INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
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RESEARCH PROGRAM ON Policies, Institutions, and Markets
CGIAR
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IFPRI Discussion Paper 02102

January 2022

Agricultural R&D Investments and Policy Development Goals in Sub-Saharan Africa

Assessing Prioritization of Value Chains in Senegal

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ABSTRACT

This paper looks at the prioritization of agricultural value chains (VCs) for the allocation of R&D resources that maximize development outcomes (poverty, growth, jobs, and diets). Considering that growth in VCs affects those various outcomes differently, as expansion pathways result in the diverse use of production factors and inputs, trade-offs from linkages across sectors, and changes throughout the agri-food system, this analysis uses (i) the RIAPA dynamic computable general equilibrium model to identify which agricultural VCs, when expanded through TFP growth, provide the strongest effects on the development outcomes of interest; (ii) the perpetual inventory model (PIM) to represent the lagged effect of research through knowledge stocks of agricultural R&D investments; and (iii) information on the elasticities of VC agricultural activity TFP with respect to agricultural R&D knowledge stocks, to discuss the VC priority allocations of R&D resources in Senegal. Results indicate that no one VC (crop- or livestock-related) is the most effective at improving all development outcomes. When accounting for policy preferences that attribute relative priority weight to development objectives, results (based on a ranking scale) indicate that R&D investments for maximizing development objectives can be most effective in Senegal's VCs for traditional export crops (growth, diets, jobs, and to some extent poverty), groundnuts (poverty, diets, and jobs), rice (poverty and jobs), poultry/eggs (diets and jobs), sorghum/millet (poverty and growth), and cattle (diets and growth). Other promising VCs with potential effects at scale if strategically targeted include vegetables (poverty, diets, and jobs), oilseeds (poverty and growth), and fruits (diets and jobs). While these results can inform strategies aimed at improving multiple development outcomes, future modeling needs to focus on deepening the standardization and integration of R&D investments costs into the framework, disentangle the relevance of different types of R&D investments sources, and bring together other factors and complementary agrifood system investment dimensions relevant to sustainable and inclusive agricultural VC growth.

Keywords: Agriculture, CGE model, TFP, R&D investments, knowledge stocks, poverty reduction, AFS growth, job creation, dietary diversity.

ACKNOWLEDGMENTS

This paper was prepared with funding from the CGIAR Research Program on Policies, Institutions, and Markets (PIM) for which we are very grateful. We also acknowledge the IFPRI Nexus Team for making available the Senegal SAM, and the RIAPA project Team for the modeling code. Alejandro Nin-Pratt kindly shared the product specific R&D elasticities and related insights. All opinions, errors or omissions are the sole responsibility of the authors.

ACRONYMS

AFS	Agrifood System
ASTI	Agricultural Science and Technology Indicators
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGE	Computable General Equilibrium (Model)
CGIAR	Consultative Group for International Agricultural Research
ERS	Economic Research Service
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
IFPRI	International Food Policy Research Institute
KS	Knowledge Stocks
LES	Linear Expenditure (Demand) System
LSMS	Living Standards Measurement Study
PIM	CGIAR Research Program on Policies Institutions and Markets
PIM (Model)	Perpetual Inventory Method
R&D	Research and Development
RIAPA	Rural Investment and Policy Analysis Model
TFP	Total Factor Productivity
USDA	United States Department of Agriculture
VC	Value Chain

1. Introduction

Evidence suggests that growth in the agricultural sector is very effective at reducing poverty and promoting inclusive economic growth, particularly in countries where agriculture remains the predominant sector in the economy (Fan, et al., 2002; Christiaensen et al., 2011; Benfica and Henderson, 2021). Over the years, agricultural R&D has played an important role in boosting agricultural productivity in all regions. During the Green Revolution of the 1960s and 1970s, large public investment in crop genetic improvement and yield enhancing inputs—built on the scientific advances in high-income countries and adapted to low- and middle-income country conditions—prompted significant yield increases, especially for rice, wheat, and maize (Pingali, 2012). Global public research investment doubled between 1981 and 2016 in the context of a historic transition that transformed the landscape of global food and agricultural R&D.

Over the past couple of decades, countries in Africa south of Sahara (SSA) have invested resources in agricultural R&D but at levels (and paces) that are considerably lower (and slower) than other regions. The relatively slower growth in R&D spending contributed to the smaller role that productivity has played in output expansion in SSA—a significant share of past agricultural production growth in SSA was driven by the expansion of cultivated land area and the exploitation of the natural resource base. Great potential still exists for agricultural productivity growth in the region. Inconsistent growth in agricultural R&D spending, coupled with the persistent prevalence of poverty and hunger, calls for continued investments (Nin-Pratt, 2011). While increasing the levels of R&D investment is necessary, it is important to examine the unique development challenges faced by countries with weaker R&D systems (Benfica et al., 2021) and ensure that investment is properly prioritized. The realization of the effects of R&D on agricultural productivity will depend on the investments countries make in their R&D systems to address gaps related to human capacities, institutional weaknesses, and policy coordination.

While acknowledging the importance of overcoming those capacity and institutional constraints, this paper will focus on the issue of prioritization, i.e., in which agricultural sector value chains (VCs) should scarce agricultural R&D resources be allocated to maximize development outcomes, such as economic growth, poverty reduction, job creation, and dietary diversity? As expected, different sectors affect development outcomes differently, as individual expansion pathways result in relatively different use of factors and inputs and in trade-offs related to the linkages between sectors, the rural and urban economies, as well as in changes throughout the agrifood system (AFS). To undertake the analysis accounting for those factors, we use the RIAPA (Rural Investment and Policy Analysis) dynamic computable general equilibrium (CGE) model (Thurlow et al., 2020) to identify which agricultural VCs provide the strongest impacts on the development outcomes of interest. We use the perpetual inventory model (PIM) to represent the lagged effect of agricultural research through knowledge stocks of agricultural R&D investments. Based on the RIAPA-CGE model results for the rankings of agricultural VCs, information on the elasticity of VC agricultural activity total factor productivity (TFP) to agricultural R&D knowledge stocks (KS) is used to discuss the alternative feasible priority allocations of agricultural R&D resources. The analysis considers crop- and livestock-related VCs and looks at the results for Senegal in detail. It follows and complements prior VC prioritization analysis in Senegal by Randriamamonjy et al. (2020).

The analysis finds that growth in VC agricultural TFP in Senegal contribute to distinct outcomes differently. When individual outcomes are considered as single policy priority criteria, different VCs are the most effective at maximizing the effects on outcomes: rice (poverty), oilseeds (growth), groundnuts (jobs), and cattle (diets). Considering policy preferences that attribute positive relative priority weight to outcomes, results indicate (based on a top 10 and 5 ranking scale) that R&D investments for maximizing development objectives can be most effective in Senegal's VCs for traditional exports (growth, diets, jobs, and, to some extent, poverty), groundnuts (poverty, diets, and jobs), rice (poverty and jobs), poultry/eggs (diets and jobs), sorghum/millet (poverty and growth), and cattle (diets and growth). By weighting on targeted interventions at scale, other promising (large) VCs include vegetables (poverty, diets, and jobs), oilseeds (poverty and growth), and fruits (diets and jobs).The paper suggests that future research and modeling to inform the prioritization of VCs should be aimed at deepening and standardizing the integration of R&D investment costs in the framework, untangling the relevance of different types of R&D investments for individual VCs, and considering other complementary investments such as irrigation, extension services, targeted subsidies, and road and communications infrastructures that play key roles in enabling and sustaining inclusive agricultural VC growth.

The route for this paper is as follows. The next section summarizes the methodology, including the model for VC prioritization, the description of the perpetual inventory model (PIM) that derives the measure of agricultural R&D KS, and the approach for deriving the required KS increase to achieve the necessary agricultural TFP growth using R&D KS elasticities of TFP. Section 3 describes the data and model parameters. Section 4 presents descriptive statistics. Section 5 presents the analytical results including the VC prioritization and key recommendations for R&D investments. The final section concludes.

2. Methodology

This analysis uses a suite of methods. First, the RIAPA-CGE dynamic model is used to assess the ranking of VCs in line with alternative development outcomes. Second, the perpetual inventory model (PIM) is used to represent the lagged effect of research through knowledge stocks (KS) of agricultural R&D investments. Finally, considerations on the existing information on elasticities of agricultural activity TFP to KS are used to analyze the feasibility of allocation of resources to agricultural activities in alternative top ranked value chains in Senegal.

The RIAPA-CGE model for value chain prioritization

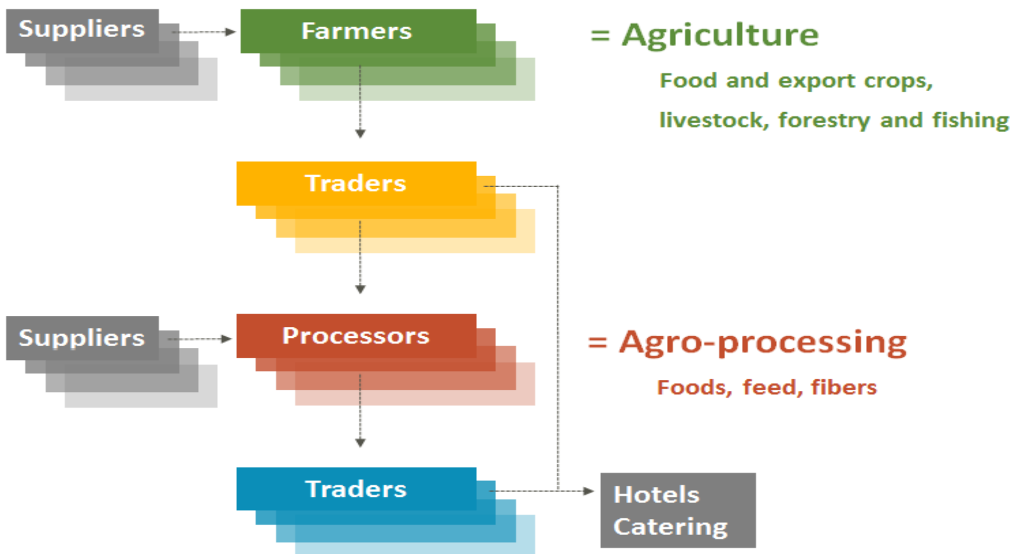
RIAPA is an economywide model that captures linkages between sectors and rural and urban economies, as well as changes throughout the agrifood system (AFS).[1]

The centrality of the Agrifood System. RIAPA's main feature is that it captures the entire *AFS,* which comprises all the agriculture-related VCs in an economy (Figure 1). The total value-added generated by all farmers is equal to agricultural gross domestic product (agricultural GDP)—all crops, livestock, forestry, and fisheries activities. The total value-added generated by all forms of agricultural processing (processed foods and beverages, animal feed, plant-based fibres, and timber from forestry) is equal to agro-processing GDP, which is an important part of the manufacturing sector. The AFS also includes a portion of the value-added generated by domestic producers of the intermediate inputs used in the agricultural and agro-processing sectors. The model tracks the flow of inputs between sectors and differentiates between domestically produced and imported goods and services. Finally, the AFS includes the value of foods prepared and consumed away from home. As economic growth and structural transformation proceed, the overall share of the AFS in the economy measured by the agricultural GDP+ (and agricultural

[1] This section draws on Thurlow et al. (2020) and RIAPA Model training materials.

employment+) falls, but a greater share of the drop is in the primary agriculture component, the share of the food processing and services components being relatively stable.

Figure 1. Defining the agrifood system



Source: RIAPA Model (background materials).

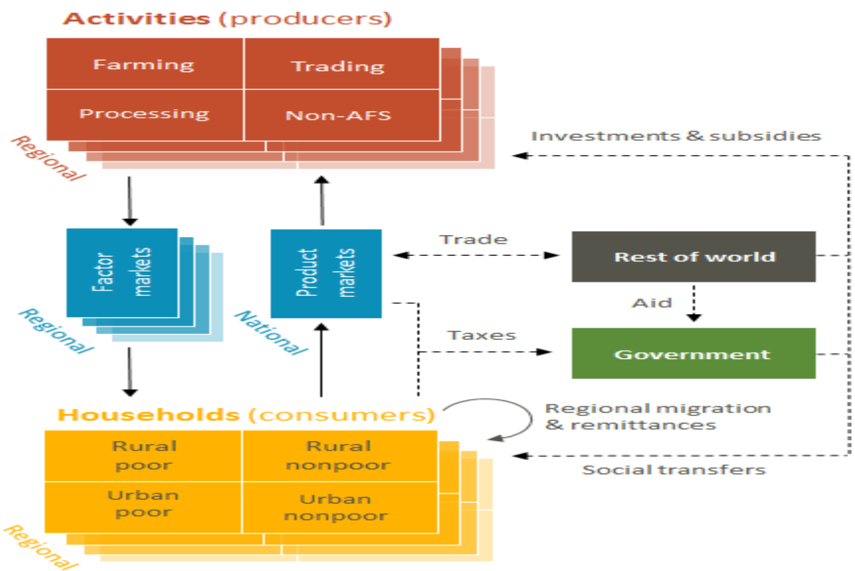
Economywide modeling framework. Economywide models are ideal for evaluating the impacts of large-scale interventions, especially those involving complex relationships between producers and consumers. Larger-scale interventions are more likely to generate economywide spillovers. When production in a VC is scaled-up, it is important to consider *positive spillovers* and negative trade-offs. Value chains are also complex by nature: they involve multiple sectors and actors. Actors in the VC compete for scarce resources and market opportunities. When one component of the VC faces constraints or new opportunities, other components of the same VC are affected. It is therefore important to consider how expanding production in a VC may come at the expense of other existing VCs.[2]

RIAPA is a dynamic computable general equilibrium (CGE) model that simulates the functioning an economy, including markets for products and factors (Figure 2). The model measures how production changes are mediated through prices and resource reallocations, while

[2] For example, introducing high-yielding maize varieties into an economy may displace existing traditional maize varieties. This is due to both resource and market constraints.

all resource and macro-financial constraints are respected (Thurlow et al., 2020). The latter is particularly important for larger-scale interventions, such as a VC operating at scale. RIAPA provides a consistent "simulation laboratory" for quantitatively examining VC interactions and spillovers at national, sub-national, and household levels.

Figure 2. Economywide framework



Source: RIAPA model (background materials).

The model divides the economy into producers (or activities) and consumers (household groups) that interact with each other in factor and product markets. The model consists of behavioral and structural equations. The former governs the decision-making behavior of economic agents; the latter maintains consistency between the incomes and expenditures of agents and within the macroeconomy.

Producers combine ***factors*** (land, labor, capital, machinery, etc.) and ***intermediate inputs*** (fertilizer, purchased seeds, etc.) using sector–specific technologies to maximize profits. Workers are divided by education levels, and agricultural capital is separated into crop and livestock. Labor and capital are in fixed supply, but less-educated workers are treated as underemployed. Factor demand is governed by constant elasticity of substitution (CES) functions that allow producers to imperfectly substitute between labor, land, and capital based on changes in the relative factor prices. The ease with which producers shift between factors is determined by elasticities of factor substitution, which are econometrically estimated for a country or drawn from the literature. RIAPA also captures differences in production technologies (i.e., intermediate input demand). The combination of inputs that sectors use is not determined by changes in relative prices, but rather by price–insensitive engineering relationships—demand for intermediate inputs is determined by a Leontief specification. The output produced by each sector is supplied to national product markets. The model captures international trade flows between national and foreign product markets. Commodities can be traded domestically or with the rest of the world, and export and import quantities are determined by relative prices. Substitution between imports and domestic goods is governed by a CES function. The decision to export is based on a constant elasticity of transformation (CET) function. World prices are fixed under a small country assumption.

The model tracks changes in incomes and expenditures for ***representative household groups***, including changes in food and nonfood consumption patterns. Households are separated by location (rural or urban), farm or nonfarm status, and by nationally defined per capita expenditure groups. Households choose between producing goods for their own consumption and purchasing goods from markets. They are the main owners of the factors of production, and their wages, rents, and profits are used to consume goods and services, pay taxes, and save. Consumption levels are determined by a linear expenditure system (LES) of demand, with income elasticities typically estimated using national household surveys, e.g., Living Standards Measurement Study (LSMS) managed by the World Bank Center for Development Data (C4D2).

Top–down micro-simulation modules estimate changes in poverty rates and dietary diversity. Households in the LSMS survey are mapped to their representative household groups in the CGE model. The poverty module transfers proportional real consumption changes from the CGE model down to the households in the LSMS survey and then recalculates each household's consumption levels and their poverty status (using official poverty lines). Likewise, a survey-based nutrition module measures changes in household dietary diversity.

RIAPA includes other actors, such as the ***government*** and the ***rest of the world***. Governments collect tax revenues via several direct and indirect tax instruments, including sales, value-added and excise taxes on products, and corporate and personal income taxes on enterprises and households. Interactions with the rest of the world include international trade flows and international transfers (worker remittances, repatriated profits, foreign direct investment, and foreign aid).

Model macro closure rules. The model maintains macroeconomic consistency by using "*closure rules*" governing three macroeconomic accounts: (a) current account, (b) government account, and (c) savings-investment account. Closure rules reflect how a country's macroeconomy adjusts to exogenous shocks. Typical closure rules for RIAPA include (a) *Current account*: Foreign capital inflows are assumed to be fixed and a flexible exchange rate adjusts to maintain the supply and demand of foreign exchange. An alternative closure would fix the exchange rate and allow the level of foreign capital inflows to adjust; (b) *Government account*: The government earns tax revenues based on fixed tax rates and these are used to finance fixed levels of recurrent spending, leaving the recurrent deficit to adjust to maintain fiscal balance. An alternative closure would fix the recurrent balance and allow tax rates to adjust; and (c) *Savings-investment*: Investment is "savings-driven," meaning that households' marginal propensities to save are fixed. Rising incomes lead to higher levels of savings and investment. An alternative closure would fix the level of investment and allow savings rates to adjust.

As a recursive dynamic model, capital stocks in each sector are updated every year to reflect capital depreciation and investments from the previous period. Sectors with above–average profits receive a larger share of new capital stocks than their share of installed capital in the previous period. New capital can be allocated across sectors, but once invested, it becomes sector specific.

Baseline dynamics and counterfactual impact analysis. The model is initially calibrated to the base year reflected in the social accounting matrix (SAM) (2017 in the case of Senegal). The model is then run forward over time to create a baseline growth path. The baseline scenario is therefore determined by annual growth in factor supplies and productivity. Except for capital, factor and productivity growth rates are calibrated to observed historical trends. For example, changes in labor supply are usually based on population projections for rural and urban areas, and on labor force participation rates for workers with different education levels. Similarly, agricultural land either expands alongside rural population or is calibrated to long-term trends in total harvested land area from historical data. The annual growth capital stocks are targeted so that it grows at a relatively smooth rate in relation to GDP. This is done either by assigning base-year capital-output ratios or adjusting the price of capital. After a suitable baseline scenario has been calibrated, it is possible to conduct counterfactual simulations. Alternative growth paths are evaluated by changing exogenous variables in the model from baseline levels.

The model is re-solved and deviations from the baseline are attributed to the simulated change in policies or external factors. The model is therefore an ideal tool for *ex ante* evaluation of investment options in countries where historical evidence is lacking, and *ex post* analysis is difficult. While the model's general equilibrium specification is based on economic theory, its detailed calibration to observed data provides a "quasi-empirical" laboratory for conducting complex experiments within a consistent framework.

Value chain prioritization and development outcomes. The RIAPA model simulates the effects of expanding output via growth in TFP in the agricultural activity of agricultural VCs on development outcomes, such as poverty (headcount ratio), growth (agricultural GDP+), jobs (agricultural employment+), and diets (dietary diversity score). TFP growth in each group of agricultural products (that define the value chain) is accelerated beyond baseline growth rates such that, in each VC scenario, total agricultural GDP is 1 percent higher at the end of the period (2020–2025) than it is in the baseline scenario.[3]

The model results generate a ranking of VCs based on the effects they have on those development outcomes following an expansion in their agricultural activity TFP (φ_i) that leads to a 1 percent growth in agricultural GDP. These shocks have implications on the AFS and the economy because of relative price adjustments, economic linkages, and the competition for resources, with the model solution resulting (in each case) in changes in Agricultural GDP+ and Agricultural Employment+, as well as in poverty and diets. RIAPA measures and compares outcomes from expanding agricultural production in different VCs. Expanding agricultural production increases supply to downstream processing activities and generates demand for agricultural trade and transport services. Since agricultural sectors differ in size, it is necessary for smaller sectors to expand more rapidly than larger ones to achieve the same absolute increase in total agricultural GDP. This is further illustrated and discussed later in the paper for the case of Senegal.

[3] The choice to target a 1 percent increase in agricultural GDP is somewhat arbitrary since results are largely unaffected by the magnitude of the target growth acceleration (Thurlow et al., 2020).

Given the linkages each VC has in the local economy as it expands, the resulting impacts on different development outcomes differ. While practically all value chains can have a positive impact on development outcomes, no single one is expected to be the most effective at achieving all objectives. In this analysis we look at the impacts of expansion on development outcomes in two ways. First, from the perspective of each development outcome individually, i.e., by giving all weight in the policy preference function to each individual outcome at a time. Second, a more realistic approach is one where policy preferences are shaped by attributing relative priority weight to all objectives. In essence, in addition to a scenario where equal weights are placed on each of the four development outcomes, four other scenarios are considered, each biased toward each of the four outcomes (poverty-biased, growth-biased, jobs-biased, and diets-biased). In each case, the sector toward which the bias is directed gets half of the weight and the others receive equal weights that sum up to the remaining half.

The knowledge stocks of agricultural R&D investments

Agricultural R&D investments result in knowledge that can be translated into productivity gains over time. An important challenge is how to best represent and measure agricultural R&D investments, particularly the lagged effects of research. We use the perpetual inventory method (PIM) to represent the lagged effect of research through knowledge stocks (KS) of agricultural R&D investments.

The PIM approach assumes an infinite lag distribution that depends on the R&D investment characteristics.[4] The key underlying assumption is that a string of R&D investments creates a stock of knowledge (KS) that yields returns into the future (Hall, Mairesse and Mohnen, 2009). To calculate the KS, we consider how quickly R&D investments enter and exit the stock of knowledge, and how the stock depreciates. Little information is required for this approach: the series of R&D investments, an initial value of the KS, and three key parameters (a geometric depreciation or decay rate of the stock (δ), a gestation lag period (G), and a parameter (β) that defines the shape of the gestation period (Nin-Pratt, 2021)).

[4] It has been extensively used in the R&D literature (Hall, Mairesse and Mohnen 2009), and applied to the analysis of agriculture by Esposti and Pierani (2003) and Nin-Pratt and Magalhaes (2018) to calculate knowledge stocks from agricultural research (Nin-Pratt, 2021).

Formally, and assuming that there is no contribution of R&D expenditure (R) to knowledge stock during the gestation period, the knowledge stock (KS) in period t can be represented as:

$$KS_t = KS_{t-1}(1-\delta) + R_{t-G} \quad (1)$$

where t is the current period, δ is the decay rate or "depreciation" and G the gestation period.

The more general representation of the R&D stock is

$$KS_t = KS_{t-1}(1-\delta) + \sum_{s=1}^{G} \Omega_{G-s} R_{G-s} \quad (2)$$

with Ω=1 if $s=G$; $\Omega=[(1-\beta)s]/[(G-\beta s)]$ if $s<G$

where s is the investment age, and Ω represents the age-efficiency weights (the contribution of investments to KS in year n), and β defines the shape of the contribution of investment to KS during the gestation period.

Esposti and Pierani (2003) argue that there is a conceptual link between values of the parameters of the PIM model and the type of research represented by the model. They distinguish three main types of research: basic, applied, and developmental research, and report that few studies in the literature explicitly estimate the decay rate δ (Alston et al. 2000) and that none of them refer to agriculture. The values for δ that Esposti and Pierani (2003) found in the literature range from 0.12 to 0.36, with 0.15 as the most frequently assumed in empirical research. They also found that, in general, the more basic the research, the smaller the δ and the larger the G. The literature does not give indications on the β parameter (Nin-Pratt et al., 2021).

Agricultural R&D KS elasticities of TFP and R&D investment priorities

The agricultural R&D KS elasticities of agricultural TFP is an important parameter in our analysis. Several steps are followed for calculating the elasticities. First, agricultural TFP growth by activity is calculated using output growth (FAO) and input growth (USDA) through a simple method of proportional allocation (Lips, 2017). Average agricultural TFP and knowledge stock growth for the period 1981–2018 were used to calculate agricultural R&D elasticities by activity, which are decomposed into domestic public R&D elasticity (γ_{pub}), external public spillover elasticity (ρ_{pub}), CGIAR elasticity (ρ_{cg}), and private R&D elasticity (ρ_{pv}). These are expressed as elasticities of agricultural TFP with respect to a change in the stock of domestic public, external public, CGIAR, and private knowledge stocks, respectively.

Under this framework, TFP growth is defined as the difference between the rate of change in total output and the rate of change in total input.[5] Formally, it can be expressed in terms of TFP changes:

$$\frac{dTFP}{TFP} = \sum_{m=1}^{M} \alpha_m y_m - \sum_{n=1}^{N} \sum \theta_n x_n$$

$$= \gamma_{pub} \frac{dKS_{pub}}{KS_{pub}} + \rho_{pub} \frac{dSP_{pub}}{SP_{pub}} + \rho_{cg} \frac{dSP_{cg}}{SP_{cg}} + \rho_{pv} \frac{dSP_{pv}}{SP_{pv}} \quad (3)$$

where α_m are revenue shares of commodity *m* and θ_n is the cost share of input *n*. The parameters γ_{pub}, ρ_{pub}, ρ_{cg} and ρ_{pv} are the elasticities of productivity with respect to a change in the stock of domestic public, external public, CGIAR and private knowledge stocks, respectively. According to the model in equation (3), productivity growth is the result of relative changes in knowledge stocks (with *d* representing change in the corresponding variable).

Changes in agricultural TFP represented in equation (3) are important from the point of view of a government analyzing the costs and benefits of public investment in agricultural research. First, the costs result from public R&D expenditure in previous periods that contribute to a change in KS in the year of analysis while the benefits are given by the contribution of those investments to agricultural TFP growth. Second, from a social point of view, the availability of knowledge from other sources affects the returns to public investment. For example, the impact of public investment in a sector that receives large spillovers is likely to be smaller than in a sector equal in size but where no external or private spillovers are available (Nin-Pratt, 2021). Finally, for simplicity, in our analysis, we look at the total elasticity of the agricultural activity that is the sum of all the four elasticities ($\in_i = \gamma_{pub}+\rho_{pub}+\rho_{cg}+\rho_{pv}$).

These elasticities are used to assess and inform the feasible orientation of agricultural R&D investments that allows for the maximization of the development objectives. More specifically, the analysis takes the RIAPA model results on the prioritization of VCs to undertake an analysis of the feasible set of priority VCs to be expanded through agricultural TFP growth induced by

[5] Following Fuglie (2012), when the underlying production technology F(X) is represented by a constant-returns-to-scale production function, producers maximize profits so that the output elasticity with respect to an input equals the cost share of that input.

increased agricultural R&D KS. Given the information on the required growth in agricultural TFP ($\Delta\varphi_i$) for individual activities to reach a unitary (comparable) agricultural GDP growth, and the individual elasticities ($\in_i$), the required growth in KS (ΔKS) is derived as:

$$\Delta KSi = \frac{\Delta\varphi i}{\in i} \quad (4)$$

Due to resource constraints for R&D investments and the associated generation of KS, activities that minimize the level of ΔKS required while maximizing the relative impact on development outcomes will be favored over those that require large KS growth while having a relatively weaker impact on development outcomes.[6]

This paper makes a careful assessment to determine the recommended set of VCs to be efficiently supported through agricultural R&D investments to maximize development outcomes in Senegal, i.e., considering the RIAPA-ranked VCs based on alternative weighted (equal weighted and development outcome-biased) policy preferences and the necessary levels of agricultural R&D–induced KS for agricultural TFP growth.

3. Data and model parameters

This analysis uses several data sources: first, the RIAPA-CGE data that includes the social accounting matrix (SAM) data and other model calibration parameters; second, the household survey data used to link the model results to impacts on outcomes at the household level; and finally, agricultural knowledge stocks (KS) and total factor productivity (TFP) for individual commodities, and the derived elasticities of agricultural TFP with respect to R&D KS.

Social accounting matrix. The values of most of RIAPA's variables and parameters are drawn from a SAM. The SAM captures all income and expenditure flows between producers, consumers, the government, and the rest of the world during a particular year. The SAM contains several "accounts" for different agents in the model, including sectors (producers) and households (consumers). The rows and columns of the SAM represent incomes and payments,

[6] Like the assessment of the activity specific TFP growth requirements, in the case of KS, a given percentual increase in activities with levels that are relatively higher at baseline will mean higher levels of investment needs than activities with lower baseline levels and the same percentage increase requirements. In this analysis, however, we look exclusively at a comparison based on the percentage changes for both the TFP growth requirements and for the corresponding KS changes.

respectively, from one account to another. As with double–entry accounting, the SAM is a *consistent* economywide database because row and column totals must be equal. In other words, a payment from one account always becomes an income for another. The SAM provides the base-year equilibrium state for the RIAPA model—2017 for the Senegal case. There are several data sources for constructing a SAM: national accounts, input-output tables, nationally representative household budget surveys, and other data sources. The ***national accounts*** provide information on the composition of GDP at factor cost and by broad expenditure groups at market prices. The technical coefficients in the input-output table are used to estimate intermediate demand based on sectors' level of GDP or gross output. ***Government budgets*** provide information on tax rates, revenues, and expenditures. The government budgets (and household surveys) also determine the level and distribution of social transfers. Customs and revenue authorities provide data on ***imports and exports*** and their associated ***tariffs and subsidies***. The ***balance of payments***, usually compiled by a country's central bank, is used to populate the external or "rest of the world" account, including information on transfer receipts and payments and the current account balance. ***Trade margins*** are estimated using information on producer and consumer prices, and input-output or supply-use tables.

Behavioral elasticities and other external data. Behavioral elasticities are needed for the consumption, production, and trade functions. The linear expenditure system (LES) demand function requires information on ***income elasticities and the Frisch parameter*** (Frisch, 1959). We econometrically estimate income elasticities using household survey data, following the approach described in King and Byerlee (1978). Marginal budget shares are derived by combining the estimated income elasticities with the average budget shares drawn directly from the SAM. ***Trade elasticities*** determine how responsive producers and consumers are to changes in relative prices when deciding to supply goods to (or purchase goods from) foreign markets. Higher elasticities are expected when substituting between more homogenous products, such as maize and copper. Lower elasticities are expected for more differentiated product categories, such as chemicals and machinery. In most developing countries the data needed to econometrically estimate country-specific elasticities do not exist—at least in an appropriate form (Arndt et al., 2002). RIAPA therefore assigns default values to the two trade elasticities using global estimates from Dimaranan (2006).

The ***elasticities governing factor substitution in the production functions*** also rarely exist for developing countries. In the absence of reliable country-specific estimates, the model's default values assume elastic factor substitution for most activities. This is consistent with recent meta-analyses of econometrically estimated elasticities (Boys and Florax, 2007) and cross-country econometric analysis (Behar, 2009).

Household level consumption and expenditure survey. The model also uses LSMS type household survey data that includes information on consumption expenditure, labor use, etc. As indicated earlier, the survey data are used to segment labor markets in the SAM and define the expenditure patterns and distribution of factor incomes to representative household groups. The survey data are therefore the main determinant of differential income and distributional effects across household groups in the RIAPA model. Through the household survey data, RIAPA extends the IFPRI Standard Model (Lofgren et al., 2001; Diao and Thurlow, 2012) by including a micro-simulation module to access the implications on household-level poverty and a survey-based nutrition module that measures how households' dietary patterns are affected by expanding investment and production in different value chains.

Agricultural total factor productivity, knowledge stocks, and TFP elasticities. As described in the previous section, knowledge stocks are used to represent R&D investments accounting for its lagged structure and to assess the relationship with specific agricultural TFP through elasticities. Elasticities are computed using available information from output growth (FAO), input growth (ERS-USDA), knowledge stocks (ASTI-IFPRI), and other data sources. The elasticities used in this paper are related to crop and livestock activities.

4. Descriptive analysis

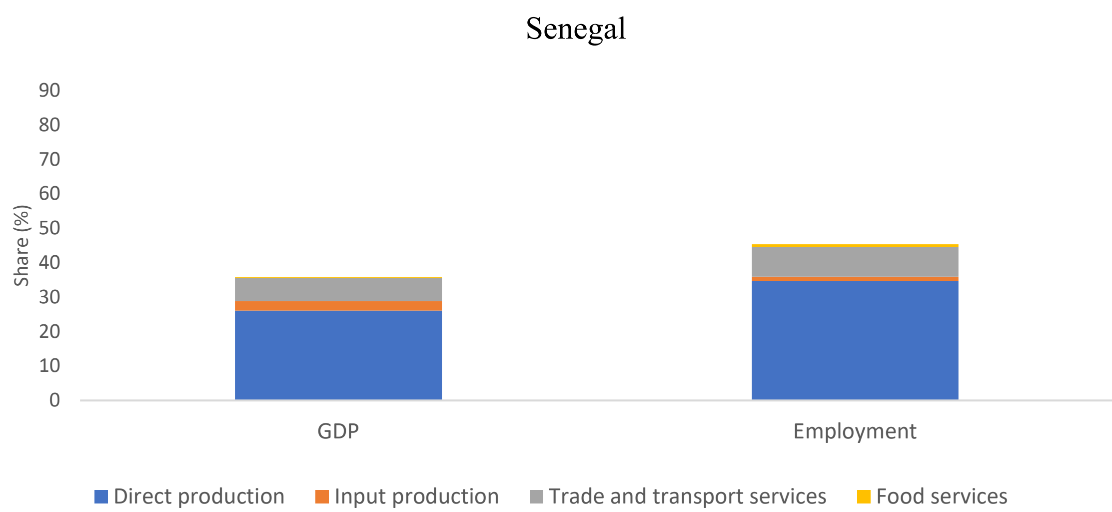
This section first looks at basic statistics on the AFS in the national economy of Senegal. Then it examines the structure of the key agricultural VCs in the country with respect to GDP, employment, and land use. Finally, it looks at the R&D TFP elasticities of knowledge stocks of individual VCs from R&D for the domestic public sector, external public sector, the CGIAR system, and the private sector.

Agrifood system in the national economy

The analysis of the AFS in the national economy uses information from the 2017 SAM for

Senegal. Besides the agriculture node, the AFS includes agricultural processing and service sectors. These sectors use domestically produced inputs from agriculture, such as seeds and animal feed, whose production creates additional value-added and jobs within the AFS. Another component—trade and transportation—involves moving agriculture-related products between farmers, processors, and markets. Finally, households also consume meals prepared outside the home provided by the formal and informal food services sector. The AFS in Senegal generates about 36 percent of the country's GDP and contributes to about 45 percent of total employment (Figure 3). Direct agricultural output production is the predominant AFS activity when compared to the production of agricultural inputs, or trade and transportation services. Food services are still only a small fraction of the AFS.

Figure 3. Agrifood system in GDP and employment, 2017



Source: National accounts (Senegal).

Agricultural value chains in the agrifood System

The AFS in Senegal involves a multitude of value chains related to crops, livestock, fisheries, and forestry products. Table 1 looks at the contributions of different agricultural activities from VCs in total agricultural GDP, agricultural employment, and the share of land use in crops. Crops are dominant in Senegal's agricultural GDP (60 percent) and employment (63 percent).

Table 1. Structure of agricultural GDP, employment, and land use, Senegal, 2017

	Senegal		
	GDP share (%)	Employment share (%)	Land area share (%)
Agricultural sector	100.0	100.0	
Crops	60.2	63.7	100.0
Maize	3.3	2.4	6.6
Sorghum & millet	**10.0**	**7.9**	**36.8**
Rice	**8.3**	**5.3**	**6.4**
Wheat & barley	-	-	-
Pulses	1.4	1.9	6.0
Groundnuts	6.2	7.7	**35.3**
Oilseeds	6.9	8.5	1.8
Cassava	1.5	2.1	1.3
Potato	0.7	0.9	0.2
Vegetables	**12.0**	**14.6**	1.4
Banana	-	-	-
Fruits	7.8	9.1	3.2
Trad. export crops	1.6	2.8	0.9
Beverage crops	-	-	-
Sugarcane	-	-	-
Other crops	0.5	0.5	0.2
Livestock and fisheries	36.6	33.6	
Cattle	**7.0**	**6.0**	-
Milk & dairy	3.9	5.8	-
Poultry & eggs	**9.9**	**9.7**	-
Goats & sheep	3.8	4.7	-
Fish & aquaculture	**11.5**	**6.6**	-
Other livestock	0.5	0.8	-
Forestry	3.3	2.7	-

Source: SAM database/RIAPA model.

The most important sectors in agricultural GDP are vegetables, fish/aquaculture, sorghum/millet, and rice. Vegetables are the most important as a share of agricultural GDP (12 percent) and employment (15 percent), though much important in terms of land area cultivated (only 1.4 percent). Sorghum/millet (37 percent) and groundnuts (35 percent) take up the greatest area cultivated, though the latter contributes a relatively lower share in both agricultural GDP and employment. Fish/aquaculture, poultry/eggs, and cattle are the most important non-crop sectors.

R&D knowledge stock elasticities of agricultural TFP

The magnitude of the elasticities is an important factor for the determination of the level of investments needed to achieve agricultural TFP growth.[7] Table 2 shows the agricultural R&D KS elasticities of TFP for crop and livestock activities, disaggregated by domestic public sector, external public sector spillovers, CGIAR, and private sector. The last column presents the total activity elasticity. No information is available for the fisheries (fish/aquaculture) sector.

Table 2. R&D knowledge stock elasticities of agricultural TFP, by activity, Senegal, 2017

Activities	SENEGAL				
	R&D KS Elasticity of VC agricultural TFP				
	Private sector	Domestic public sector	CGIAR	External public (Spillovers)	Activity (Total)
Crops					
Maize	0.006	0.072	0.031	0.032	0.141
Sorghum & millet	0.011	0.144	0.062	0.067	0.284
Rice	0.020	0.263	0.113	0.122	**0.518**
Pulses	0.011	0.148	0.064	0.068	0.291
Groundnuts	0.022	0.291	0.126	0.135	**0.574**
Oilseeds	0.013	0.172	0.074	0.079	0.338
Cassava	0.024	0.317	0.136	0.147	**0.624**
Potato	0.018	0.237	0.102	0.111	**0.468**
Vegetables	0.020	0.255	0.110	0.118	**0.503**
Fruits	0.013	0.167	0.072	0.077	0.329
Trad. export crops	0.026	0.335	0.144	0.155	**0.660**
Livestock and fisheries					
Cattle	0.006	0.083	0.036	0.038	0.163
Milk & dairy	0.007	0.086	0.037	0.040	0.170
Poultry & eggs	0.007	0.085	0.036	0.039	0.167
Goats & sheep	0.018	0.233	0.100	0.032	**0.459**

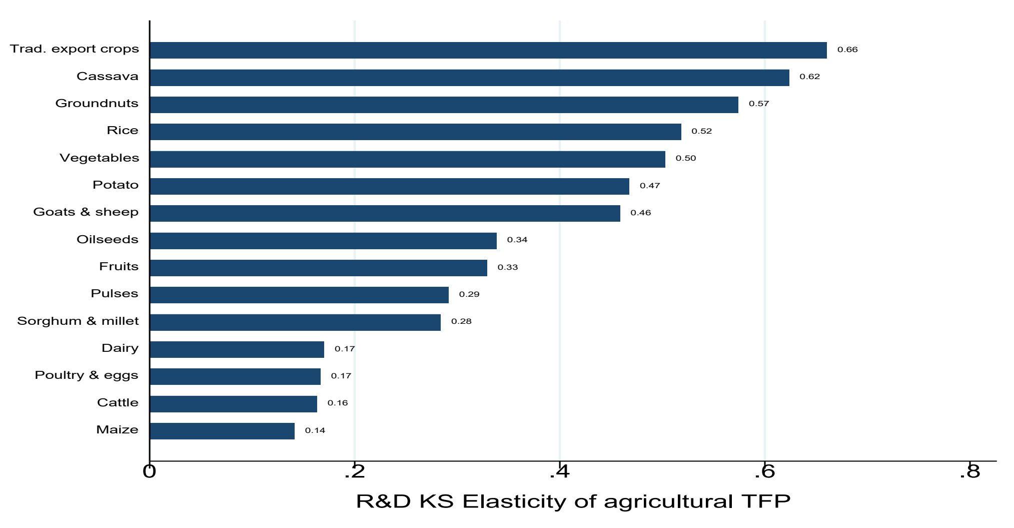
Source: ASTI data (IFPRI), USDA.

Elasticities from public sector R&D are greater than from KS for private and CGIAR R&D for all agricultural activities. The sectors with the greatest elasticities include, by order of magnitude, traditional export crops (sugarcane, tobacco, cotton, tea, coffee, coco, and cut flowers), cassava, groundnuts, rice, vegetables, and potatoes. Among livestock sectors, goats/sheep have the highest elasticities (Figure 4). Among the crop sectors with the greatest shares in GDP and employment, only rice and vegetables have relatively high elasticities. Among the sector with the

[7] The higher the elasticity the smaller the level of KS needed to achieve a TFP level that induces agricultural productivity growth leading to agricultural GDP growth.

greatest shares of land area cultivated (sorghum/millet and groundnuts), only groundnuts have a relatively high elasticity.

Figure 4. Ranking R&D knowledge stocks (KS) elasticity of agricultural TFP, by activity, Senegal



Source: ASTI data (IFPRI), ERS/USDA, FAO.

Because we do not have information on R&D KS elasticities for fisheries (fish/aquaculture), it is excluded from the analysis.

5. Analytical results

The effects of growth in agricultural activity TFP in value chains on development outcomes depend on several key transmission channels in an economywide context. Those mechanisms are related to how prices, income generation, and employment differ across agricultural value chains and how these differences affect economywide income generation, employment, poverty, and nutrition. Randriamamonjy et al. (2020) make an in-depth analysis of value chain prioritization in Senegal.[8] In this analysis, we do not go through those mechanisms in detail, but rather focus on the resulting rankings and how they relate to the required investments in agricultural R&D.

This section presents the analytical results in two stages. First, RIAPA model simulations are used to rank how the expansion of agricultural activities in different value chains contribute to

[8] Randriamamonjy et al. (2020) use a 2015 social accounting matrix and run simulations for the 2018-2022 period. In our analysis, we use a 2017 SAM and simulations for 2020-2025. As a result, there are some differences in the reported results. Also, our analysis is focused on crops and livestock VCs, and the exclusion of the fisheries sector due to lack of information on R&D elasticities for that sector.

development outcomes. Following the methodology described earlier, we rank value chains (1) by considering policy preferences towards single priority outcomes, and (2) by assuming different weighting schemes—equal weights and weights biased towards each of the four development outcomes (poverty reduction, AFS growth, AFS job creation, and dietary diversity). Second, we take the information on agricultural TFP of KS elasticities and the assessed KS growth requirements for agricultural TFP growth needed to achieve a comparable agricultural GDP growth to establish (out of the top ranked VCs in (2)) the priority sectors where feasible R&D investments should be focused.

Ranking of agricultural value chains in Senegal

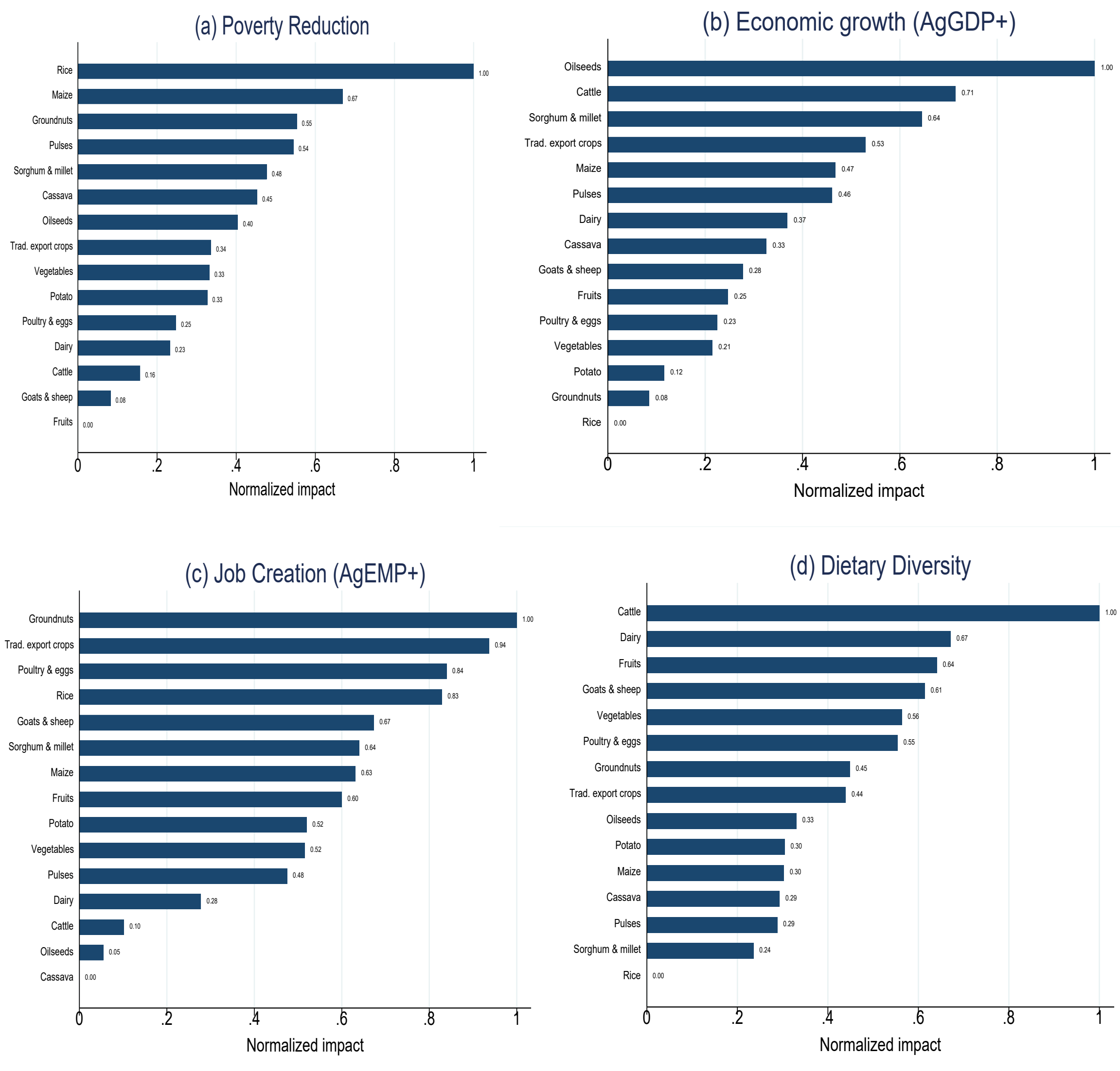
Rankings of value chains under individual priority objectives

Considering policy preferences that fully favor single development outcomes, the analysis finds that no value chain is the most effective at reaching all the four objectives. Given that outcome indicators have different units and ranges we normalize the values of the indicators. Normalization converts indicator values into a standardized range from 0 to 1 with consistent interpretations, where 1 is the value chain with largest impact and 0 is the value chain with the smallest impact.

Figure 5 shows that among the crops and livestock value chains, rice is the most effective at reducing poverty (and to some extent in job creation); oilseeds are the most effective at generating economywide growth but falls short of contributing to other development outcomes; groundnuts lead in job creation with some links to poverty reduction and dietary diversity; and cattle leads in the promotion of dietary diversity, but also contributes GDP+ growth. Other livestock related sectors (dairy, poultry, and goats/sheep) are particularly important for dietary diversity, with the latter two also critical for AFS job creation in Senegal.

Figure 5. Normalized impact on development outcomes per unit of agricultural GDP growth driven by each value chain assuming individual policy outcome preferences, Senegal

(1 is value chain with largest impact | 0 has smallest impact)



Source: RIAPA model results and authors estimations.

Rankings of value chains under different policy outcome biases

Using the more realistic approach that considers policy preferences that attribute relative priority weight to all objectives (equal weights and development outcome-biased weighting) as describe earlier, Table 3 and Figure 6 present the prioritization results for Senegal.

Overall, no VC is the top-ranked in achieving all the outcome-biased development goals. However, some can be highlighted as prominently ranked. Among the 15 VCs in the analysis, 5 are in the top 10 of all outcome-biased indicators—traditional export crops, groundnuts, maize, poultry/eggs, and sorghum/millet. Vegetables rank in the top 10 for poverty, jobs, and diets, and (marginally, at 11th)AFS growth. Cattle and dairy are in the top 10 for improving diets and AFS growth, but not in reducing poverty and creating jobs. Rice is top rated for poverty reduction and job creation but not for other outcomes. Goats/sheep and fruits are rank in the top 10 for dietary diversity and job creation.

Table 3. Final rankings of value chains under different weighting schemes, Senegal

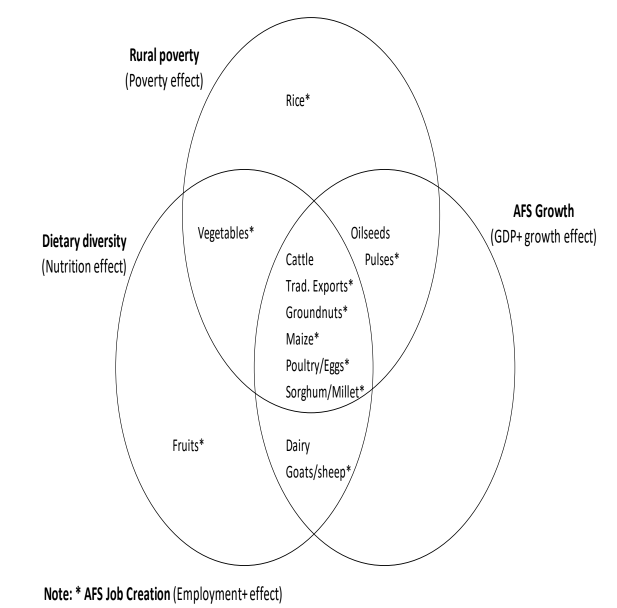
Rank	Equal weights	Poverty Bias	AFS Growth Bias (AgGDP+)	AFS Jobs Bias (AgEMP+)	Nutrition Bias
1	Trad. Expo. crops	Rice	Oilseeds	***Trad. Expo. crops***	Cattle
2	Groundnuts	***Maize***	*Cattle*	***Groundnuts***	***Trad. Expo. crops***
3	Maize	***Groundnuts***	***Trad. Expo. crops***	***Poultry & eggs***	***Groundnuts***
4	Sorghum & millet	***Sorghum & millet***	***Sorghum & millet***	Rice	***Poultry & eggs***
5	Cattle	***Trad. expo. crops***	***Maize***	***Maize***	Dairy
6	Poultry & eggs	Pulses	Pulses	***Sorghum & millet***	Goats & sheep
7	Rice	Oilseeds	***Poultry & eggs***	Goats & sheep	Fruits
8	Oilseeds	***Poultry & eggs***	Dairy	Pulses	Vegetables
9	Pulses	Vegetables	***Groundnuts***	Fruits	***Maize***
10	Goats & sheep	*Cattle*	Goats & sheep	Vegetables	***Sorghum & millet***
11	Vegetables	Dairy	Vegetables	Potato	Oilseeds
12	Dairy	Cassava	Fruits	Cattle	Pulses
13	Fruits	Potato	Rice	Dairy	Potato
14	Potato	Goats & sheep	Cassava	Oilseeds	Rice
15	Cassava	Fruits	Potato	Cassava	Cassava

Source: RIAPA CGE Model and SAM. Note: Rankings based on weighted sum of outcome indicators. Equal weighting is one-quarter each; biased weighting favors one indicator (one-half) at the expense of others (one-third of the other half each).

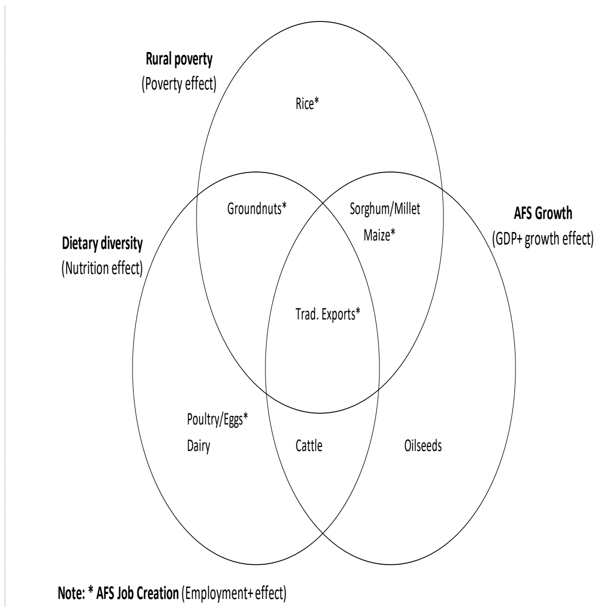
Focusing on the top five value chains for Senegal (Figure 6b), results indicate that, while no VC is the single top-ranked chain, traditional exports (coco, sugarcane, non-food crops like tobacco, cotton and cut flowers, and beverage crops like coffee and tea) are the only ones in the top five ranking for all four development objectives, and thus the only VCs close to contributing to all development objectives effectively. Cattle is effective in improving diets and generating growth. Sorghum/millet and maize are effective at reducing poverty and generating growth (with the latter also creating jobs), while groundnuts reduce poverty, improve diets, and create jobs, and poultry/eggs improve diets and promote jobs. The rice VC is effective at reducing poverty and contributing significatively to job creation, while oilseeds only contribute to AFS growth, and dairy only to dietary diversity.

Figure 6. Value chains with strong poverty, growth, jobs and nutrition effects, Senegal

(a) Value Chains in Top 10 ranking



(b) Value Chains in Top 5 ranking



Source: RIAPA model results.

Which value chains to invest in R&D in Senegal?

The identification of value chains to prioritize for the allocation of R&D resources takes the results of the VC rankings described in the previous section as the first step. It then uses the information on the R&D KS elasticity of agricultural TFP and the assessed KS growth requirements for activity-specific agricultural TFP growth needed to achieve a comparable 1 percent agricultural GDP growth (in 2025) to establish the priority sectors where feasible agricultural R&D investments should be focused. Value chains that maximize development objectives while minimizing or requiring acceptable levels of agricultural R&D investment requirements will be preferred over those that impose significant costs in a resource-constrained environment.

Priority value chains for R&D in Senegal

Based on the analysis in the previous section, the overall top ten value chains with the greatest impacts on the four development outcomes considered in this analysis are listed in Table 4. Those marked with "Δ" are in the top 5, while those with "ₒ" are ranked 6–10. For each, we also indicate the level of activity-specific agricultural TFP growth required to achieve a comparable 1 percent growth in agricultural GDP, the agricultural TFP elasticity with respect to KS, and the implied change in KS required for achieving that agricultural TFP growth in Senegal (using Equation (4)).

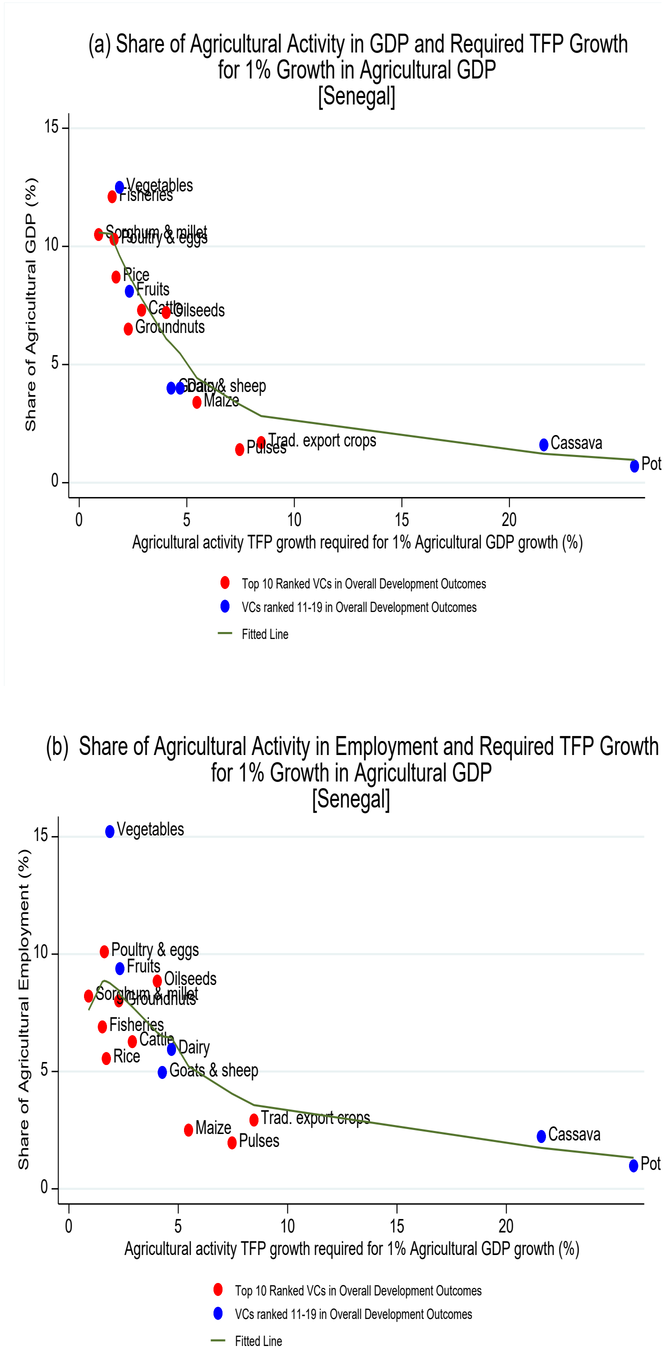
Table 4. Priority value chains: Comparative analysis for agricultural R&D investments, Senegal

		Development Outcomes				Required agricultural TFP growth, TFP/KS Elasticity, and required KS growth		
		Poverty	Growth	Jobs	Diets	Required growth in TFP (%)	TFP/KS Elasticity	Required ΔKS (%)
1	**Trad. export crops**	Δ	Δ	Δ	Δ	8.5	0.660	12.8
2	**Groundnuts**	Δ	o	Δ	Δ	2.3	0.574	4.0
3	Maize	Δ	Δ	Δ	-	5.5	0.141	38.7
4	**Sorghum & millet**	Δ	Δ	o	O	0.9	0.284	3.2
5	**Cattle**	o	Δ	-	Δ	2.9	0.163	17.8
6	**Poultry & eggs**	o	o	Δ	Δ	1.6	0.167	9.7
7	**Rice**	Δ	-	Δ	-	1.7	0.518	3.3
8	Oilseeds	o	Δ	-	-	4.0	0.338	11.9
9	Pulses	o	o	o	O	7.5	0.291	25.6
10	Goats & sheep	-	o	o	O	4.3	0.459	9.3
11	Vegetables	o	-	o	O	1.9	0.503	3.7
12	Dairy	-	o	-	Δ	4.7	0.170	27.6
13	Fruits	-	-	o	O	2.3	0.329	7.1
14	Potato	-	-	-	-	25.8	0.468	55.2
15	Cassava	-	-	-	-	21.6	0.623	34.6

Source: RIAPA Model results. Note: Δ=Top 5 ranked; O=Ranked 6–10.

The required growth in agricultural TFP is inversely related to the share of the agricultural activity in agricultural GDP and employment, i.e., smaller sectors require growth rates that are relatively larger. For example, sorghum/millet, with one of the highest shares in agricultural GDP (10 percent) and employment (8 percent), needs an agricultural activity TFP growth of about 0.9 percent to generate a 1 percent growth in agricultural GDP. On the opposite side, sectors such as traditional exports and pulses with shares below 3 percent of agricultural GDP and employment would have to grow TFP much faster, at rates above 7.5 percent. Non-top-ranked sectors like cassava and potato, that also have relatively lower shares in agricultural GDP and employment, have TFP growth requirements that are even higher, i.e., above 20 percent. Figure 7 highlights the inverse relationship and shows the top 10 priority VCs in red and the lower ranked (11–15) in blue.

Figure 7. Agricultural activity shares in agricultural GDP, employment, and land area, and required TFP growth for unitary agricultural GDP growth, Senegal

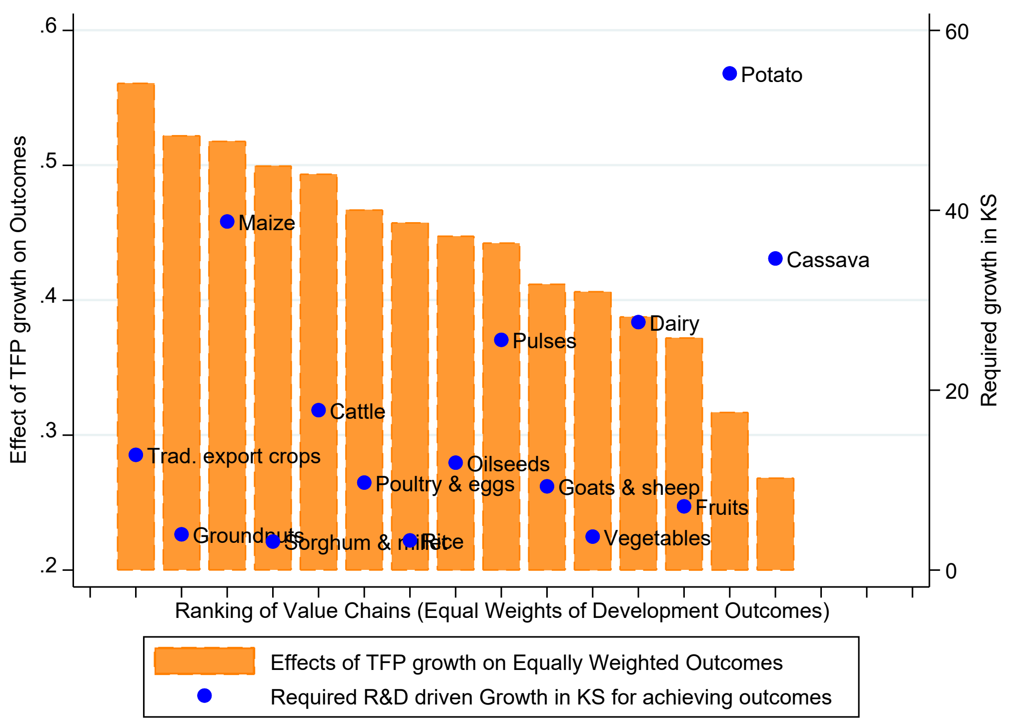


Source: RIAPA Model simulation results.

The results of the assessment and recommended VCs where agricultural R&D investments should be prioritized in Senegal are summarized in Figure 8 (for equally weighted development objectives) and Figure 10 (weighting biased towards each of the four development objectives), and the Venn diagrams in Figure 9.

Overall, looking at the scenario with equally weighted development objectives, the VCs that optimize the maximization of the overall development objectives, while requiring relatively lower R&D expansion costs to achieve the necessary TFP growth, include traditional exports, groundnuts, sorghum/millet, poultry/eggs, rice, and cattle.

Figure 8. Prioritization of R&D investments for equally weighted development outcomes, Senegal

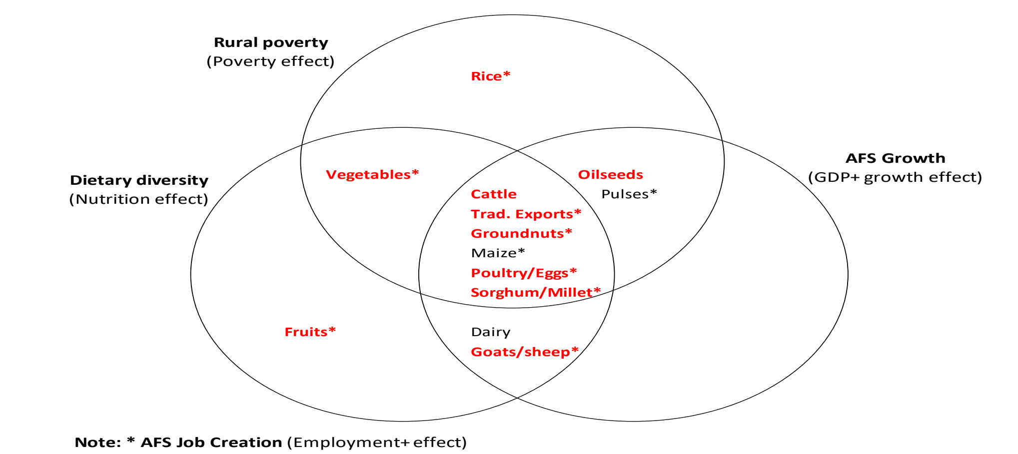


Source: RIAPA Model results and authors estimations.

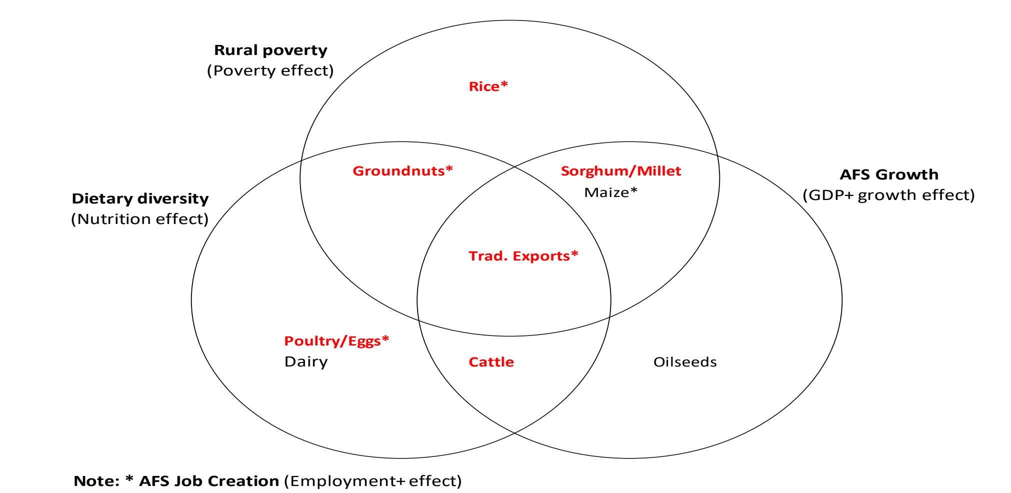
Looking at the scenario with outcome-biased weighting of policy preferences (highlighting the outcomes that are more strongly influenced by VC growth), untangles the results suggested in the equal weighting scenario, and Figures 9a and 10a-d also show some interesting results. First, it highlights the 4 VCs consistently in the top 10 across development objective–biased rankings that also seem to be R&D feasible (traditional exports, groundnuts, sorghum/millet, poultry/eggs, and cattle). Second, some value chains, while not top-rated among the top 10 in all criteria, deserve some consideration for R&D investments given their relative strengths in influencing selected development outcomes, and the relatively lower KS growth requirements. Those include goats/sheep (AFS growth, diets, and AFS jobs), rice (poverty and AFS jobs), oilseeds (poverty and AFS growth), vegetables (poverty and dietary diversity), and fruits (dietary diversity and AFS jobs).

Figure 9. Top ranked value chains with strong poverty, growth, jobs, and nutrition effects recommended VCs to invest in agricultural R&D, Senegal

(a) Value Chains in Top 10 Ranking across Development Objectives

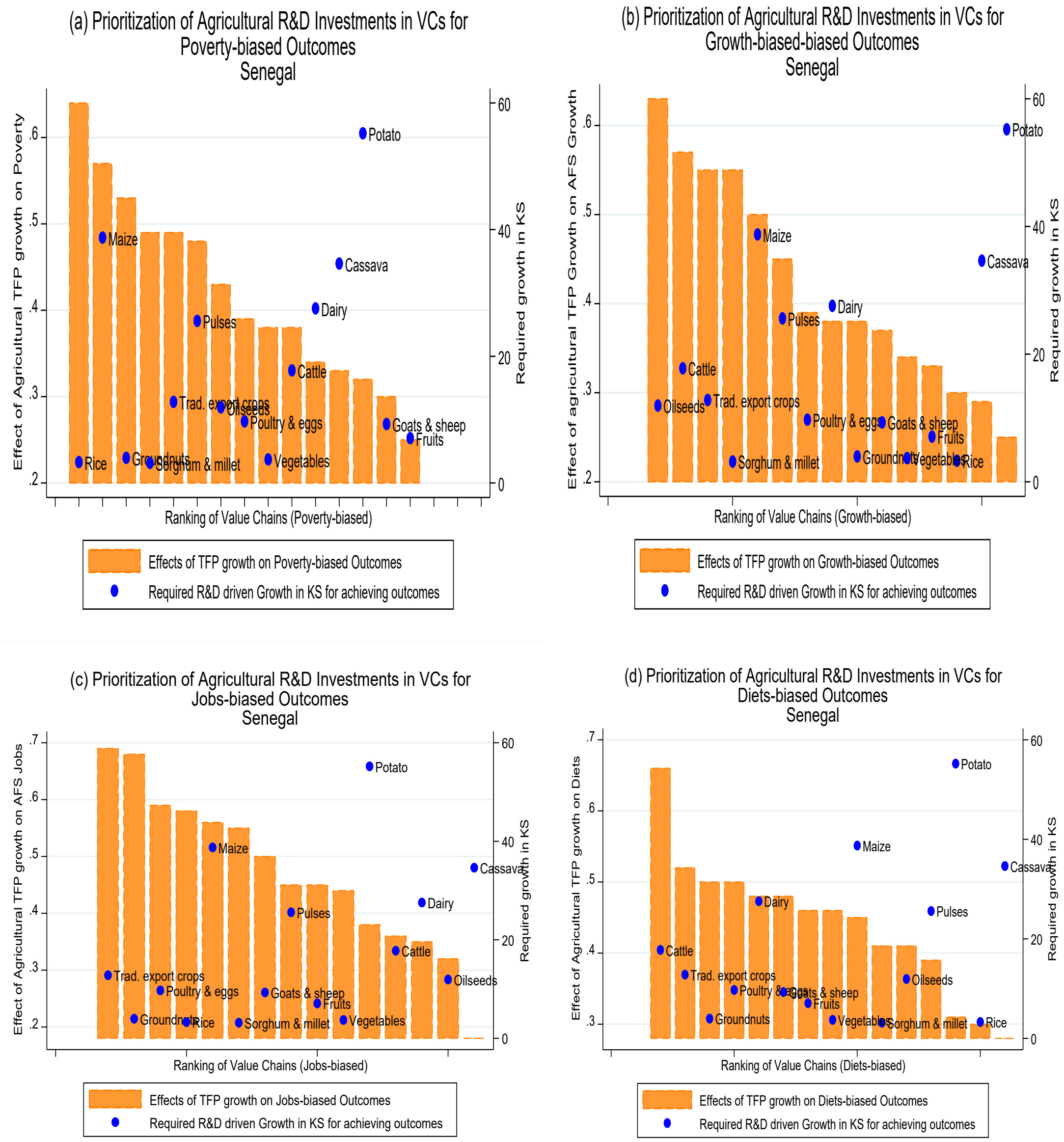


(b) Value Chains in Top 5 Ranking across Development Objectives



Source: RIAPA model results and authors estimations.
Notes: **Red bold** indicates the value chains recommended for R&D investments.

Figure 10. Prioritization of R&D investments in VCs for alternative development outcomes, Senegal



Source: RIAPA model results and authors estimations.

Finally, narrowing the analysis down to the top 5 VCs (Figure 9b), we find that traditional exports (that aggregate sugarcane, tobacco, cotton, tea, coffee, coco, and cut flowers) are the single value chain that systematically ranks in the top 5 of all outcome-biased rankings. In addition to (a) traditional exports, other value chains that are effective at maximizing at least two development outcomes while minimizing the levels of changes in investment required to generate the necessary agricultural TFP growth are (b) groundnuts (poverty, diets, and AFS jobs), (c) rice (poverty and AFS jobs), (d) poultry/eggs (diets and AFS jobs), (e) sorghum/millet (poverty and AFS growth), and (f) cattle (diets and AFS growth). Vegetables (the lead crop in agricultural GDP and employment shares), while not ranked in the top 5 for any development outcome–biased ranking, is particularly appealing due to its relatively low R&D growth requirements and the potential it has to impact poverty reduction, dietary diversity, and AFS job creation, if an aggressive and strategic approach to its growth is pursued. Along the same lines, strategically targeted approaches could also be successful in supporting growth in oilseeds (poverty and AFS growth) and fruits (diets and AFS jobs) that are also relatively large sectors with potentially great returns to R&D investments over the long run.

6. Conclusions and implications

This paper focuses on the prioritization of value chains for the allocation of agricultural R&D resources that maximize development outcomes—poverty reduction, agrifood systems (AFS) growth and job creation, and dietary diversity. It starts from the premise that growth in agricultural production activities of VCs in a country affect those outcomes differently, as individual expansion pathways result in varied uses of factors and inputs and in trade-offs related to the linkages between sectors, the rural and urban economies, as well as changes throughout the AFS. To account for those interactions, we use the RIAPA (Rural Investment and Policy Analysis) dynamic computable general equilibrium (CGE) model (Thurlow et al., 2020) to identify which sectors, when expanded to achieve a comparable growth in agricultural GDP, provide the strongest effects on those outcomes. Based on the model results for the VC rankings on individual outcomes (and a weighted aggregate ranking), information on the agricultural R&D knowledge stocks elasticity of agricultural TFP is combined with simulated activity-specific agricultural TFP growth requirements for a unitary expansion of agricultural GDP. This defines the priority allocations for R&D resources in Senegal. Value chains that maximize development objectives, while minimizing or requiring acceptable levels of R&D investment growth, are preferred over those that impose significant costs in a resource-constrained environment. We identify and rank the top VCs in order of importance, defined by the number of development objectives to be maximized with R&D–induced KS–driven agricultural TFP growth.

Results indicate that, while no single VC in Senegal (among the 15 VCs considered) is the most effective at improving all the development objectives while minimizing or requiring efficient levels of R&D investment, there are a set of value chains contributing to multiple objectives that can be recommended. Accounting for policy preferences that attribute relative priority weight to all objectives, results indicate (based on a top 5 ranking scale) that the most effective VCs to be efficiently supported through agricultural R&D investments to maximize development objectives in Senegal are (a) traditional exports (AFS growth, diets, AFS jobs, and to some extent poverty), (b) groundnuts (poverty, diets, and AFS jobs), (c) rice (poverty and AFS jobs), (d) poultry/eggs (diets and AFS jobs), (e) sorghum/millet (poverty and AFS growth), and (f) cattle (diets and AFS growth). We also recommend that strategically targeted approaches could be used to extend R&D investments in vegetables (poverty, diets, and AFS jobs), oilseeds (poverty and AFS growth), and fruits (diets and AFS jobs), which are also relatively large sectors with potentially great returns to R&D investments at scale.

Finally, while we make suggestions regarding the most optimal set of value chains to be subject to expansion through agricultural R&D investments, to better inform strategies aimed at sustainably improving multiple development outcomes, it will be critical to deepen the understanding and standardize the integration of the R&D investment cost dimensions, disentangle the relevance of different types of R&D investment sources (particularly, public, private, and CGIAR), and take into consideration other complementary investments (unique to the countries and relevant sectors) beyond R&D such as irrigation, extension services, and targeted input subsidies (Benfica et al., 2019). Equally important are policies and investments in road, and communications infrastructures that play key roles in enabling and sustaining inclusive growth in the AFS and beyond. Future research and prioritization modelling should, therefore, include such efforts.

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