042)	(0.213)	(0.055)	(0.067)	(0.167)	(0.146)	(0.127)	(0.055)	(0.023)	(0.032)	(0.015)
Seeds dummy	0.13**	-0.14	-0.04	0.04	-0.21	-0.07	-0.19	0.05	0.07**	0.06	0.04*
	(0.053)	(0.499)	(0.065)	(0.084)	(0.245)	(0.184)	(0.196)	(0.072)	(0.030)	(0.042)	(0.020)
Observations	6,774	428	4,534	2,454	850	1,014	949	3,315	25,820	7,858	52,795

Source: Authors, based on data from NISR (2018)

Notes: Observations are the number of farm households. Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. RTBs = roots, tubers, and bananas.

Table A9: **Estimates of productivity gains in livestock of selected agricultural interventions using from the 2017 Agricultural Household Survey (AHS) and EICV5**

Dependent variable: log (value of milk per cow)	EICV5	AHS
Livestock (artificial insemination) dummy	-0.08	0.33***
	(0.082)	(0.078)
Livestock (health) dummy	0.24***	0.02
	(0.081)	(0.096)
Livestock (feed) dummy	0.06	-0.05
	(0.102)	(0.081)
Livestock (extension) dummy	0.26**	0.40***
	(0.112)	(0.111)
Observations	670	2,034

Source: Authors, based on data from NISR (2017, 2018).

Notes: Observations are the number of farm households. Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table A10: Summary table of productivity coefficients and elasticities from estimations and used in the model

1. Inorganic fertilizer	Exponential value							
	EICV5	SAS 1	SAS 2	EICV5	SAS 1	Average	Elasticity used in the model	Remarks
Maize	0.21	0.26	0.09	0.23	0.30	0.21	0.16	Reduced the value for increasing extension coefficient
Rice	NS	NS	0.04	NS	NS	0.04	0.04	
Irish potatoes	0.32	0.33	0.05	0.38	0.39	0.27	0.16	Reduced the value for increasing extension coefficient
Soybeans	NS	-0.14	-0.04	NS	-0.13		0.06	Consistent with beans
Vegetables	0.46	0.32	0.07	0.58	0.38	0.34	0.08	Reduced the value for increasing irrigation coefficient
Sugarcane	NS	NS	NS	NS	NS		0.08	Consistent with vegetables
Coffee and tea	0.24	NS	0.06	0.27	NS	0.17	0.08	Reduced the value for increasing extension coefficient
Other cereals	0.09	0.15	0.03	0.09	0.16	0.10	0.16	Consistent with maize
Other RTBs	0.09	-0.14	-0.04	0.09	-0.13		0.16	Consistent with maize
Beans	0.08	-0.05	NS	0.08	-0.05		0.06	
Other crops	0.09	NS	NS	0.09			0.16	Consistent with maize

Note: NS denotes statistically insignificant coefficient estimate. RTBs = roots, tubers, and bananas.

Table A10 (continued)

2. Improved seeds	Exponential value							
	EICV5	SAS 1	SAS 2	EICV5	SAS 1	Average	Elasticity used in the model	Remarks
Maize	0.13	0.4	0.45	0.14	0.49	0.36	0.35	
Rice	NS	-0.41	0.54	NS	-0.34	0.54	0.35	
Irish potatoes	NS	NS	NS	NS	NS		0.35	Using maize value
Soybeans	NS	0.42	NS	NS	0.52	0.52	0.35	Reduced the value for increasing extension coefficient
Vegetables	NS	0.21	0.22	NS	0.23	0.23	0.08	Reduced the value for increasing irrigation coefficient
Sugarcane	NS	1.48	1.48	NS	3.39	2.44	0.17	Estimates are unreliable, possible capturing irrigation
Coffee and tea	NS	NS	NS	NS	NS		0.38	Close to maize value
Other cereals	NS	0.55	0.6	NS	0.73	0.67	0.35	Consistent with maize
Other RTBs	0.07	0.59	0.6	0.07	0.80	0.49	0.35	Consistent with maize
Beans	NS	NS	NS	NS	NS		0.35	Consistent with maize
Other crops	0.04	0.74	1.03	0.04	1.10	0.72	0.35	Consistent with maize

Note: NS denotes statistically insignificant coefficient estimate. RTBs = roots, tubers, and bananas.

Table A10 (continued)

3. Combining fertilizer and seeds	Exponential value					
	SAS 2	EICV5	SAS 1	Average	Elasticity used in the model	Remarks
Maize	0.66	0.37	0.79	0.57	0.57	
Rice	0.76			0.58	0.40	
Irish potatoes				0.27	0.57	
Soybeans			0.39	0.52	0.46	
Vegetables	0.32		0.61	0.57	0.17	
Sugarcane				2.44	0.27	
Coffee and tea				0.17	0.49	
Other cereals	0.85		0.90	0.76	0.57	
Other RTBs	0.78	0.17	0.67	0.49	0.57	
Beans					0.43	
Other crops					0.57	

Note: NS denotes statistically insignificant coefficient estimate. RTBs = roots, tubers, and bananas.

Table A10 (continued)

4. Combining fertilizer, seeds and extension			Elasticity used in the model	Remarks
	EICV5	AHS		
Maize			0.82	
Rice			0.63	
Irish potatoes			0.82	
Soybeans			0.77	
Vegetables			0.27	
Sugarcane			0.38	
Coffee and tea			0.61	
Other cereals			0.82	
Other RTBs			0.82	
Beans			0.68	
Other crops			0.82	
5 Livestock				
Animal breeding	NS	0.33	0.41	Estimates only for cows
Animal health	NS	NS	0.18	Estimates only for cows
Animal feed	0.24	NS	0.25	Estimates only for cows
Livestock extension	0.26	0.4	0.60	Estimates only for cows
Combining livestock			1.44	

Source: Authors, based on data from NISR (2017, 2017–19, 2018).
Note: NS denotes statistically insignificant coefficient estimate. RTBs = roots, tubers, and bananas.

Table A11: Input use, extension and irrigation coverage rates from different surveys and used in the model (%)

1. Inorganic fertilizer					2. improved seeds			
	SAS	AHS	EICV5	Used in the model	SAS	AHS	EICV5	Used in the model
Maize	25.0	41.7	43.8	41.7	28.0	41.6	33.6	41.7
Rice	88.0	81.3	69.1	87.8	41.0	36.3	39.7	87.8
Irish potatoes	57.0	62.1	45.9	39.8	3.0	8.7	33.1	27.0
Soybeans	12.0	23.9	40.6	31.0	2.0	12.5	31.5	10.1
Vegetables	63.0	66.2	67.8	80.0	41.0	49.5	55.5	80.0
Sugarcane	33.0	61.3	53.8	91.8	9.0	34.4	40.9	91.8
Coffee and tea	34.0	51.6	49.3	80.0	36.0	53.6	31.2	40.0
Other cereals	10.0	18.7	40.1	19.0	2.0	9.5	29.3	19.0
Other RTBs	12.0	30.7	44.9	31.0	0.8	15.2	33.8	15.0
Beans	16.0	30.8	40.0	31.0	1.2	4.1	30.8	5.0
Other crops	17.0	57.3	45.5	57.3	4.0	44.2	34.8	44.0

Notes: Coverage rates from SAS are three-year (2017–2019) averages and are measured as the percent of area cultivated. Coverage rates from EICV5 (2016/17) and AHS (2017) are measured as the percentage share of farm households. Irrigation coverage rates from EICV5 are measured in terms of the percentage share of area cultivated. 'Other crops' in the AHS data include vegetables, sugarcane, and coffee. 'Other RTBs' and 'Coffee and tea' in the EICV5 data refer to cooking cassava and coffee respectively. Cabbage is also used to calculate the coverage of vegetables in the EICV5 data. RTBs = roots, tubers, and bananas.

Table A11 (continued)

3. Extension			4. Irrigation			
	AHS	Used in the model	SAS	AHS	EICV5	Used in the model
Maize	35.3	41.7	0.6	9.8	4.5	6.4
Rice	60.7	87.8	84.0	69.5	37.9	87.8
Irish potatoes	33.8	39.8	1.4	7.1	2.8	10.2
Soybeans	31.0	31.0	1.0	14.4	3.8	10.1
Vegetables	39.5	80.0	32.0	52.3	8.5	61.4
Sugarcane	45.9	91.8	5.0	20.6	3.2	91.8
Coffee and tea	40.0	80.0	0.0	10.8	3.3	0.0
Other cereals	29.1	19.0	0.4	9.1	2.1	2.3
Other RTBs	33.8	31.0	0.6	12.3	3.1	1.5
Beans	30.6	31.0	1.0	10.4	3.2	2.6
Other crops	40.1	44.0	2.0	31.6	2.9	2.7

Notes: Coverage rates from SAS are three-year (2017–2019) averages and are measured as the percent of area cultivated. Coverage rates from EICV5 (2016/17) and AHS (2017) are measured as the percentage share of farm households. Irrigation coverage rates from EICV5 are measured in terms of the percentage share of area cultivated. 'Other crops' in the AHS data include vegetables, sugarcane, and coffee. 'Other RTBs' and 'Coffee and tea' in the EICV5 data refer to cooking cassava and coffee respectively. Cabbage is also used to calculate the coverage of vegetables in the EICV5 data. RTBs = roots, tubers, and bananas.

Table A11 (continued)

5. Remarks	
Maize	AHS coverage rate is used; extension coverage is consistent with input use; irrigation coverage is closed to the average of AHS and EICV5.
Rice	SAS fertilizer coverage is used for determining all other adoption rates.
Irish potatoes	Fertilizer coverage used in the model is slightly lower than the estimates of surveys considering the extremely low-level seed coverage in SAS and AHS; seed coverage is close to the average of AHS and EICV5; extension coverage is consistent with fertilizer use; irrigation coverage used in the model is higher than the survey estimates considering Irish potatoes as a highly promoted cash crop.
Soybeans	Fertilizer and seed coverages used in the model are close to the average of AHS and EICV5; extension coverage is consistent with fertilizer use; irrigation coverage used in the model is higher than survey estimates considering soybeans as a highly promoted cash crop.
Vegetables	Fertilizer and seed coverages used in the model are high considering vegetables are a highly diverse group of cash crops that often use small-scale irrigation; irrigation coverage is thus higher too; extension coverage is consistent with input uses.
Sugarcane	Inputs and extension coverages are consistent with irrigation coverage that is high used in the model given that sugarcane is a highly irrigated crop.
Coffee and tea	Fertilizer and seed coverages used in the model are higher than SAS and EICV5 estimates because the two surveys cover only coffee; it is understandable that input coverages are much higher for tea plantations; extension coverage is consistent with input use.
Other cereals	AHS fertilizer coverage is used for seeds use and extension; EICV5 irrigation coverage is used.
Other RTBs	AHS coverages for fertilizer and seed are used; extension coverage is consistent with fertilizer use; irrigation coverage is close to the average of SAS and EICV5.
Beans	AHS fertilizer coverage is used. Extension coverage is consistent with fertilizer use; a relatively low seed coverage is used considering its extremely low coverage in SAS and AHS. EICV5 irrigation coverage rate is used.
Other crops	AHS fertilizer and seed coverages are used; extension coverage is consistent with seeds use. EICV5 irrigation coverage is used.

Source: Authors, based on data from NISR (2017, 2017–19, 2018).

Notes: Coverage rates from SAS are three-year (2017–2019) averages and are measured as the percent of area cultivated. Coverage rates from EICV5 (2016/17) and AHS (2017) are measured as the percentage share of farm households. Irrigation coverage rates from EICV5 are measured in terms of the percentage share of area cultivated. 'Other crops' in the AHS data include vegetables, sugarcane, and coffee. 'Other RTBs' and 'Coffee and tea' in the EICV5 data refer to cooking cassava and coffee respectively. Cabbage is also used to calculate the coverage of vegetables in the EICV5 data. RTBs = roots, tubers, and bananas.

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