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Agricultural R&D investments and development goals in sub-Saharan Africa: Assessing prioritisation of value chains in Senegal

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Abstract

We look at the prioritisation of agricultural value chains (VCs) for the allocation of R&D resources that maximise development outcomes (poverty, growth, jobs and diets) in Senegal. This study used (a) the rural investment and policy analysis (RIAPA) computable general equilibrium (CGE) model; (b) the perpetual inventory model (PIM), and (c) information on the elasticities of VC total factor productivity (TFP) with respect to R&D knowledge stocks (KS) to discuss the value chain priority allocations of R&D resources. The results indicate that no value chain is the most effective at improving all outcomes. The most effective value chains to be efficiently supported through R&D investments are traditional export crops, groundnuts, rice, poultry, sorghum/millet and cattle. Other promising value chains with potential effects at scale include vegetables, oilseeds and fruits. Future modelling needs to focus on deepening the standardisation and integration of R&D investments in this framework and bring together other factors and complementary agri-food system (AFS) investment dimensions that are relevant to sustainable and inclusive agricultural growth.

Key words: agricultural R&D, development outcomes, knowledge stocks, computable general equilibrium, total factor productivity

1. Introduction

Growth in agriculture is effective at reducing poverty and promoting economic growth in countries where agriculture remains the predominant sector (Christiaensen *et al*. 2011; Benfica & Henderson 2021). Agricultural R&D plays an important role in boosting productivity in all regions. During the Green Revolution of the 1960/1970s, large public investment in crop genetic improvement and yield-enhancing inputs prompted significant yield increases, especially for rice, wheat and maize (Pingali 2012).

Over the past few decades, sub-Saharan African (SSA) countries have invested resources in agricultural R&D, but at levels (and pace) considerably lower (and slower) than other regions. The slower growth in R&D spending contributed to a relatively smaller role of productivity in output expansion. Limited agricultural R&D spending, coupled with the persistent prevalence of poverty and hunger, calls for continued investments (Nin-Pratt 2011). While it is necessary to increase the levels of R&D investment, it is important to examine the unique development challenges faced by countries with weaker R&D systems (Benfica *et al*. 2021). The realisation of the effects of R&D on agricultural productivity will depend on the investments countries make in their R&D systems to address gaps in human capacities, institutional and policy coordination.

This paper focuses on the issue of prioritisation, i.e. to which value chains (VCs) should scarce R&D resources be allocated to maximise development outcomes (economic growth, poverty reduction, job creation and dietary diversity)? Value chains affect outcomes differently, as expansion pathways result in different uses of factors and inputs and in trade-offs related to intersectoral linkages. We used 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 effects on development outcomes. We also used the perpetual inventory model (PIM) to represent the lagged effects of R&D through knowledge stocks (KS) of agricultural R&D investments. Based on the results of the RIAPA-CGE model for the rankings of VCs, information on the R&D KS elasticity of VC TFP was used to identify feasible priority allocations of R&D resources. The analysis considers crops and livestock value chains. It complements prior value chain prioritisation analysis for Senegal by Randriamamonjy *et al*. (2020).

Considering policy preferences that attribute equal weights to outcomes, the most effective VCs to be supported through R&D investments are traditional exports (growth, diets, jobs and 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). We suggest that future research deepens the integration of R&D investments in the framework and consider complementary investments, such as irrigation, extension services, targeted subsidies, and road and communications infrastructure, whose role is key to sustain inclusive growth.

The route for this paper is as follows. Section two summarises the methodology. Section three describes the data. Section four presents descriptive statistics on the agri-food system (AFS) in the national economy. Section five presents the results on VC prioritisation and recommendations for R&D investments, while the final section concludes.

2. Methodology

This analysis uses a suite of methods. First, the RIAPA dynamic CGE model assesses 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) on agricultural R&D investments. Finally, estimated elasticities of total factor productivity to knowledge stocks are used to analyse the feasibility of allocating resources to top-ranked value chains.

2.1 The RIAPA CGE model for value chain prioritisation

RIAPA is an economy-wide model that captures linkages between sectors and rural and urban economies, as well as changes throughout the agriculture food system (AFS).[1]

2.1.1 The centrality of the AFS

The agri-food system (AFS) comprises all the agriculture-related VCs in an economy (Figure 1). The total value-added farmers generate corresponds to agricultural GDP generated by all crops, livestock, forestry and fisheries activities. The total value-added generated in agricultural processing corresponds to agro-processing GDP. The AFS also includes the value added generated by domestic

[1] This section draws on Thurlow *et al*. (2020).

producers of 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 (agriculture +) in the economy measured by the agricultural GDP + (and agricultural employment +) falls, but a greater share of the drop is in the primary agriculture component, with the share of the food-processing and services components relatively stable.

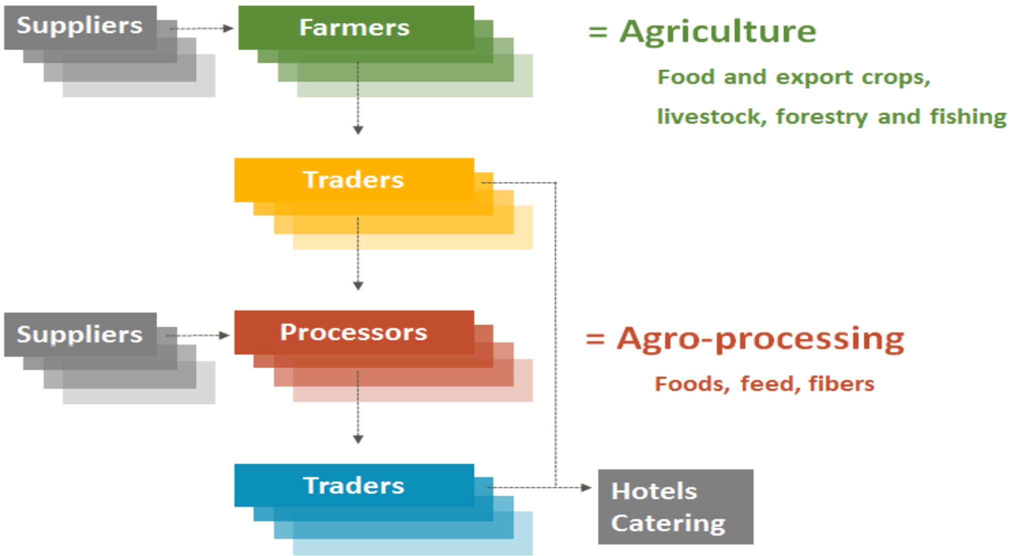


Figure 1: Defining the agriculture food system
Source: RIAPA model (Thurlow *et al*. 2020).

2.1.2 RIAPA model framework

Economywide models like RIAPA are ideal for evaluating the effects of large-scale interventions, especially those involving complex relationships between producers and consumers. 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, as they involve multiple sectors and actors competing for scarce resources and market opportunities. When one component of the VC faces constraints or new opportunities, other components of the same VC and other VCs are affected. It therefore is 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 of an economy, including markets for products and factors (Figure 2). The model measures how changes in production are mediated through prices and resource reallocations, while all resource and macro-financial constraints are respected (Thurlow *et al*. 2020). RIAPA provides a consistent 'simulation laboratory' for quantitatively examining VC interactions and spillovers at the national, sub-national and household levels.

[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.

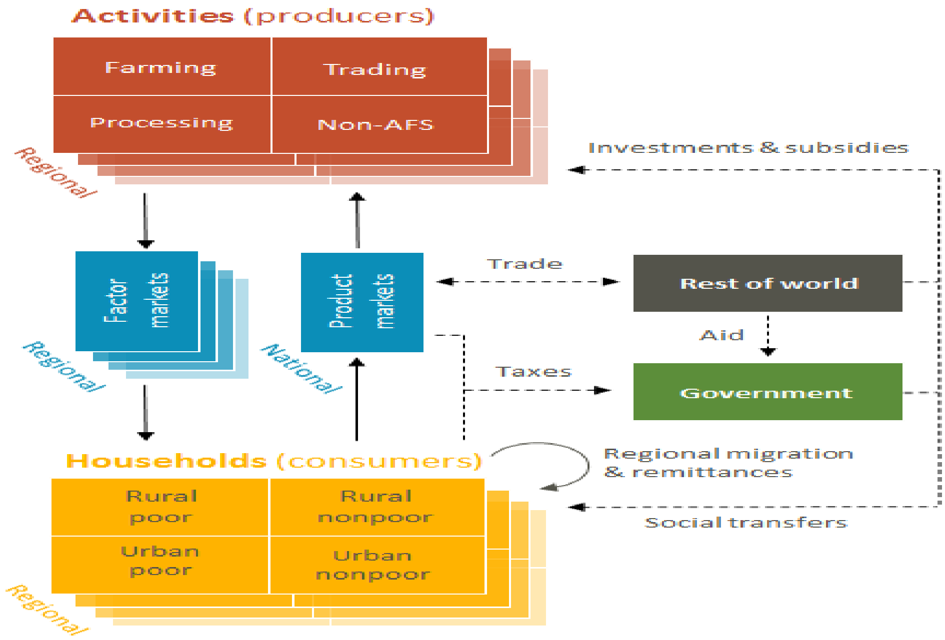


Figure 2: Economy-wide framework
Source: RIAPA model (Thurlow *et al.* 2020).

The model divides the economy into producers (or activities) and consumers (households) that interact with each other in factor and product markets. It consists of behavioural equations governing the decision-making of economic agents and structural equations maintaining consistency between incomes and expenditures within the macro-economy.

Producers combine *factors* (land, labour, capital, machinery, etc.) and *intermediate inputs* (fertiliser, purchased seeds, etc.) using sector-specific technologies to maximise profits. Workers are divided by education levels, and agricultural capital is separated into crops and livestock. Labour 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 labour, land and capital, based on changes in relative factor prices. RIAPA also captures differences in production technologies. The combination of inputs that sectors use is not determined by changes in relative prices, but rather by price-insensitive engineering relationships. The output produced by each sector is supplied to national product markets. Commodities can be traded with the rest of the world, with domestic, export and import quantities 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 non-food 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.

RIAPA includes the *government*, which collects taxes and spends in goods, services and transfers; and the *rest of the world*, which covers international trade flows and transfers. The model maintains consistency by using *closure rules* governing three macroeconomic accounts: the current account, the savings investment, and the government budget. Closure rules reflect how a country's macroeconomy adjusts to exogenous shocks.

Top-down micro-simulation modules estimate changes in poverty and dietary diversity. Survey households are mapped to representative groups in the CGE model. The poverty module transfers proportional real consumption changes from the CGE model down to the households in the survey, and then recalculates each household's consumption levels and its poverty status. Likewise, a survey-based nutrition module measures changes in household dietary diversity.

2.1.3 Baseline dynamics and counterfactual impact analysis

The model is initially calibrated to the base year reflected in the 2017 Senegal social accounting matrix (SAM). It is then run forward over time to create a baseline growth path. The baseline scenario is determined by annual growth in factor supplies and productivity. Except for capital, factor and productivity growth rates are calibrated to historical trends. For example, changes in labour supply are based on population projections for rural and urban areas, and on labour force participation rates for workers with different education levels. Agricultural land expands alongside rural population, or is calibrated to long-term trends in harvested land area. The growth in capital stocks is targeted so that it grows at a smooth rate relative to GDP.

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 changes.

2.1.4 Value chain prioritisation and development outcomes

The RIAPA model simulates the effects of expanding output via growth in TFP in agricultural value chains on development outcomes – poverty (headcount), growth (agricultural GDP +), jobs (agricultural employment +), and diets (dietary diversity score). Total factor productivity growth in each group of agricultural products (that define the VC) is accelerated beyond baseline growth rates such that, in each VC scenario, total agricultural GDP is one percent higher at the end of the period (2020 to 2025) compared to the baseline scenario.[3]

The results of the model generate a ranking of VCs based on the effects they have on development outcomes following an expansion in their TFP (φ_i) that leads to a 1% growth in agricultural GDP. Expanding agricultural production increases supply to downstream processing activities and generates demand for agricultural trade and transport services. Agricultural subsectors differ in size, therefore to achieve the same absolute increase in total agricultural GDP it is necessary for smaller VCs to expand more rapidly than larger ones. This is illustrated further and discussed later in the paper.

Given the linkages each VC has as it expands, the effects on outcomes differ across VCs. While practically all VCs can have a positive effect on outcomes, no single VC is expected to be the most effective at achieving all objectives.

[3] The choice to target a one 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).

2.2 The knowledge stocks of agricultural R&D investments

Agricultural R&D investments result in knowledge that is translated into productivity gains over time. The challenge is how to best represent and measure 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 R&D investments.

The PIM approach assumes an infinite lagged distribution that depends on the R&D investment characteristics. The underlying assumption is that a string of R&D investments creates a stock of knowledge (KS) that yields returns into the future (Hall *et al*. 2009). To calculate the knowledge stock, we consider how fast R&D investments enter and exit the stock of knowledge, and how the stock depreciates. Little information is required by this approach: the series of R&D investments, an initial value of the KS, and three 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).

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

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

where *t* is the current period, δ is the decay rate or 'depreciation', and *G* is the gestation period.

The more general representation of the R&D stock is

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

with $\Omega = 1$ *if* $s = G$; $\Omega = [(1\text{-}\beta)s]/[(G\text{-}\beta s)]$ if $s < G$.

Here, *s* is the investment age, *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, 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. In general, the more basic the research, the smaller the δ and the larger the *G*. The literature does not give indications for the *β* parameter (Nin-Pratt 2021).

2.3 Agricultural R&D knowledge stock elasticities of total factor productivity and R&D investment priorities

The agricultural R&D knowledge stock elasticities of value chain TFP is an important parameter in our analysis. Several steps are followed for calculating the elasticities. First, TFP growth by activity is calculated using output growth (FAO) and input growth (USDA) through a simple proportional allocation. Average TFP and knowledge stock growth for the period 1981 to 2018 were used to calculate R&D elasticities by activity, which were decomposed into own public R&D elasticity (γ_{pub}), spillover elasticity (ρ_{pub}), CGIAR elasticity (ρ_{cg}), and private R&D elasticity (ρ_{pv}). These are expressed as elasticities of TFP with respect to a change in the stock of domestic public, external public, CGIAR and private knowledge stocks respectively. TFP growth is defined as the difference between the rate of change in total output and the rate of change in total input.[4] Formally, it can be expressed in terms of 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. In Equation (3), productivity growth is the result of relative changes in knowledge stocks (with *d* representing change in the corresponding variable).

The changes in TFP represented in equation (3) are important from the point of view of a government analysing 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 knowledge stock in the year of analysis, while the benefits are given by the contribution of those investments to 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 influence of public investment on a sector that receives large spillovers is likely to be smaller than on a sector equal in size but where no external or private spillovers are available (Nin-Pratt, 2021).

In our analysis, we look at the total elasticity of the VC activity as the sum of all four elasticities,

$$\epsilon_i = \gamma_{pub} + \rho_{pub} + \rho_{cg} + \rho_{pv}, \text{ for each } VC_i. \quad (4)$$

These VC elasticities are used to assess the feasible orientation of R&D investments that will allow for the maximisation of the development objectives dictated by agricultural GDP growth induced by VC expansion. More specifically, the analysis uses the results of the RIAPA model for the prioritisation of VCs driven by the potential growth in R&D KS-driven TFP to undertake an analysis of the feasible set of VCs to be expanded through growth in R&D investments. Given the information on the required growth ($\Delta\varphi_i$) for individual VCs to reach a unitary (comparable) agricultural GDP growth, and the individual VC elasticities (ϵ_i), the required growth in VC KS (ΔKS) is derived as

$$\Delta KSi = \frac{\Delta\varphi i}{\epsilon i}. \quad (5)$$

Agricultural VCs that minimise the level of ΔKS required while maximising the relative effect on development outcomes will be favoured over those that require large KS growth and have a weaker effect on development outcomes.

The analysis recommends the set of VCs to be supported through R&D investments to maximise development outcomes in Senegal, viz. considering the RIAPA-ranked VCs based on alternative weighted policy preferences and the required agricultural R&D-induced KS for TFP growth.

[4] Following Fuglie (2016), when the underlying production technology F(X) is represented by a constant-returns-to-scale production function, producers maximise profits so that the output elasticity with respect to an input equals the cost share of that input.

3. Data and model parameters

This analysis uses several data sources. The RIAPA-CGE data includes the social accounting matrix (SAM) and model calibration parameters. Survey data was used to link the model to effects at the household level, KS and TFP for individual commodities, along with the derived elasticities of R&D.

The values of most of RIAPA's variables and parameters were drawn from a social accounting matrix (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 rows and columns of the SAM represent incomes and payments 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 – 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 Senegal.

Behavioural elasticities are needed for the consumption, production and trade functions. The demand function of the linear expenditure system (LES) requires information on *income elasticities* and the *Frisch parameter*. Income elasticities are econometrically estimated using household surveys. *Trade elasticities* determine how responsive producers and consumers are to changes in relative prices when deciding to supply (or purchase) goods from foreign markets.

The model uses *consumption expenditure* and labour use from household surveys to segment labour markets in the SAM and to define the expenditure patterns and distribution of factor incomes to households. RIAPA extends the IFPRI standard model (Löfgren *et al*. 2001; Diao & Thurlow 2012) by including a micro-simulation module to access the implications for household-level poverty, and a nutrition module that measures how households' dietary patterns are affected by expanding investment and production in VCs.

Knowledge stocks are used to represent R&D investments accounting for its lagged structure and assess the relationship with ***VC-specific TFP*** through elasticities. The elasticities are computed using information on output growth (FAO), input growth (ERS-USDA), and knowledge stocks (ASTI-IFPRI).

4. Descriptive analysis

4.1 The agri-food system in the national economy

In addition to agriculture, the agri-food system (AFS) includes agricultural processing and services. These sectors use inputs from agriculture, such as seeds and animal feed, whose production adds value and jobs in the AFS. Trade and transportation involve moving products between farmers, processors and markets. Finally, households also consume meals away from home provided by the food services sector. The AFS in Senegal generates about 36% of the country's GDP and contributes to about 45% of employment (Figure 3). Direct agricultural production is the predominant AFS activity.

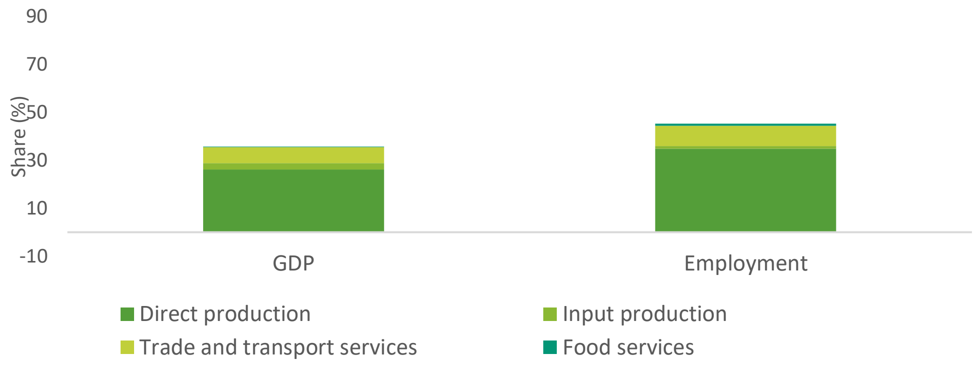


Figure 3: Senegal agri-food system in GDP and employment, 2017
Source: Senegal national accounts

4.2 Agricultural VCs in the agri-food systems

The AFS in Senegal involves value chains related to crops, livestock, fisheries and forestry. Table 1 looks at the contribution of VCs to GDP, employment, and the share of land use in crops. Crop VCs are dominant in Senegal's agricultural GDP (60%) and employment (63%).

The vegetables VCs is the most important as a share of agricultural GDP (12%) and employment (15%), though a lot less important in terms of land area cultivated. Sorghum/millet (37%) and groundnuts (35%) take the greatest area cultivated, though the latter contributes a relatively lower share in both output and employment. Fish/aquaculture, poultry/eggs, and cattle are the most important non-crop VCs.

Table 1: Structure of agricultural VCs' production, employment and land use, Senegal 2017

	GDP share (%)	Employment share (%)	Land area share (%)
AGRICULTURE	**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: ASTI-IFPRI data

4.3 Elasticities of agricultural R&D knowledge stocks of value chain total factor productivity

The magnitude of the VC elasticities is an important factor for determining the level of investments needed to achieve value chain total factor productivity growth.[5] Table 2 shows the agricultural R&D elasticities of VC TFP of KS for the crop and livestock VCs by private and public sector and CGIAR. The last column presents the elasticity of the total VC activity. No information is available for the fisheries sector.

Table 2: Elasticities of R&D knowledge stocks of VC TFP, Senegal 2017

Activities	R&D KS elasticity of VC TFP			
	Private sector	Public sector	CGIAR	VC activity (total)
Crops				
Maize	0.006	0.072	0.031	0.141
Sorghum & millet	0.011	0.144	0.062	0.284
Rice	0.020	0.263	0.113	**0.518**
Pulses	0.011	0.148	0.064	0.291
Groundnuts	0.022	0.291	0.126	**0.574**
Oilseeds	0.013	0.172	0.074	0.338
Cassava	0.024	0.317	0.136	**0.624**
Potatoes	0.018	0.237	0.102	**0.468**
Vegetables	0.020	0.255	0.110	**0.503**
Fruits	0.013	0.167	0.072	0.329
Traditional export crops	0.026	0.335	0.144	**0.660**
Livestock and fisheries				
Cattle	0.006	0.083	0.036	0.163
Milk & dairy	0.007	0.086	0.037	0.170
Poultry & eggs	0.007	0.085	0.036	0.167
Goats & sheep	0.018	0.233	0.100	**0.459**

Source: ASTI data (IFPRI), USDA

Elasticities from public sector R&D are greater than those from KS for private and CGIAR R&D for all VCs. The sectors with the greatest elasticities are traditional export crops (sugarcane, tobacco, cotton, tea, coffee, cocoa and flowers), cassava, groundnuts, rice, vegetables and potatoes. Goats/sheep have the highest elasticities among livestock VCs (Figure 4).

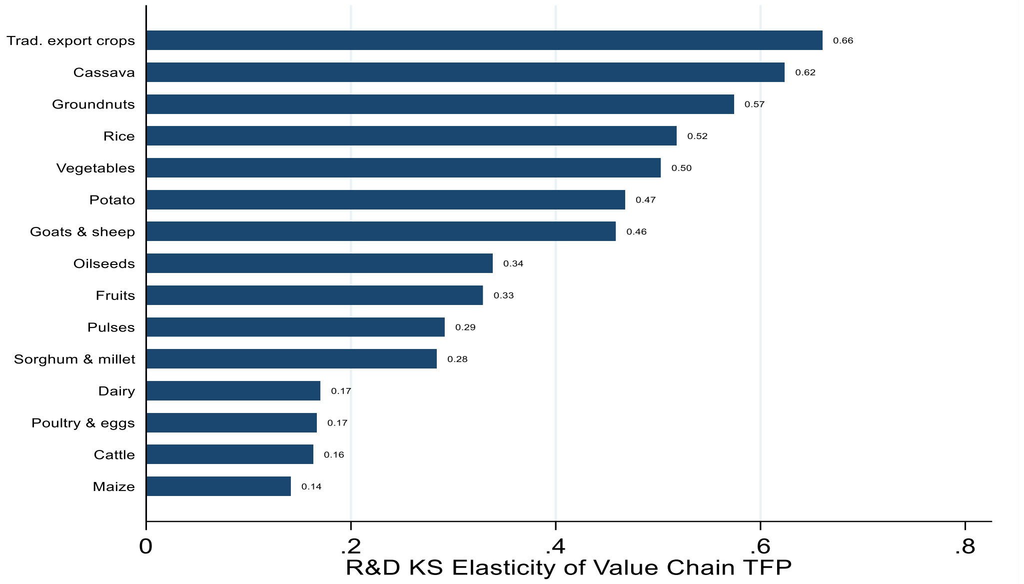


Figure 4: Ranking of R&D elasticities of VC TFP of knowledge stocks, Senegal

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

[5] The higher the elasticity, the smaller the level of KS needed to achieve a given TFP level.

Among the sectors with the greatest shares in GDP and employment, only rice and vegetables have relatively high elasticities. Among the sectors with the greatest shares of land area cultivated, only groundnuts have a relatively high elasticity.

5. Analytical results

The effects of growth in agricultural VCs on development outcomes depend on several key transmission channels in an economy-wide context. Those mechanisms are related to how prices, income generation and employment differ across agricultural VCs, and these differences affect economy-wide income generation, employment, poverty and nutrition. Randriamamonjy *et al*. (2020) undertook an in-depth analysis of VC prioritisation in Senegal.[6] 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.

RIAPA model simulations were used to rank how the expansion of different VCs contribute to development outcomes. We ranked VCs considering policy preferences that assume different weighting schemes: (a) equal weights, and (b) weights biased towards each of the four outcomes (poverty reduction, AFS growth, job creation and dietary diversity). Then, we took the information on the value chain TFP of KS elasticities, and the assessed KS growth for the VC TFP growth needed to achieve comparable agricultural GDP growth, to establish (out of the top-ranked VCs) the priority sectors on which R&D investments should be focused.

5.1 Rankings of VCs under different policy-outcome preferences in Senegal

Considering preferences that attribute relative priority weight to all objectives (equal weights and development outcome-biased weighting), as describe earlier, Table 3 and Figure 5 present the prioritisation results for Senegal.

No value chain is ranked in the top 10 in all the outcome-biased development goals (Figure 5a). Among the 15 VCs, five are in the top 10 of all outcome-biased indicators – traditional export crops, groundnuts, maize, poultry/eggs, and sorghum/millet. Vegetables are ranked in the top 10 in poverty, jobs and diets. Cattle and dairy are in the top ten for improving diets and AFS growth, while rice is top rated only for poverty reduction and job creation. Goats/sheep and fruits are ranked in the top 10 for dietary diversity and job creation.

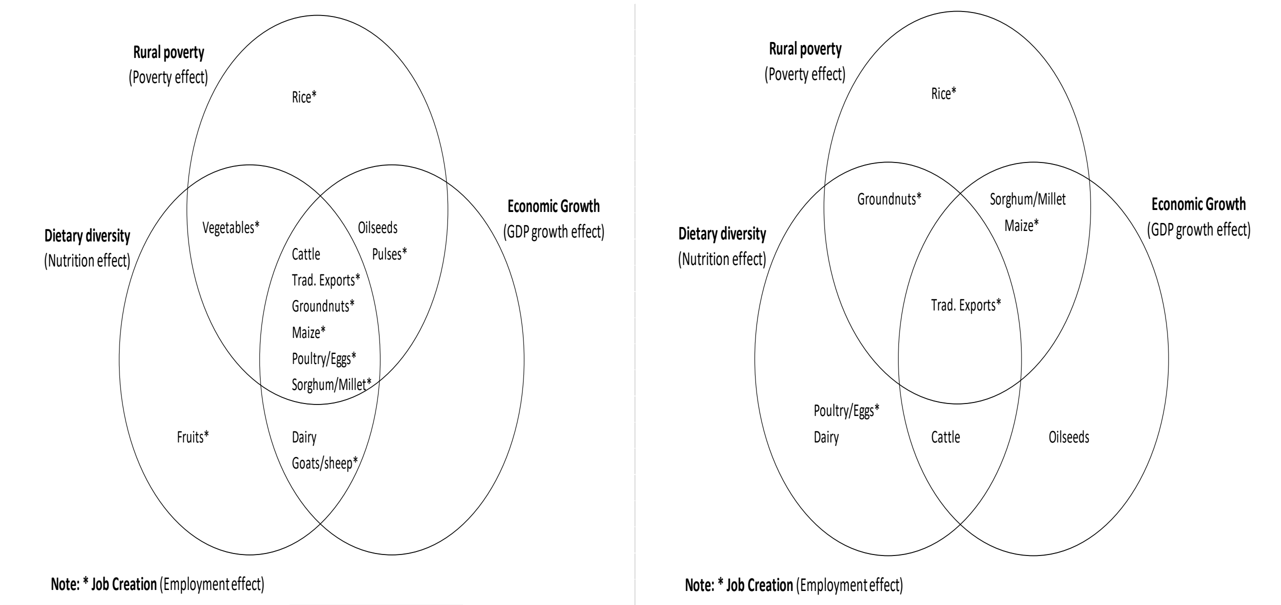
[6] Randriamamonjy *et al.* (2020) used a 2015 SAM and ran simulations for 2018 to 2022. We used a 2017 SAM and simulations for 2020 to 2025.

Table 3: Final rankings of VCs under different weighting schemes, Senegal

Rank	Equal weights	Poverty bias	Growth bias	Jobs bias	Nutrition bias
1	Traditional export crops	Rice	Oilseeds	***Traditional export crops***	Cattle
2	Groundnuts	***Maize***	*Cattle*	***Groundnuts***	***Traditional export crops***
3	Maize	***Groundnuts***	***Traditional export crops***	***Poultry & eggs***	***Groundnuts***
4	Sorghum & millet	***Sorghum & millet***	***Sorghum & millet***	Rice	***Poultry & eggs***
5	Cattle	***Traditional export 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 favours one indicator (one-half) at the expense of the others (one-third of the other half each).

Narrowing down to the top five VCs for Senegal (Figure 5b) indicates that, while no VC is the single top ranked, traditional exports (that include cocoa, sugarcane, non-food crops like tobacco, cotton and cut flowers, and beverage crops like coffee and tea) are the only one in the top-five ranking for all four development objectives. Cattle are effective for improving diets and generating growth. Sorghum/millet and maize are effective in 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 in reducing poverty and contributing significatively to job creation, while oilseeds contribute only to AFS growth, and dairy only to dietary diversity.



(a) Value chains in top 10 ranking (b) Value chains in top five ranking

Figure 5: Value chains with strong poverty, growth, jobs and nutrition effects, Senegal
Source: Results of RIAPA model

5.2 What value chains in Senegal need investment in R&D?

The identification of value chains that should be prioritised for the allocation of R&D resources takes the results of the value chain rankings described in the previous section as the first step. It then uses the information on the value chain total factor productivity of KS elasticities, and the assessed KS growth requirements for value chain TFP growth, to achieve a comparable 1% agricultural GDP growth (in 2025) to establish the priority sectors for R&D investment. Value chains that maximise development objectives, while minimising or requiring acceptable levels of R&D investment, are preferred over those that impose significant costs.[7]

5.3 Priority value chains for R&D in Senegal

The overall top 10 VCs with the greatest effects are listed in Table 4. Those marked with ‘Δ’ are in the top five, while those marked with ‘o’ are ranked from six to 10. We also indicate the level of VC-specific total factor productivity growth required to achieve a comparable 1% growth in agricultural GDP, the value chain TFP elasticity with respect to KS, and the implied change in KS required to achieve that TFP growth in Senegal (using equation (5)).

The required growth in total factor productivity for individual value chains is inversely related to the share of the value chain in agricultural GDP and employment, i.e. smaller VCs require growth rates that are relatively larger. For example, sorghum/millet, with one of the highest shares in agricultural GDP (10%) and employment (8%), needs a total factor productivity growth of about 0.9 percent to generate a 1% growth in agricultural GDP. In contrast, sectors such as traditional exports and pulses, with shares below 3% of agricultural GDP and employment, would have to grow total factor productivity much faster, at rates above 7.5%. Non-top-ranked sectors, like cassava and potato, which also have relatively lower shares in agricultural GDP and employment, have TFP growth

[7] The fisheries VC does not have information on R&D elasticities – it therefore is excluded from the analysis.

requirements that are even higher, viz. above 20%. Figure 6 highlights the inverse relationship and shows the top-10 priority VCs in red, and the lower ranked value chains (11 to 15) in blue.

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

		Development outcomes				Required TFP growth, TFP/KS elasticity, and required KS growth		
		Poverty	**Growth**	**Jobs**	**Diets**	**Required growth in TFP (%)**	**TFP/KS elasticity**	**Required ΔKS (%)**
1	**Traditional 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: Results of RIAPA model.
Note: Δ = ranked in top five; o = ranked six to 10

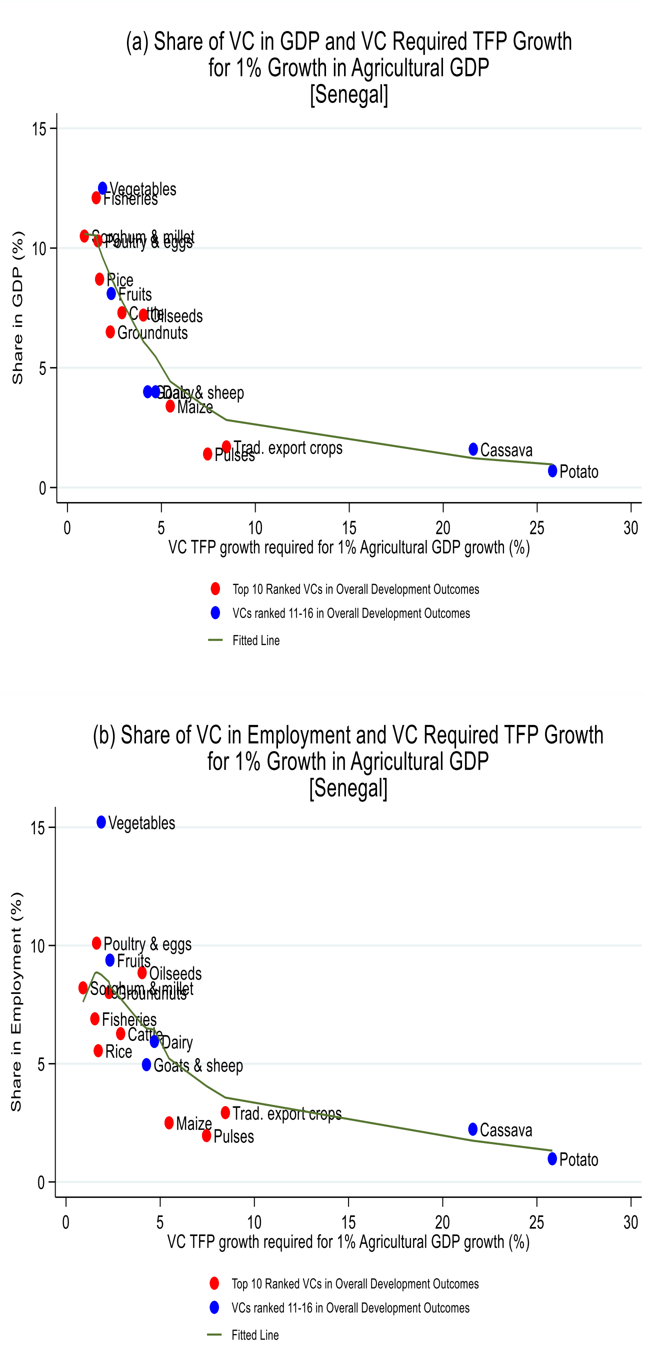


Figure 6: Value chain shares in GDP, employment and land area, and required TFP growth for unitary agricultural GDP growth, Senegal
Source: Simulation results of RIAPA model

The results of the assessment and recommended value chains in which R&D investments should be prioritised in Senegal are summarised in Figures 7 (for equally weighted development objectives) and 9 (for each of the four development objectives), and in the Venus diagrams in Figure 8.

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

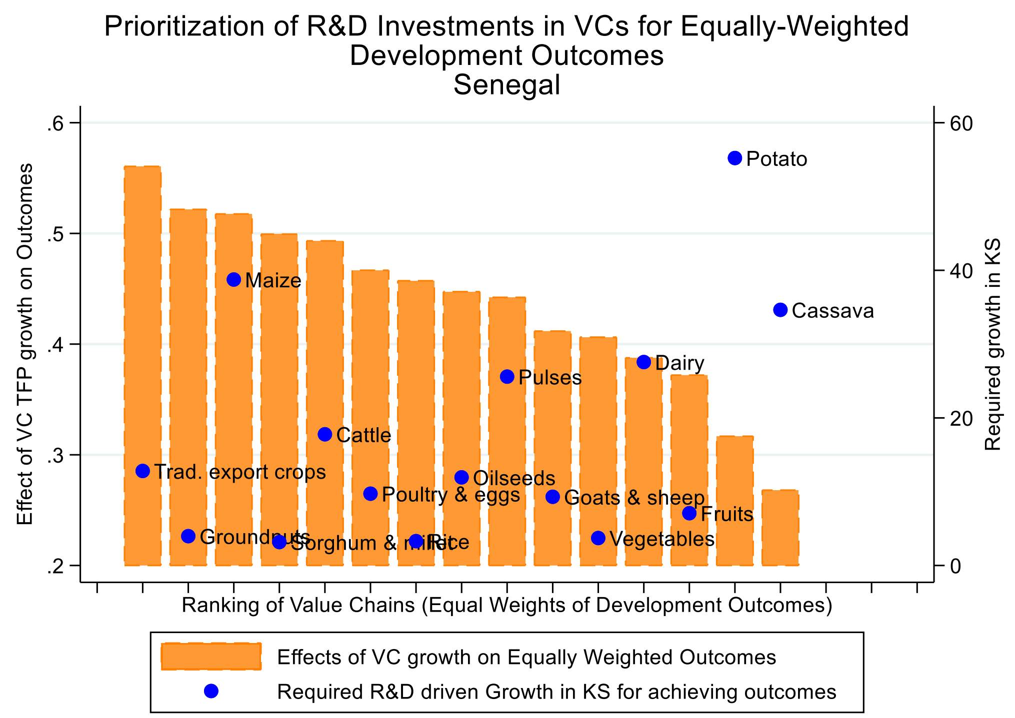
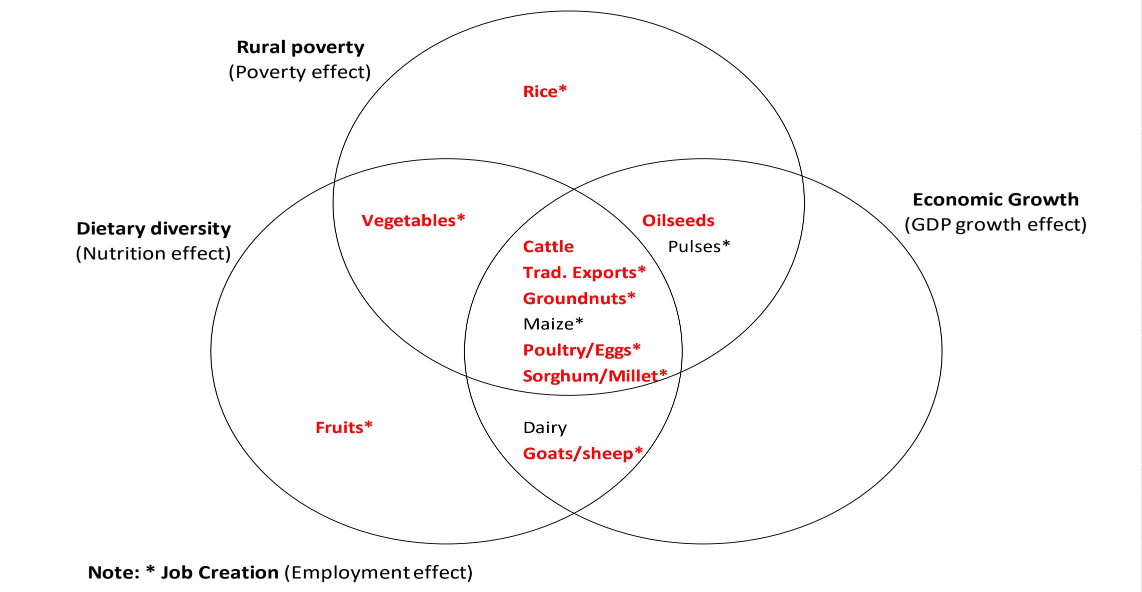


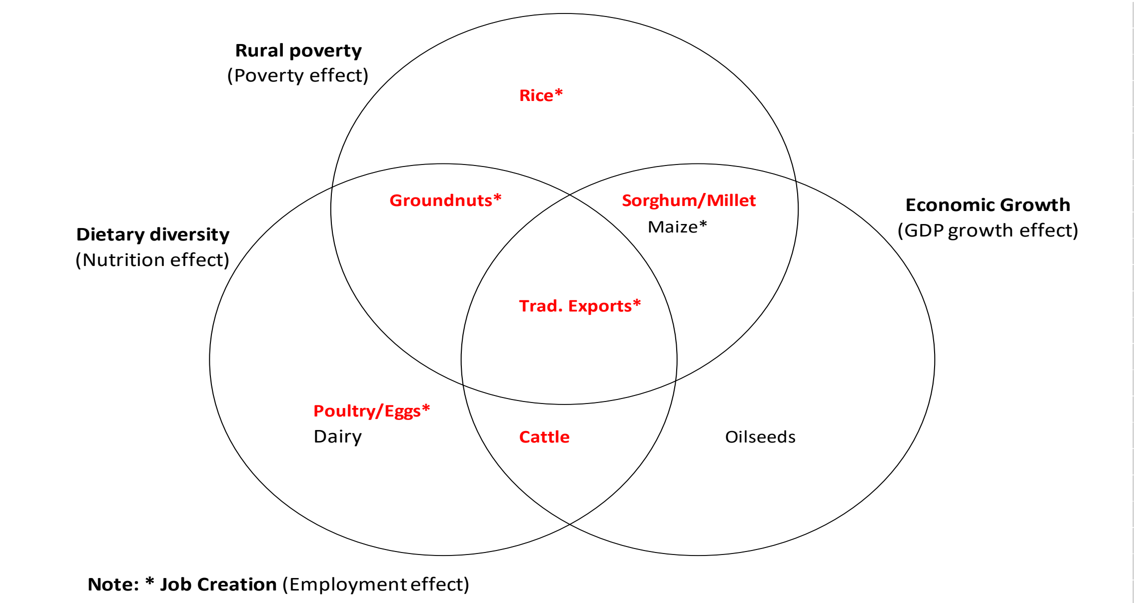
Figure 7: Prioritisation of R&D investments in value chains for equally weighted development outcomes, Senegal

Source: Results of RIAPA model and author's estimations

Looking at the scenario with an outcome-biased weighting of policy preferences (to highlight the outcomes that are more strongly influenced by value chain growth), and untangling the results suggested in the equal weighting scenario, Figures 8a and 9a to 9d also show some interesting results. First, they highlight the four value chains 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, they show that some VCs, while not top-rated for the top 10 in all criteria, deserve some consideration for R&D investments, given their relative strength in influencing selected development outcomes, and the relatively lower KS growth requirements. These include goats/sheep (growth, diets and jobs), rice (poverty and jobs), oilseeds (poverty and growth), vegetables (poverty and dietary diversity), and fruits (dietary diversity and jobs).



(a) VCs in top 10 ranking across development objectives



(b) VCs in top five ranking across development objectives

Figure 8: Value chains with strong poverty, growth, jobs and nutrition effects, with VCs among top ranked recommended for investment in R&D, Senegal

Note: **Red bold** indicates the VCs recommended for R&D investments.

Source: RIAPA model results and author's estimations.

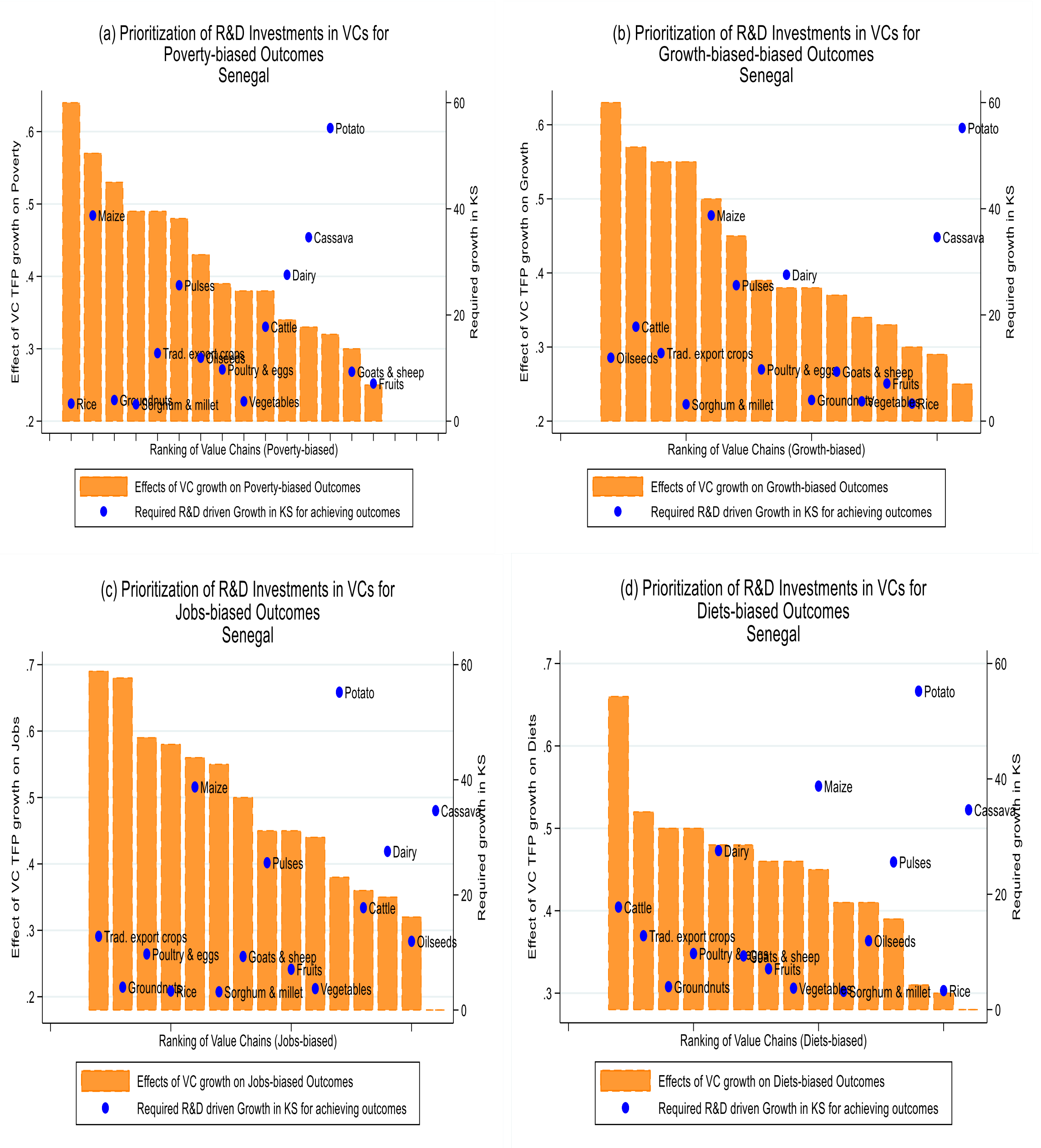


Figure 9: Prioritisation of R&D investments in VCs for alternative development outcomes, Senegal

Source: RIAPA model results and author's estimations.

Finally, narrowing the analysis down to the top five VCs (Figure 8b), we find that traditional exports (that aggregate sugarcane, tobacco, cotton, tea, coffee, cocoa and cut flowers) comprise the single VC that is ranked in the top five of all outcome-biased rankings. In addition to (a) traditional exports, other VCs that are effective at maximising at least two development outcomes, while minimising the levels of investment required to generate the necessary TFP growth, are (b) groundnuts (poverty, diets, and jobs), (c) rice (poverty and jobs), (d) poultry/eggs (diets and jobs), (e) sorghum/millet (poverty and growth), and (f) cattle (diets and growth). While not ranked in the top five for any development outcome-biased ranking, vegetables (the lead crop in GDP share and employment) are particularly appealing due to their relatively low R&D growth requirements and the potential they have for influencing poverty reduction, dietary diversity and job creation if an aggressive and strategic approach to their growth is pursued. Along the same lines, strategically targeted approaches could also succeed is supporting growth in oilseeds (poverty and growth) and fruits (diets and jobs), which are also relatively large sectors with potentially good long-run returns to R&D investments.

6. Conclusions and implications

This paper focuses on the prioritisation of value chains for the allocation of R&D resources to maximise development outcomes. The analysis uses the RIAPA dynamic CGE model to identify which agricultural VCs, when expanded to achieve a comparable growth in agricultural GDP, provide the strongest effects on those outcomes. Model results for the VC rankings and information on the elasticity of the value chain R&D knowledge stocks of total factor productivity were combined with simulated value chain-specific total factor productivity growth requirements, for a unitary expansion of agricultural GDP, to define the priority allocations of R&D resources in Senegal. Value chains that maximise development objectives, while minimising or requiring acceptable levels of R&D investment growth, are preferred over those that impose significant costs.

The results indicate that no single value chain is the most effective at improving all objectives. Accounting for policy preferences that attribute relative priority weight to all objectives, the results (assuming equal weights) indicate that the most effective VCs to be supported efficiently through R&D investments in order to maximise development objectives are (a) traditional exports (growth, diets and jobs), (b) groundnuts (poverty, diets and jobs), (c) rice (poverty and jobs), (d) poultry/eggs (diets and jobs), (e) sorghum/millet (poverty and growth), and (f) cattle (diets and growth). We also recommend that strategically targeted approaches could be used to extend R&D investments in vegetables (poverty, diets and jobs), oilseeds (poverty and growth) and fruits (diets and jobs), which are also relatively large sectors with potentially great returns to R&D investments.

Finally, while we make suggestions regarding the optimal set of value chains to be subject to expansion through R&D investment, it will be critical to deepen the understanding and standardise the integration of the R&D investment dimensions to better inform strategies aimed at sustainably improving multiple development outcomes, and to take into consideration other complementary investments beyond R&D, such as irrigation, extension services, and targeted input subsidies. Equally important are policies and investments in road and communications infrastructure that enable and sustain inclusive value chain growth. Future research and prioritisation modelling should be extended to include such efforts and inform a coherent set of interventions.

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References

Benfica R & Henderson H, 2021. The effect of the sectoral composition of economic growth on rural and urban poverty. Review of Income and Wealth 67(1): 248–84.

Benfica R, Chambers J, Koo J, Nin-Pratt A, Falck-Zepeda J, Stads G & Arndt C, 2021. Food system innovations and digital technologies to foster productivity growth and rural transformation. United Nations Food Systems Summit Brief Paper. https://dx.doi.org/10.48565/scfss2021-6180

Christiaensen L, Demery L & Kuhl J, 2011. The (evolving) role of agriculture in poverty reduction – An empirical perspective. Journal of Development Economics 96(2): 239–54.

Diao X & Thurlow J, 2012. A recursive dynamic computable general equilibrium model. In Diao X, Thurlow J, Benin S & Fan S (eds.), Strategies and priorities for African agriculture: Economywide perspectives from country studies. Washington DC: IFPRI.

Esposti M & Pierani F, 2003. Building the knowledge stock: Lags, depreciation, and uncertainty in R&D investment and link with productivity growth. Journal of Productivity Analysis 19: 33–58.
Fuglie K, 2016. The growing role of the private sector in agricultural research and development world-wide. Global Food Security 10: 29–38.
Hall BH, Mairesse J & Mohnen P, 2009. Measuring the returns to R&D. NBER Working Paper w15622, NBER, Cambridge MA.
Löfgren H, Harris RL & Robinson S, 2001. A standard computable general equilibrium (CGE) model in GAMS. IFPRI-TMD Discussion Papers 5, International Food Policy Research Institute, Washington DC.
Nin-Pratt A, 2011. Agricultural R&D investment, poverty, and economic growth in sub-Saharan Africa. Prospects and needs to 2050. Conference Working Paper No. 9, IFPRI, Washington DC.
Nin-Pratt A, 2021. Returns to R&D investment to inform priority setting in the One CGIAR and NARS. IFPRI Discussion Paper 01559, International Food Policy Research Institute, Washington DC.
Pingali PL, 2012. Green revolution: Impacts, limits, and the path ahead. Proceedings of the National Academy of Sciences 109(31): 12302–8.
Randriamamonjy J, Thurlow J & Wiebelt M, 2020. Identifying priority agricultural VCs in Senegal. PEGNet Policy Studies, IFPRI, Washington DC.
Thurlow J, Sahoo A & Benfica R, 2020. Rural investment and policy analysis (RIAPA): An economy-wide model for prioritizing VC investments in developing countries. Unpublished IFPRI document.