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**Parameter Uncertainty in Policy Planning Models:
Using Portfolio Management Methods to Choose
Optimal Policies under World Market Volatility**

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Abstract

This paper suggests using portfolio management methods in policy planning models as a practical tool for determining optimal policy under model parameter uncertainty. We suggest that in addition to calculating the standard policy return estimates, policy options should also be analyzed from the risk perspective by using metrics that inform the effect of parameter uncertainty on policy impact variation. We demonstrate the approach in a Computable General Equilibrium model that analyzes pro-poor agricultural value chains in Senegal under world market uncertainty. We show that prioritizing the rice sector is the most effective policy in terms of expected policy return, but this policy is also associated with the highest risk, leading to an increase in poverty under unfavorable yet realistic scenarios. Much like diversified portfolios in finance, mixed policies that assume the rice sector's promotion combined with other sectors such as milk, vegetables, oilseeds, or fishery, can offer risk reduction at the cost of reduced expected policy return.

Keywords: policy analysis; CGE modeling; portfolio management; pro-poor growth
JEL classification: D58, C68, O13, Q11, I3, O21, G110

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Declarations of interest

None.

1. Introduction

Modern evidence-based policy requires to quantitatively formulate the impact of policy options considered by policymakers. One of the standard tools utilized for such purpose is the Computable General Equilibrium (CGE) modeling (Dixon and Rimmer, 2016; Taylor, 2016; Henning et al., eds, 2018). This type of model allows estimating the economywide implications of potential policy shocks, and in various fields, CGE models are used to compare policy options and define optimal policy intervention¹ However, policy conclusions based on the classic deterministic CGE models can be corrupted by exogenous model parameter uncertainty. Reparameterization of a CGE model can affect the quantitative and even qualitative impact of policy simulations (e. g., Fugazza and Maur 2008; Olekseyuk and Schürenberg-Frosch 2016; Phimister and Roberts 2017), and comparative analysis of policy options in a standard deterministic fashion might not allow defining optimal policy.

This paper suggests using portfolio management methods in CGE-based policy planning models as a practical tool for defining optimal policy under model parameter uncertainty. In addition to the standard policy impact estimates, we suggest analyzing policy options from the risk perspective, with indicators of policy impact variation caused by parameter uncertainty being used as volatility/risk metrics. Similar to portfolio theory, policy options are explicitly characterized by both policy return and risk perspective, and the selection of optimal policy depends on policymakers' risk/return preferences (Markowitz, 1952, 1959; Sharpe, 1994). To our knowledge, this is the first paper that suggests the use of portfolio theory in CGE-based studies in order to explicitly account for model parameter uncertainty.

We apply our approach to the CGE-based analysis of agricultural value chains in Senegal. Poverty reduction and pro-poor growth are declared as of the most important goals of the country (World Bank, 2020b; African Development Bank, 2010), and many studies demonstrate that agriculture remains the most significant sector in achieving these goals (e. g. Diao et al. 2010; Valdés and Foster 2010; Klasen and Reimers 2017). However, developing a country-specific pro-poor agricultural policy requires a comparative analysis of each agricultural value chain (e. g. Pauw and Thurlow 2015; Chhuor 2017; Benfica and Thurlow 2017; Otchia 2018; Ferrari 2018).

In the case of the Senegalese CGE model with a focus on agricultural policy planning, the set of model parameters representing world markets is essential. In the context of

¹For example, Ojha et al. (2013) use a CGE model of India and compare economic and distributional consequences of policies that promote growth of physical capital, human capital or technological progress. Liu et al. (2015) use China's financial CGE model to investigate the effectiveness of various monetary policy options in response to oil price shocks. Ge and Lei (2017) use China's bioethanol CGE model and argue that demand incentives are better than supply incentives for GDP growth, energy saving, and emission reduction. Benfica et al. (2019) use a CGE model of Mozambique and show that the government should have reallocated resources towards agricultural research and extension, as this is the most effective policy at raising growth and reducing poverty in all regions of the country.

increased volatility on the international markets (World Bank, 2020c), and recommendations for the policymakers in developing countries to explore counter-cyclical mechanisms for external shocks (FAO, 2011), the standard assumption about constant world market prices in policy planning models becomes particularly weak. When analyzing Senegal’s agricultural value chains, we use portfolio management methods to explicitly account for the world market uncertainty. As a domain of endogenous policy outcomes, we consider the Poverty-Growth Elasticities (PGE) of ten primary agricultural sectors, and as a domain of uncertain model parameters, we consider the Rest of the World (RoW) parameters - that is, the world market prices and the country’s current account. Similar to financial portfolio management, we treat indicators representing expected PGE and its variation due to RoW volatility as return and risk metrics of policy options. Furthermore, because PGE of agricultural sectors are not perfectly correlated (due to different production structures, trade characteristics, economic linkages, etc.), we consider portfolio diversification methods that can offer risk reduction (for a given return) or increase of return (for a given risk). In addition to standard sector-specific policy comparison scenarios, we sample mixed-policy scenarios and estimate the PGE of all policy scenarios under various RoW scenarios.

We demonstrate that a policy that exclusively promotes the rice sector is the most effective in poverty reduction when only looking at expected policy return, but this option is also associated with the highest risk. Under the least favorable RoW scenarios, this policy can even lead to an increase in poverty. Mixed policies that assume the rice sector’s promotion combined with other sectors can offer risk reduction at expected return costs. We show that the promotion of milk, vegetables, oilseeds, or fishery sectors can mitigate the risks associated with the country’s reliance on the rice sector. Given the government’s current prioritization of the rice sector in response to the 2008 food crisis (Liesbeth et al., 2013), the suggested application of widely known portfolio management principles can be particularly beneficial for Senegal’s practical policymaking.

The rest of this paper proceeds as follows. Section 2 provides a brief overview of the CGE modeling literature that addresses model parameter uncertainty and describes the suggested use of portfolio methods in the CGE-based policy studies. Section 3 describes the application to the analysis of the Senegalese pro-poor agricultural value chains. Finally, section 4 highlights the potential implications for policy analysis and concludes.

2. Portfolio management methods in CGE modeling

Policy choices based on the estimates and point predictions produced by deterministic models can be very fragile, as policy conclusions often rest on critical assumptions, and communication of the uncertainty either of the researchers with the policymakers or of the policymakers with the public can be rarely found in practical policy analysis (Manski,

2011). In CGE modeling, the choice of exogenous model parameters is critical, as it can often affect the quantitative and even qualitative impact of policy simulations (see e. g. Fugazza and Maur 2008; Olekseyuk and Schürenberg-Frosch 2016).

As a response to this problem, the concept of Systematic Sensitivity Analysis (SSA), popularized by Arndt and Pearson (1998), is increasingly used in CGE-based studies. The concept addresses the problem of parameter uncertainty by treating exogenous CGE parameters as random variables. The SSA implies estimating the variation of CGE endogenous variables of interest by sampling exogenous model parameters from assumed or estimated distributions. For example, Valenzuela et al. (2007) suggest using the SSA to validate the global agricultural CGE model by sampling output shocks and comparing simulated and historically observed price volatility in various world regions. Webster et al. (2008) use the SSA to address the uncertainty in projections of emissions and atmospheric stabilization costs for five climate scenarios. Phimister and Roberts (2017) use the SSA to investigate the implications of allowing uncertainty in exogenous shocks when modeling a new onshore wind sector in North East Scotland. Chatzivasileiadis et al. (2018)) conduct SSA to address parameter uncertainty when analyzing the effects of sea-level rise on the global economy. Mukashov et al. (2019); Ziesmer et al. (2020) extend SSA's principles to policy parameters and demonstrate how the model uncertainty can affect policy impact estimations and optimal policy choice.

Methodologically this paper follows recent literature strands and uses the SSA methods to represent the impact of parameter uncertainty on endogenous variables of interest. However, our approach's peculiarity is the suggestion to integrate SSA methods into the portfolio management framework.

Our approach is mainly targeted at those cases when a comparison of policy options under standard SSA methods fails to define optimal policy. Specific policy options might be robustly superior regardless of the model's reparameterization. In this case, SSA sampled parameters/scenarios affect policy impact estimates, but not policy rankings themselves. However, if policy scenarios are not robust under certain SSA reparameterizations (e. g., Fugazza and Maur 2008; Olekseyuk and Schürenberg-Frosch 2016), it becomes difficult to define univocally optimal policy. As a solution to this problem, we suggest explicitly representing risk/return trade-offs of policy options and use portfolio management principles to select an optimal policy.

The important prerequisite to refer to portfolio management tools is the standard tools' inability to define optimal policy. Therefore, as a first step, it is necessary to investigate important shock transmission mechanisms of a specific model and define the set of uncertain model parameters that can affect policy impact estimates. The SSA methods should then be used to compare policy options under the uncertain exogenous model parameters; if none of the policies is robustly superior under the SSA sampled scenarios, portfolio management tools can be used.

Modern portfolio and risk management methods are very diverse, and the specifics of mathematical finance concepts are beyond this paper’s scope. In our application to CGE-based analysis of agricultural value chains in Senegal, we use simple portfolio theory concepts defined in Markowitz (1952, 1959); Sharpe (1994); Jorion (2007). To represent risk/return trade-offs, we use simple metrics such as the average value of policy impact (represents expected policy return), standard deviation of policy impact (represents the volatility/risk of a policy), and minimum policy impact (represents the worst-case policy return). Furthermore, because considered agricultural policy options are not perfectly correlated, much like diversified portfolios in finance, we consider diversified (mixed) policies. We rank all policy options based on expected return or risk and represent a (sub)set of efficient policies where higher expected return requires taking more risk, or lower risk requires lowering return expectations. Thus, investors (policymakers) faced with a trade-off between expected return and risk have to select an optimal policy based on their risk/return preferences.

Although our method does not offer a universal tool to define optimal policy, the suggested application of portfolio management methods contributes to practical policymaking by offering widely-known financial instruments for direct communication of model uncertainty with policymakers. In this context, our framework can encourage policymakers to express their risk and return preferences explicitly and, therefore, increase the transparency of their policy choices (see Manski 2011, 2018, for more details).

3. Agricultural policy in Senegal under the world market uncertainty

3.1. The standard approach to define the pro-poor agricultural value chain

We use the recursive-dynamic CGE model of the International Food Policy Research Institute (IFPRI) developed by Löfgren et al. (2002) and Diao and Thurlow (2012) and the 2015 Social Accounting Matrix (SAM) constructed by Randriamamonjy and Thurlow (2019). We select five years as our simulation horizon (2020-2024)² and tailor the IFPRI CGE model and the SAM to reflect specific adjustment possibilities of the Senegalese economy in the medium-term (see appendix A.1 and A.2 for more details). Used SAM and selected functional forms and closures define the set of CGE parameters, and we use different sources, estimates, and approximations to assign fixed parameter values (see appendix A.3 for more details).

²Years 2015-2019 are run in the background to approximate already known developments.

As a set of policy parameters, we consider the Total Factor Productivity (TFP) growth of ten primary agriculture sectors (table 1, col. 1-2). In general, productivity increase means that a country can increase output with the same available production factors (capital, labor, and land). Consequently, households (who own most of the country’s production factors) should receive a higher income and increase consumption. In turn, a productivity increase of agricultural sectors should particularly benefit poorer rural residents³, who own most of the agricultural capital, labor, and land. However, depending on the sectors’ structural characteristics, the effectiveness of specific sectors within agriculture might vary significantly.

Table 1: Considered agricultural sectors

Sector	Short	GDP, %	Export in output, %	Import in consumption, %	TFP growth per year	Standard PGE	Rank
Sorghum, millet	sorg	1.46	-	0.0	1.49	-1.04	10
Rice	rice	1.15	19.4	53.6	2.94	0.84	1
Groundnuts	gnut	1.01	6.0	0.0	2.70	-0.53	9
Other oilseeds	oils	1.48	4.3	1.2	1.91	-0.40	7
Vegetables	vege	1.78	10.2	4.6	1.49	-0.38	6
Fruits	frui	1.55	7.4	3.9	1.30	-0.40	7
Cattle	catt	1.21	0.0	0.2	2.53	-0.30	4
Poultry	poul	0.85	0.1	0.3	2.99	-0.30	4
Raw milk	milk	1.20	-	-	2.04	0.02	2
Fishery	fish	1.43	8.2	0.0	2.22	-0.29	3

Source: SAM (2015) and CGE simulations by the authors.

Following Wiebelt et al. (2020), who conducted the standard CGE-based policy analysis of the Senegalese agricultural value chains, we define standard TFP sectoral scenarios such that 1 percent growth of total agriculture by 2024 is achieved uniquely by respective sectors (table 1, col. 6). Then, obtained policy impact estimates represent sectors’ effectiveness in poverty reduction per 1 percent of agricultural growth. Therefore, we define policy impact estimates under standard TFP sectoral scenarios as (semi) Poverty-Growth elasticities (PGE⁴, table 1, col. 7) and rank sectors (table 1, col. 8). We obtain a similar conclusion to Wiebelt et al. (2020) that rice and milk are the only sectors that can reduce the national poverty headcount, with the rice sector being outstandingly more effective than milk.

3.2. Uncertain model parameters

The rice sector’s estimated high effectiveness can be primarily attributed to its trade intensiveness (table 1, col. 4 and 5). The increased output should be absorbed by

³Per-capita consumption of rural households is 3.7 times lower than of urban residents; poverty incidence in rural areas is 57 percent compared to 26 percent in Dakar and 41 percent in other cities (Randriamamonjy and Thurlow, 2019; ANSD, 2013).

⁴In order to operate with the term ‘return’ in the meaning similar to finance, we calculate PGE as percentage difference of poverty headcount under the no-policy vs. policy scenario. In other words, positive PGE indicates poverty reduction and vice-versa.

domestic or external demand, and the trade intensive rice sector benefits from import substitution or export expansion opportunities, and *ceteris paribus*, can expand more than less tradable sectors. These estimates are in line with Senegal’s actual agricultural policy, where the rice sector is under the policymakers’ particular focus since the 2008 food crisis. The current national rice policies consist of trade liberalization accompanied by massive investments to intensify domestic production (Liesbeth et al., 2013).

However, this policy shock transmission mechanism’s effectiveness is based on the assumption about constant RoW model parameters. If one assumes the downward price trend on the agricultural markets (e. g. 1985-1992 or 2011-2020, see figure 1), investing in tradable sectors becomes less profitable, as they are expected to face increased price pressure from the international markets. Under these conditions, the promotion of non-tradables can become a more effective policy because of overall economywide effects.

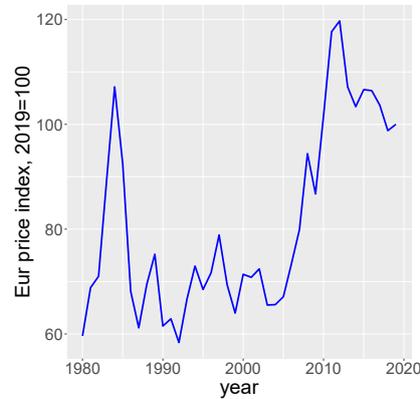


Figure 1: Price index of agricultural commodities

See appendix A.3 for sources and details.

This indirect channel’s effectiveness largely depends on the economic linkages between the agroprocessing and primary agriculture sectors (table 2). Less tradable sectors have to reduce prices because their increased output can be sold on the domestic markets without price competition from the rest of the world. In turn, downstream sectors with a large share of affected intermediate costs can reduce their own prices, which should lead to increased demand and production (for example, grain/cereal milling can be expected to benefit from the fall of the prices of sorghum and millet and increase production). At the same time, the performance of all sectors, including non-tradables, can be susceptible to external volatility because of imported intermediates (for example, all petroleum products and fertilizers in Senegal are imported).

In the context of increased volatility on the international markets (World Bank, 2020c; FAO, 2011), the standard assumption about constant world market prices becomes particularly weak, and our CGE model’s properties demonstrate that the agricultural sectors’ effectiveness in generating income and reducing poverty can be sensitive to the RoW assumptions. Therefore, as a domain of varying model parameters, we consider world

Table 2: Linkages between agroprocessing and primary agriculture

Sector	Intermediate costs, %	of which primary agr., %
Meat	41.1	69.7
Fish and seafood	49.0	77.5
Dairy	52.2	32.1
Grain/cereal milling	70.9	81.5
Fruits, vegetables & other	68.4	62.0
Beverages	48.5	39.9
Other foods	41.1	42.6
Cotton yarn & other	58.0	2.2
Leather & other	63.5	6.8
Miscellaneous non-food	68.5	10.0

Source: SAM (2015).

markets, which, unlike other uncertain but relatively rigid model parameters (e. g., trade elasticities), can change significantly and affect medium-term agricultural policy planning.

As was demonstrated in 2007-08 and 2020, developing countries like Senegal are exposed to the volatility on the international markets not only through the prices of tradable commodities but also indirectly via the international capital flows that affect the exchange rate, investment, and growth (World Bank, 2020c; FAO, 2011). Therefore, in addition to the price indices, we use the current account deficit estimates by the IMF (2020) to represent the uncertainty in RoW (table 3).

Table 3: Varying exogenous model parameters

Original data	Mapping to CGE model	Short
Agriculture index	change of the world price of agricultural commodities	pw_agri
Manufactures Unit Value Index	change of the world price of manufacturing products	pw_MUVi
Energy index	change of the world price of energy commodities	pw_ener
Fertilizers index	change of the world price of fertilizers	pw_fert
Metals & Minerals index	change of the world price of metal or minineral commodities	pw_mtmn
CPI Services (France)	change of the world price of services	pw_serv
Current account deficit	change of foreign savings	fsav

See appendix A.3 for sources and details.

3.3. Systematic Sensitivity Analysis

Let us consider standard sectoral PGE but allow for the variation of RoW parameters. To sample RoRoW scenarios, we follow Webster et al. (2008) and use the Latin Hypercube Sampling from a multivariate Gaussian distribution. We estimate the mean and the variance of the Gaussian distribution (see appendix A.4 for details) and treat sampled parameters as possible RoW scenarios (table 4). Then, we calculate PGE and rank the poverty reduction effectiveness of agricultural sectors for each sampled RoW scenario (table 5).

Rice is ranked as the most effective in poverty reduction in six of ten sampled RoW scenarios. Under four scenarios (#3, 5, 7, 9), the rice sector's promotion is a sub-optimal policy as other sectors are more effective in generating income and poverty reduction.

Table 4: Sampled RoW scenarios

Scenario	pw_agri	pw_MUVi	pw_ener	pw_fert	pw_mtmn	pw_serv	fsav
row1	4.89	2.58	7.78	0.67	-0.67	1.03	-6.94
row2	0.42	1.02	3.05	7.39	-7.41	1.50	16.07
row3	-3.11	-3.91	-11.54	-0.24	-5.73	0.11	-12.14
row4	2.48	-3.12	-1.87	12.58	3.52	2.64	7.31
row5	-5.46	-0.67	-5.99	-9.33	-10.37	2.29	1.59
row6	-0.89	-2.16	6.39	-2.66	4.89	-0.06	11.06
row7	-1.95	0.70	-8.96	-11.42	-3.70	2.07	-15.11
row8	3.60	3.62	-3.03	9.03	10.36	0.80	4.99
row9	2.29	1.86	12.19	3.23	0.10	0.47	-1.66
row10	-3.91	-1.65	0.99	-6.00	7.17	1.59	-5.95

Source: Authors compilation. See appendix A.4 for details.

In particular, scenarios #3, 5, and 7 assume an overall decrease of the world market prices, and under these scenarios, the rice sector is ranked as one of the worst policy options. Less tradable sectors with stronger upward linkages tend to become more efficient options under the overall low world market prices (the groundnuts sector is the best option under scenario # 3, and fishery becomes the best option under scenarios #5 and 7). Furthermore, under scenario #9, which assumes high energy prices, the rice sector is less effective than vegetables. The non-tradable milk sector, which has the second-highest PGE under the standard approach (table 1, col. 7), demonstrates its robustness and is ranked as a second or third best policy option under the majority of scenarios.

Table 5: Sectoral ranking and PGE under different RoW scenarios

Scenario	Rank1	Rank2	Rank3	Rank4	Rank5	Rank6	Rank7	Rank8	Rank9	Rank10
row1	rice	vege	gnut	oils	frui	milk	catt	fish	poul	sorg
	0.58	0.38	0.35	0.32	0.32	0.31	0.29	0.29	0.05	0.02
row2	rice	oils	vege	catt	fish	milk	poul	gnut	frui	sorg
	0.78	0.36	0.36	0.24	0.24	0.23	0.05	0.05	0.05	-0.53
row3	gnut	fish	milk	poul	vege	oils	frui	rice	sorg	catt
	0.09	0.01	-0.01	-0.09	-0.13	-0.13	-0.13	-0.33	-0.36	-0.41
row4	rice	vege	fish	oils	frui	catt	poul	milk	gnut	sorg
	0.31	-0.08	-0.10	-0.10	-0.10	-0.10	-0.14	-0.14	-0.37	-0.57
row5	fish	milk	catt	vege	frui	oils	poul	gnut	sorg	rice
	0.66	0.65	0.52	0.26	0.26	0.26	0.26	0.24	0.18	0.16
row6	rice	milk	vege	oils	frui	fish	gnut	catt	poul	sorg
	0.61	0.18	0.08	0.07	0.07	-0.11	-0.18	-0.21	-0.21	-0.69
row7	fish	milk	gnut	rice	oils	frui	vege	poul	catt	sorg
	0.04	-0.03	-0.13	-0.22	-0.24	-0.24	-0.29	-0.39	-0.41	-0.82
row8	rice	milk	oils	vege	fish	frui	catt	poul	gnut	sorg
	0.71	0.00	-0.08	-0.08	-0.09	-0.14	-0.14	-0.14	-0.22	-0.36
row9	vege	rice	milk	fish	catt	poul	frui	gnut	oils	sorg
	0.38	0.31	0.27	0.27	0.25	0.20	-0.03	-0.03	-0.17	-0.32
row10	rice	milk	poul	oils	fish	catt	vege	gnut	frui	sorg
	0.10	0.00	-0.02	-0.10	-0.16	-0.27	-0.29	-0.32	-0.34	-0.65

Source: CGE simulations by the authors.

Depending on the RoW scenario, different sectors are ranked as the most efficient in poverty reduction, meaning that comparative analysis of agricultural policy options in a standard deterministic fashion does not define optimal policy.

3.4. Portfolio management methods

Having established the inability of standard tools to define optimal policy under the RoW uncertainty, we refer to portfolio management methods and perform the comparative analysis of policy options based on portfolio management principles.

In the context of our case study, besides the standard comparison of sectors, consideration of mixed policies is necessary. By design of our CGE model, returns of considered agricultural sectors are not perfectly correlated (different production structure, trade characteristics, economic linkages, etc.), which means that portfolio diversification methods used in finance can be applied to policy options to reduce the risk for a given return or increase the return for a given risk. To cover the spectrum of possible mixed policies, we sample 1000 scenarios of various combinations of the TFP shocks such that the growth of total agriculture for all scenarios is 1 percent by 2024 (see appendix A.5 for more details). In other words, simulations under mixed policy scenarios assume that all agriculture's weighted average TFP growth is 1 percent by 2024. Therefore, these scenarios' estimated policy impacts are treated as PGE similar to the standard comparative analysis of sectoral scenarios.

We treat indicators representing the expected poverty reduction as expected policy returns, and indicators representing the volatility of poverty outcomes due to RoW scenarios as risk metrics. It should be noted that our comparative analysis of PGE relies on the implicit assumption that costs of productivity growth across all sectors of primary agriculture in Senegal are constant and depend only on sectors' size. In other words, we assume that agricultural sectors of the same size for the same money should realize the same TFP increase. This assumption is not unusual and can be met even in the literature strands that compare the effectiveness of much more heterogeneous sectors (such as agriculture versus non-agriculture; see, for example, Valdés and Foster 2010; Diao et al. 2010). However, a study by Henning et al. (2017) that analyzed the Comprehensive Africa Agriculture Development Program in Malawi demonstrates that this assumption should be treated cautiously. Most importantly, the authors use the Cobb-Douglas function and assume a diminishing marginal impact of budget spending on sectoral TFP. Estimated exponent parameters of the crop sector (0.525) and livestock sector (0.363) imply that the crop sector in Malawi, for the same money, should grow faster than the livestock sector (in other words, crops have a higher potential for productivity growth than livestock). Because the integration of this approach into this paper requires a lot of additional in-

formation and estimation, we leave it for future work and assume that sectors of primary agriculture in Senegal are technologically homogeneous.

Due to computational limitations, each policy scenario (including non-diversified options, 1010 scenarios in total) is simulated for ten exogenous RoW scenarios considered above (10100 simulations in total). Given sample restrictions, we do not use advanced mathematical finance methods that involve analysis of return distributions and application of the latest available modern portfolio theory methods. To represent risk/return trade-off, we use simple metrics such as the average value of PGE (represents expected return), standard deviation of PGE (represents the volatility of expected return), or minimum value of PGE (represents the worst-case expected return of a policy).

Table 6: Top five policies based on expected return (avg[PGE])

Policy	Weights/composition										Avg	STD	Min
	sorg	rice	gnut	oils	vege	frui	catt	poul	milk	fish			
rice		100.0									0.30	0.38	-0.33
D361	1.2	45.8	4.7	2.2	12.6	3.4	1.7	3.8	23.6	1.0	0.20	0.22	0.00
D831	0.6	46.6	2.4	14.6	17.6	4.3	4.4	3.9	3.4	2.2	0.19	0.21	-0.04
D923	5.1	67.4	1.5	4.1	0.7	1.3	11.3	3.9	2.0	2.7	0.18	0.22	-0.04
D896	5.2	43.7	1.5	2.5	7.3	0.1	1.2	5.1	22.8	10.6	0.18	0.20	0.00

Source: CGE simulations by the authors.

Table 7: Top five policies based on worst-case return (min[PGE])

Policy	Weights/composition										Min	Avg	STD
	sorg	rice	gnut	oils	vege	frui	catt	poul	milk	fish			
D361	1.2	45.8	4.7	2.2	12.6	3.4	1.7	3.8	23.6	1.0	0.00	0.20	0.22
D896	5.2	43.7	1.5	2.5	7.3	0.1	1.2	5.1	22.8	10.6	0.00	0.18	0.20
D767	1.0	55.7	7.5	0.2	3.6	5.8	3.6	8.2	3.4	11.1	0.00	0.18	0.22
D151	1.3	60.5	2.4	0.3	1.6	5.8	8.6	3.0	15.7	0.6	0.00	0.18	0.20
D766	4.9	50.0	5.0	3.3	4.7	10.2	1.2	5.3	4.8	10.7	0.00	0.17	0.20

Source: CGE simulations by the authors.

Table 8: Top five policies based on Sharpe ratio (avg[PGE] / STD[PGE])

Policy	Weights/composition										Sharpe	Avg	STD
	sorg	rice	gnut	oils	vege	frui	catt	poul	milk	fish			
D891	1.8	63.7	3.6	2.0	2.1	0.7	1.7	0.6	17.3	6.4	1.07	0.16	0.15
D896	5.2	43.7	1.5	2.5	7.3	0.1	1.2	5.1	22.8	10.6	0.94	0.18	0.20
D361	1.2	45.8	4.7	2.2	12.6	3.4	1.7	3.8	23.6	1.0	0.92	0.20	0.22
D831	0.6	46.6	2.4	14.6	17.6	4.3	4.4	3.9	3.4	2.2	0.91	0.19	0.21
D151	1.3	60.5	2.4	0.3	1.6	5.8	8.6	3.0	15.7	0.6	0.86	0.18	0.20

Source: CGE simulations by the authors.

Table 6 shows the top five policies ranked based on expected return. The option that has the highest expected poverty reduction is an exclusive promotion of the rice sector. However, this policy option is also associated with the highest volatility (highest standard deviation, STD). Under the least favorable RoW conditions, an exclusive promotion of the rice sector can even lead to negative returns (min PGE is negative, which means

an increase in poverty). Consequently, policymakers might consider less risky options with a lower expected return. The next four options with the highest return assume diversified promotion of several sectors and have a much lower level of risk (≈ 60 percent less volatility), which comes at the cost of decreased poverty reduction (≈ 50 percent less expected return). All four options are not significantly different in terms of expected return and risk and assume the rice sector's promotion in combination with other sectors that demonstrate high returns under the specific RoW (table 5). In particular, sectors with high weights besides rice are milk, vegetables, oilseeds, or fishery.

Another criterion used to rank policies is the worst-case return (represents the expected return of a policy option under the least favorable RoW scenarios, table 7). This criterion is a simplified version of the Value at Risk indicator used in finance to represent the risk of loss for investments (Jorion, 2007). The top five policy options guarantee non-negative returns (all $\min=0$) and do not significantly differ in expected return or volatility. Like expected return criteria, all options assume reliance on the rice sector with various combinations of other sectors, mostly milk, vegetables, and fishery.

The last criterion that we consider is the Sharpe ratio (expected return / standard deviation, table 8) - an indicator used in finance to represent the reward to-variability metric (Sharpe, 1994). Similar to the worst-case return criteria, an exclusive promotion of rice option does not perform well under this criterion, and the five best options are diversified policies that assume a mix of rice with other 'balancing' sectors, the most notable of which are milk, vegetables, and fishery.

Presented policy options reflect only a small part of the efficient set and do not include all potential optimal policies. Risk/return preferences of policymakers not necessarily concentrate in the extreme return/risk domains; for example, policymakers might have a particular appetite for a guaranteed positive outcome (for example, $\min[PGE] > 0.1$) or volatility (for example, $STD[PGE] \in [0; 0.1]$), and concrete portfolio selection processes require analysis of the respective parts of the efficient set. This task, however, requires complementary information on the risk/return preferences of policymakers. In this regard, the demonstrated application of portfolio management methods paves the way for future work on investigating various potential optimums associated with the various risk and return preferences.

4. Conclusion

In recent years many CGE-based studies apply the SSA concept to represent the impact of parameter uncertainty on policy impact estimates. However, in some studies aimed at comparing policy options, using the SSA methods might not define optimal policy intervention. If none of the policy options is robustly superior, we suggest integrating the SSA methods into the portfolio management framework. Similar to finance, indicators

representing the expected policy impacts can be treated as expected policy returns, and indicators representing the dispersion of policy impacts due to model reparameterization can be used as risk metrics. Furthermore, much like diversified portfolios in finance, it might be beneficial to consider mixed policies that can offer risk reduction for a given return or increase return for a given risk.

As a case study, we investigate pro-poor agricultural policy in Senegal and demonstrate that a simple comparison of policy options under the SSA sampled RoW uncertainty scenarios does not define optimal policy. Therefore, we apply portfolio management methods and analyze the spectrum of agricultural policy options from a risk and return perspective. We find that the policy that exclusively promotes the rice sector is the most effective in poverty reduction in expected policy return, but this option is also associated with the highest risk. Mixed policies that assume rice promotion combined with promotion of other sectors can offer less risk at the cost of reduced expected return. While the optimal policy's exact determination depends on policymakers' risk/return preferences, it is possible to conclude that the promotion of milk, vegetables, oilseeds, or fishery sectors can help to mitigate the risks associated with the current country's prioritization of the rice sector (Liesbeth et al., 2013).

The suggested concept can be used in other CGE-based studies aimed at comparing policy options. A set of varying/uncertain model parameters and target outcomes can be adjusted for specific research interests, and portfolio management methods can be used when the SSA methods do not establish a robustly superior policy option. For example, many environmental and ecological CGE models are naturally characterized by high uncertainty because they are used for long-term simulations and projections (e. g. Webster et al. 2008; Chatzivasileiadis et al. 2018). Consequently, our method can be used in such models if it is necessary to compare various policy options and define optimal policy intervention. Furthermore, applying commonly known portfolio management principles can find its use in practical policymaking as it allows to communicate model uncertainty with the policymakers explicitly and, therefore, increase the transparency of their policy choices (see Manski 2011, 2018 for more details).

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A. Technical appendix

A.1. Functional forms and closure rules

We define the Senegalese CGE model’s equations based on the available functional forms and closure rules defined for the standard IFPRI CGE model by Löfgren et al. (2002) and Diao and Thurlow (2012).

Table 9: Functional forms and closures of the CGE

Block	Category	Form / closure (endogenous variables)
Production	Value-added	Constant Elasticity of Substitution (CES)
	Intermediate	Leontief
	Top of technology	Leontief
Trade	Import	CES
	Export	Constant Elasticity of Transformation (CET)
Consumption	-	Linear Expenditure System (LES)
Closures	Numeraire	The exchange rate is the model numeraire ⁵ ; Consumer Price Index and domestic producers’ price level are flexible;
	Rest of the World	the current account balance and world market prices are given exogenously (exogenous shocks)
	Government	Fixed government tax rates; (dis)savings adjust to available net revenues;
	Savings/Investment	Balanced closure ⁶
	Factors	Fully employed and mobile ⁷

⁵The exchange rate of the CFA franc to the French franc (and later euro) is fixed since 1994. See Boogaerde and Tsangarides (2005) for more details.

⁶‘S-I’ closure 4, with enterprises adjusting marginal propensity to save. See Löfgren et al. (2002) for more details.

⁷Capital: ‘putty-clay’ assumption, see Diao and Thurlow (2012) for more details.

A.2. SAM adjustments

The original SAM by Randriamamonjy and Thurlow (2019) has 462 accounts, including 262 (regionalized) production activities or sectors, 75 commodities, 45 (regionalized) factors of production, 65 (regionalized) household types, and other institutional, tax, and savings or investment accounts. However, some accounts in the SAM were incompatible with our theoretical, empirical, or computational limitations. In particular:

- Certain commodities are reexported (export > domestic production);
- Certain sectors, factors, or households are tiny and can cause computational problems for the GAMS solver;
- Public goods and services are produced and consumed by both private and public entities.

Due to these incompatibilities, we perform the following adjustments:

- we net out imports for those commodities that have the reexport problem;
- Sectors or commodities that are less than 0.5 percent of GDP or absorption are aggregated with the closest matching sectors or commodities;
- Household and factor accounts are aggregated within regions;
- Public goods and services are consumed and produced only by the public sector. This amendment allows us to emphasize that public goods and services should be outside of the consumers' demand function and that the prices of these specific goods are determined by production costs only.

The resulting SAM (available upon request) has 263 accounts, including 183 accounts representing (regionalized) activities, 48 accounts representing commodities, 12 accounts representing primary production factors, 9 accounts representing households.

A.3. Sources used to define model parameters

- We use approximations and assumptions when the necessary estimates are not available. For example, we use Aguiar et al. (2016) to define values of elasticity parameters;
- based on the observed productivity decline over 2006-2015 (see IMF 2017 for more details), we assume zero productivity growth for all non-policy sectors;
- we use Euro as a trade currency and convert US dollars growth rates of world market prices to Euro or French Franc growth rates;
- full parameter specification of all model simulations is available upon request.

Table 10: Sources used to define model parameters

Parameter	Used sources
Non-policy TFP	Own assumption
Factor supply	ILO (2020) for labor; FAO (2020) for land; Feenstra et al. (2015) for economywide capital
Population	UN (2020)
World market prices	World Bank (2020a) and FRED (2020) for services
Current account deficit	IMF (2020)
Production and trade elasticities	Based on Aguiar et al. (2016)
Income elasticities	Own estimates based on ANSD (2013); King and Byerlee (1978))
Frisch parameters	Own estimates based on ANSD (2013); World Bank (2020d); Ramprakash et al. (1979)

A.4. Sampling RoW scenarios

- we use the same sources as in Table 10 and construct the historical sample of yearly growth rates throughout 1980-2019 and estimate moments of the multivariate Gaussian distribution (Table 11);
- we use Latin Hypercube Sampling implemented in the R-package ‘EnvStats’ by Millard (2013) and sample RoW scenarios from dimensions of specified multivariate Gaussian distribution;
- in order to avoid computational problems with the GAMS solver in the final years of model simulations, we truncate 0.1 percentiles from left and right.

Table 11: Mean values, standard deviations and correlations

	pw_agri	pw_MUVi	pw_ener	pw_fert	pw_mtmn	pw_serv	fsav
mean	0.00	0.00	0.00	0.00	0.00	1.26	0.00
σ	11.41	8.23	23.95	24.32	20.55	2.84	30.96
pw_agri	1.00	0.69	0.41	0.65	0.50	0.11	0.21
pw_MUVi	0.69	1.00	0.43	0.44	0.41	0.03	0.12
pw_ener	0.41	0.43	1.00	0.43	0.43	-0.09	0.40
pw_fert	0.65	0.44	0.43	1.00	0.38	0.05	0.61
pw_mtmn	0.50	0.41	0.43	0.38	1.00	-0.05	0.18
pw_serv	0.11	0.03	-0.09	0.05	-0.05	1.00	0.00
fsav	0.21	0.12	0.40	0.61	0.18	0.00	1.00

A.5. Sampling of mixed-policy scenarios

- we use R-package ‘xsample’ by den Meersche et al. (2009) to sample 1000 mixed policy scenarios;
- the Markov Chain Monte Carlo method produces sampled solutions for the under-determined problem with linear equality constraints:

$$\sum_{i=1}^{10} share_i tfp_i = tfp_{tot} \quad \text{subject to } tfp_i > 0 \quad (1)$$

where $share_i$ is share of sector i in total agricultural GDP;

tfp_i is sampled TFP shock of sector i ;

$tfp_{tot} = 1$ is the targeted TFP growth of the whole agriculture (1 percent by 2024);

- produced sample is distributed (jointly) uniformly over the feasible space of TFP parameters, and we assume that the sample size of 1000 scenarios is sufficient to cover the parameter space of potential policy options.