

Aspects of Designing Sustainable Development Policies in Developing Countries

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Preface

This thesis is composed of the following four articles organized in a book format.

1. ‘Energy subsidy reform for growth and equity in Egypt: The approach matters’ by Clemens Breisinger, Askar Mukashov, Mariam Raouf, and Manfred Wiebelt. The paper is published in *Energy Policy* (2019, Vol. 129, 661-671, [doi:10.1016/j.enpol.2019.02.059](https://doi.org/10.1016/j.enpol.2019.02.059)).

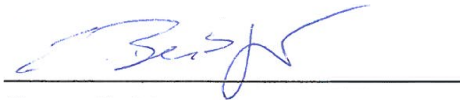
Contributions of the co-authors:

- Clemens Breisinger: general concept and research questions; policy relevance and actuality in the context of energy subsidy reform; interpretation of simulation results and policy recommendations;
- Askar Mukashov: implementation of Computable General Equilibrium (CGE) simulations; analysis and interpretation of results; more details are below.
- Mariam Raouf: data collection, including the construction of the Social Accounting Matrix (SAM); country-specific literature research;
- Manfred Wiebelt: development of specific research questions and construction of the primary CGE model; interpretation of simulation results.

Detailed overview of my contribution:

- estimation of household income elasticities (using household survey data);
- other parametrization of the CGE model, including specification of trade and production elasticities, factor growth, population growth, etc.
- data input for various scenarios, including fuel price and food subsidy changes;
- various adjustments of the CGE model, including its closure rules;
- implementing, running, adjusting, and analyzing simulations in **GAMS**.

Hereby we affirm that each co-author made an essential contribution to the paper according to the **DFG- guidelines** 'Securing good scientific conduct' (DEU: 'Sicherung guter wissenschaftlicher Praxis').



Clemens Breisinger



Askar Mukashov



Mariam Raouf



Manfred Wiebelt

2. ‘Modeling conflict impact and post-conflict reconstruction: The case of Yemen’ by Clemens Breisinger, Wilfried Engelke, Askar Mukashov, and Manfred Wiebelt. The article is published as a working paper at *MENA RP Working Papers* (2020, 29) and is submitted for publication at *Economic Systems*. The current status of the paper is ‘under review’ after the first round of revisions. In this dissertation, I present the latest version of the paper.

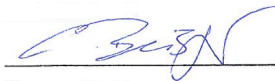
Contributions of the co-authors:

- Clemens Breisinger: general concept and research questions; policy relevance in the context of ongoing conflict; interpretation of the simulation results and conclusions;
- Wilfried Engelke: general concept and research questions; country-specific literature research, including analysis of the conflict shocks and damages; construction of the SAM, jointly with the IFPRI and local partners; discussion and interpretation of the simulation results; conclusions;
- Askar Mukashov: implementation of CGE simulations; analysis and interpretation of results; more details are below.
- Manfred Wiebelt: development of specific research questions; construction of the SAM, jointly with IFPRI and local partners; interpretation of the simulation results.

Detailed overview of my contribution:

- complete specification of the CGE model for both conflict and post-conflict periods;
- complete specification of the post-conflict uncertainty with the use of Systematic Sensitivity Analysis (SSA) method;
- implementing, running, adjusting, and analyzing simulations in *GAMS* and *R*;
- results interpretation in the context of country-specific and broad literature.

Hereby we affirm that each co-author made an essential contribution to the paper according to the *DFG- guidelines* ‘Securing good scientific conduct’ (DEU: ‘Sicherung guter wissenschaftlicher Praxis’).



Clemens Breisinger



Askar Mukashov



Wilfried Engelke



Manfred Wiebelt

3. ‘Parameter Uncertainty in Policy Planning Models: Using Portfolio Management Methods to Choose Optimal Policies under World Market Volatility’ by Askar Mukashov. The article is published in 2021 as a working paper at *Agricultural Policy Working Paper Series* (WP2021-01) and is submitted for publication at *Economic Analysis and Policy* (current status: under review).

Hereby I affirm that the paper was written in compliance with the *DFG- guidelines* ‘Securing good scientific conduct’ (DEU: ‘Sicherung guter wissenschaftlicher Praxis’).



Askar Mukashov

4. ‘The Role of Global Climate Change in Structural Transformation of Sub-Saharan Africa: Case Study of Senegal’ by Askar Mukashov, Christian Henning, Richard Robertson, and Manfred Wiebelt. The article is published as a working paper at *Kiel Working Papers* (No. 2187, June 2021). Individual contributions of the co-authors:

- Askar Mukashov: research questions; modeling framework; simulations of the primary CGE model; analysis and interpretation of results. More details are below.
- Christian Henning: general concept; design of policy interventions to counteract deagrarianization towards services;
- Richard Robertson: impact of Global Climate Change (GCC) scenarios on agricultural world market prices and productivities in Senegal; analysis and discussion of simulation results;
- Manfred Wiebelt: interpretation of the simulation results; policy implications.

Detailed overview of my contribution:

- research questions in the context of GCC in sub-Saharan Africa (sSA);
- complete specification of the Senegal’s CGE model, including adjustments of the core equations to represent interregional mobility;
- implementing, running, adjusting, and analyzing simulations in *GAMS*;
- results interpretation in the context of country-specific and broad literature.

Hereby we affirm that each co-author made an essential contribution to the paper according to the *DFG- guidelines* ‘Securing good scientific conduct’ (DEU: ‘Sicherung guter wissenschaftlicher Praxis’).



Askar Mukashov



Christian Henning



Richard Robertson



Manfred Wiebelt

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List of Abbreviations

CES Constant Elasticity of Substitution

CET Constant Elasticity of Transformation

CGE Computable General Equilibrium

DNA Dynamic Needs Assessment

IFPRI International Food Policy Research Institute

LES Linear Expenditure System

PGE Poverty-Growth Elasticity

SAM Social Accounting Matrix

SSA Systematic Sensitivity Analysis

TFP Total Factor Productivity

GCC Global Climate Change

IMPACT International Model for Policy Analysis of Agricultural Commodities and Trade

sSA sub-Saharan Africa

MENA Middle East and North Africa

YER Yemeni Rial

USD United States Dollar

LHS Latin Hypercube Sampling

PGE Poverty-Growth Elasticities

RoW Rest of the World

p.a. per annum

PM Portfolio Management

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Introduction

Development policy has shifted from the Washington consensus towards a Pro-Poor Growth and Sustainable development agenda. One of the most important consequences is the resulting/accompanying changing focus away from macroeconomic stabilization to more refined policy interventions on the sector and household levels (OECD 2007; Grimm et al. 2015). Depending on the country-specific circumstances, desired outcomes along increasingly complex dimensions of national goals can have synergies or trade-offs (UNDP 2012). The necessity to allocate public or donor funds across many potentially competing policies created the demand for the tools to quantitatively formulate and compare the effects of policy interventions (Henning et al. 2018).

One of the tools used for these purposes in modern policy analysis is Computable General Equilibrium (CGE) modeling. This class of deterministic models has certain advantages over other policy evaluation tools that made them famous in policy analysis (Robinson 1991; Taylor 1990, 2016; Dixon and Rimmer 2016). Most importantly, the structural nature of CGE models accounts for sectoral as well as household characteristics and allows reflecting both direct and indirect effects of policy interventions (Dervis et al. 1982; Löfgren et al. 2002; Diao and Thurlow 2012). Furthermore, unlike the ex-post nature of econometric-based tools, the ex-ante nature of CGE models allows considering policies that did not have precedents (Pauw and Thurlow 2015). In this context, another practical advantage of the CGE models is their ability to quantify otherwise unidentifiable economy-wide repercussions of various shocks such as disasters, sanctions, climate change, etc. (e. g., Gharibnavaz and Waschik 2017; Zhou and Chen 2020; Tan et al. 2019; Wiebelt et al. 2015).

At the same time, the use of CGE modeling methods is not straightforward, and due to their complexity, sometimes they are even labeled as a ‘black-box’ (e. g., Böhringer et al. 2003). As with many other modeling instruments, quantitative or even qualitative results and policy conclusions based on a CGE model, heavily depend on the underlying data and assumptions. Usually, CGE models are uniquely designed for a specific study and often involve constructing a corresponding unique database - Social Accounting Matrix (SAM) (see Pyatt and Round 1985; Breisinger et al. 2009). Furthermore, depending on the country’s circumstances and research questions, a researcher must specify appropriate functional forms, closure rules, and model parameters (see e. g. Dervis et al. 1982; Annabi et al. 2006). Model misspecification

at any level can heavily influence simulation results and corrupt policy conclusions (see e. g., McKittrick 1998; Fugazza and Maur 2008; Olekseyuk and Schürenberg-Frosch 2016). Therefore, in most CGE-based studies, significant attention is usually given to the context of a specific study and corresponding unique model with its underlying data and assumptions.

Following these lines, my dissertation focuses on using modern CGE modeling techniques and methods to address national development problems in three developing countries: Egypt, Yemen, and Senegal. Each of these countries faces specific policy prioritization problems, which my co-authors and I address using corresponding modeling methods.

Egypt

In the case of Egypt, we investigate the economic consequences of its long-awaited energy subsidy reform (chapter 1, ‘Energy Subsidy Reform for Growth and Equity in Egypt: The Approach Matters’). Phasing off energy subsidies is a core element of Egypt’s structural transformation program and a key instrument to balance its government budget (IMF 2015). At the same time, in the context of simultaneous devaluation of the Egyptian Pound and increased prices of imports, the government is also particularly concerned about the welfare of poor households (Breisinger et al. 2018). My co-authors and I build an energy-focused CGE model for Egypt and investigate the short and long-term effects of the reform on the economy and households. We find that phasing out energy subsidies is likely to hamper Egypt’s short-term economic growth, but depending on spending options of subsidy-payments savings, it can improve growth and household welfare in the long term. However, it will take years to materialize the full positive impact of reform, especially for certain sectors and households. We also show that the complete phaseout of subsidies over the coming years requires additional support for poor households, especially the urban poor.

Yemen

Being one of the poorest countries in the world, the Republic of Yemen continues to experience the devastating effects of its smoldering civil war. Violent conflict has severely disrupted the economic activity, caused significant infrastructural damage, and led to a wide suspension of essential public services (World Bank 2019a). The current state of its economy is unknown be-

cause the maintenance of its formerly regular statistics has suffered significantly. Reconstruction planning using conventional methods is very limited. To address these problems, my co-authors and I build a CGE model of Yemen and use it to investigate the economic consequences of the conflict and analyze the country's potential recovery prospects (chapter 2, 'Modeling conflict impact and post-conflict reconstruction: The case of Yemen'). We use the latest available pre-war data and statistics and apply the CGE model to estimate Yemen's current economic and poverty status quo. Furthermore, given the country's uncertain reconstruction prospects, we introduce uncertainty into the CGE model for the post-conflict reconstruction simulations. We find that supporting agriculture and mining activities should be the policymakers' highest priority, as this is estimated to be the fastest way for the country's revival. At the same time, even if Yemen succeeds in offsetting all conflict-related shocks, reaching the pre-conflict economic status quo is very unlikely without institutional reforms that had for decades restrained qualitative improvements in productivity, investment, and technological flexibility (World Bank 2015). In this context, our findings thus suggest that stabilization of the country in the longer term will require additional assistance beyond the reconstruction of the damaged assets and sectors.

Senegal

In the case of Senegal, my co-authors and I focus on its agricultural sector. Being a typical less developed country in sub-Saharan Africa (sSA), Senegal still heavily relies on agriculture (USAID 2017), and the most critical aspects of its national development policy are focused on the rural economy (World Bank 2020b; African Development Bank 2010). In this dissertation, my co-authors and I consider two crucial problems of Senegalese agriculture.

In single-authored chapter 3 ('Parameter Uncertainty in Policy Planning Models: Using Portfolio Management Methods to Choose Optimal Policies under World Market Volatility'), I address the problem of prioritizing Senegalese agricultural value chains under the uncertain world markets. Over the last years, the Senegalese government has prioritized the rice sector (Liesbeth et al. 2013), but this policy might be sub-optimal in the context of significantly increased volatility on the international markets (World Bank 2020c). To represent the uncertainty of world markets, I sample model parameters of export/import prices and suggest that besides policy return estimates, the policy options should also be analyzed from the risk perspective (similar to finance). When applied to the Senegalese agricultural policy, the method

shows that prioritizing the rice sector remains the most effective policy in terms of expected economic return (income generation and poverty reduction). However, this policy is also associated with the highest risk/uncertainty and can lead to an increase in poverty under unfavorable but realistic world market scenarios. Like portfolio diversification in finance, mixed policies that require the rice sector to be promoted in combination with other sectors such as milk, vegetables, oilseeds, or fisheries can provide risk mitigation at the expense of lower expected policy return.

In chapter 4 ('The Role of Global Climate Change in Structural Transformation of Sub-Saharan Africa: Case Study of Senegal'), my co-authors and I shift the focus towards Global Climate Change (GCC) and its role in the structural transformation of the Senegalese economy. The country has been experiencing a rural exodus since the 1960s, with most of the provincial migrants joining the informal urban sectors (Goldsmith 2004; WB 2018). In the context of GCC, the country's deagrarianization and fundamental transformation can be expected to amplify in the coming decades, and it becomes essential to understand these patterns. To model GCC's impact, we use a combination of biophysical and economic models and assume that deagrarianization will be the primary adaptation strategy of rural households in Senegal. Our results suggest that GCC can increase the country's deagrarianization pace, with industrial and service sectors in the capital Dakar being the most important destinations of the former agricultural labor force. Although expected urbanization allows smoothing spatial income disparities, the informal services sector's absorption of mostly uneducated agricultural labor can hamper the country's long-term growth prospects. One of the policy options that can prevent premature deindustrialization (see Rodrik 2015) can be services' productivity increase to push the former agricultural labor towards industrial sectors.

All in all, while the first two chapters focused on Egypt (chapter 1) and Yemen (chapter 2) represent classic cases of a country-specific policy prioritization problem, chapters 3-4 dedicated to Senegal have a stronger methodological focus. Although we address policy prioritization problems of Senegalese agriculture in these chapters, the extensions of CGE modeling are also applicable to other developing countries and development studies. Thus, besides addressing topical economic and social policy questions, this dissertation also contributes to literature strands focused on economic modeling.

All papers presented in this dissertation are either already published, submitted for publication, or prepared for submission in peer-reviewed journals.

Chapter 1

Energy Subsidy Reform for Growth and Equity in Egypt: The Approach Matters

This chapter is published as:

Breisinger, C., Mukashov, A., Raouf, M. and Wiebelt, M. 2019. “Energy Subsidy Reform for Growth and Equity in Egypt: The Approach Matters.” *Energy Policy* 129: 661-671.

The full article can be downloaded at

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Abstract

Phasing out energy subsidies is high on the agenda of policymakers in several Middle East and North Africa (MENA) countries. The impact of such reform can vary widely depending on the country and policy. This paper contributes to the existing literature by examining the phasing out of energy subsidies in Egypt under alternative economic scenarios. In particular, we consider Egypt’s short- and long-term economic adjustment under different assumptions on labor market flexibility, spending options of subsidy savings, and alternative social protection measures. Results from economy-wide model simulations suggest that energy subsidy cuts may hamper economic growth in the short term, but depending on the policy measure, will improve growth perspectives and household welfare in the longer term. Yet, findings also point to likely adverse impacts of the reform on household consumption in the short and longer run. To counteract such negative impacts, targeted social protection measures should be continued and scaled up in parallel with the phasing out of energy subsidies.

Keywords: economic development, poverty, energy subsidies, social protection, computable general equilibrium model, Egypt.

Chapter 2

Modeling Conflict Impact and Post-conflict Reconstruction: The Case of Yemen

A previous version of this chapter has appeared as:

Breisinger, C., Engelke, E., Mukashov, A. and Wiebelt, M. 2020. “Model-based planning for post-conflict reconstruction: The case of Yemen.” MENA RP Working Papers 29.

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The paper has been revised and submitted for publication at *Economic Systems*.

Abstract

Evidence-based planning for in-conflict countries is often constrained by missing data and the lack of appropriate analytical tools. To overcome these constraints, we use a CGE model combined with Systematic Sensitivity Analysis (SSA) to investigate the impact of conflict on Yemen’s economy and to analyze potential post-conflict recovery pathways. Our results suggest that conflict-related disruptions in agriculture and mining sent devastating shockwaves throughout the economy, constituting the lion’s share of the country’s economic losses and increase in poverty. Results suggest that supporting agriculture should have the highest priority as the sector’s reconstruction has the largest positive impact on growth and poverty reduction, followed by the mining sector. However, our estimates also highlight the importance of institutional reforms and qualitative improvements in productivity, investment, and technological flexibility to reach at least pre-conflict development levels. In addition to serving as a direct input for Yemen’s reconstruction process, our paper also demonstrates the usefulness of economywide models for conflict and post-conflict assessments.

Keywords: economywide modeling; uncertainty; conflict; reconstruction; Middle East; Yemen.

2.1 Introduction

Assessing economic and social consequences of armed conflicts requires rigorous research methods that usually involve the use or collection of extensive economic and social data¹. While such studies are essential for understanding and managing local wars and conflicts (Blattman and Miguel 2010), policymakers of in-conflict or coming-out-of conflict countries often do not have access to sufficient data and analytical instruments. Depending on the conflict intensity, consistent data are usually only available from periods before the conflict, and in some countries, the maintenance of otherwise regular statistics also suffers significantly during times of conflict. However, as countries move from an emergency or conflict mode to a recovery and development mode, evidence-based planning is essential for national governments and their international partners. Key questions often include: What is the status quo of the economy and households' incomes? Which conflict shocks contributed the most to economic and social deterioration? What should government and its international partners prioritize to bring a country on a recovery path? This paper tries to answer these and related questions for the case of Yemen by using a CGE modeling approach.

The current crisis in Yemen erupted in 2011 when the events of the Arab spring led to the resignation of the long-ruling president Saleh. After several years of political turbulence, the full-fledged armed conflict began in March 2015, when the exiled interim president Hadi formally sought the military intervention of the Arab Coalition to restore his government. Since then, the conflict has caused massive physical damage, devastated the economy, and led to an unprecedented humanitarian crisis (World Bank 2019a). Various third parties have been trying to broker ceasefire and peace agreements, and the first positive signs emerged at the end of 2020/beginning of 2021, when the UN-led political talks allowed for positive developments in the implementation of the Riyadh Agreement signed in November 2019 (OSESY 2020; U. S. Department of State 2021). In parallel to the political process, the Yemeni government and its international partners have been trying to estimate conflict damages in their Dynamic Needs

1. For example, Abadie and Gardeazabal (2003) construct a 'synthetic' control region and use real macro-level per annum (p.a.) data to estimate the economic costs of the outbreak of terrorism in the Basque Country in the 1960s. Justino and Verwimp (2012) uses a panel of households surveyed before and after the conflict in Rwanda (1994) to investigate how the conflict affected poverty. Ganegodage and Rambaldi (2014) use macro-level annual data over the period 1960-2008 to evaluate the impact of civil war in Sri Lanka (1983 to 2009) on its economic growth. Mercier et al. (2020) use a three-wave panel survey to investigate the relationship between exposure to the civil war in Burundi (1993 to 2005) and household food poverty.

Assessment (DNA) reports. This process has been very challenging, and the estimates in many instances rely on strong assumptions (World Bank 2019a). Moreover, formerly regular official statistics such as national accounts and budgets and household income and expenditure surveys have not been updated since 2014. As a result, to estimate the current state of the economy at least at an aggregated level, international organizations often have to rely on anecdotal evidence (World Bank 2019b).

In this context, our paper complements existing studies and aims to provide essential details on the country's economic damages and potential reconstruction opportunities based on an innovative approach. We use available fragmented DNA estimates made by the various organizations and integrate them into our CGE model for Yemen calibrated to the pre-war year of 2014. We use the model to simulate the degradation of the economic activity and household income throughout the conflict phase of 2015-2020 and assume that the country's reconstruction process will start in 2021. Then we use the standard five-year reconstruction planning period (World Bank 2017b, 2017a) and use the model to project the possible economic state of the country by the year 2025.

In the data scarcity environment, reference to the simulation models is relatively standard practice, and several studies used simulation methods (including CGE models) to estimate impacts of otherwise unmeasurable shocks such as sanctions, disasters, population displacement, and terrorism². In the case of Yemen, the CGE modeling approach was used to analyze the effects of the 2008 flood on the economy and food security (Breisinger et al. 2015), to measure the impact of the 2008-09 global crisis on growth and poverty (Breisinger et al. 2011), and to assess country's social and economic situation after the 'Arab spring' unrest in 2011-12 (World Bank et al. 2012). To our knowledge, this paper is among the first that uses the CGE simulation approach to assess the economic costs resulting from the conflict-related damages and shocks. As the scope of Yemen's economic losses associated with the recent armed conflict remains largely unknown, our paper attempts to provide a timely estimate of the conflict and post-conflict economic and social developments in the country.

We find that Yemen's most severe economic losses are associated with disruptions in the mining and agriculture sectors, contributing to the loss of 20.9 and 9.4% of GDP to the overall estimated contraction of 36% of GDP between 2014-2020. Altogether direct and indirect

2. See Gharibnavaz and Waschik (2017), Siddig and Mohammed (2017), and Agbahey et al. (2016) (sanctions); Zhou and Chen (2020) and Tan et al. (2019) (disasters); WB (2017) and Alix-Garcia et al. (2017) (population displacement); Nassios and Giesecke (2017) (terrorism).

consequences of the conflict led to catastrophic outcomes for the population. According to our estimates, the poverty rate increased by 31.3% from the pre-conflict poverty level of 48.6% (Government of Yemen 2014) and reached 79.9% of the population, with a particularly devastating situation in rural areas, where nine out of ten residents now live below the poverty line.

Our simulations of the post-conflict reconstruction phase suggest that recovery of the mining sector and agriculture are the most effective channels for economic revival. However, even with the complete offset of all conflict-related shocks, restoration of the pre-war status quo is very unlikely without institutional reforms that had restrained qualitative improvements of the economy for decades even before the conflict (World Bank 2015). The country's recovery prospects look even gloomier in the light of the recent COVID-19 pandemic and other not-yet properly quantified factors such as human capital depreciation or fluctuations in remittances. Thus, our findings serve as a first important step in understanding Yemen's reconstruction potential and feasibility of its stabilization in the coming years.

The rest of the paper is organized as follows. Section 2.2 describes the used data, methodology, and model. Section 2.3 discusses the simulation results for both conflict and recovery phases. Section 2.4 concludes with a summary and policy recommendations.

2.2 Data and Methodology

2.2.1 Pre-conflict economic and social status quo

The central database for our model is the SAM for the year 2014 constructed by Raouf et al. (2019). It is based on the national accounts (2014), household survey (2014), industrial survey (2013), and it already accounts for the economic and social deterioration in the country due to the 'Arab spring' events of 2011-12. The SAM thus captures the latest available macro- and micro-level data and allows us to analyze the country's economic and social characteristics before the full-fledged outbreak of the armed conflict in March 2015.

Even before the conflict, Yemen's economy had many features (Table 2.1) that characterize the least developed countries (Schwab and Sala-i-Martin 2014). In particular, the country heavily relied on the primary sector (12.6 and 23.0% of the GDP are agriculture and mining), had a relatively underdeveloped secondary sector (e. g., non-food manufacturing is only 1.7% of GDP), and a relatively high share of the government sector (11.4% of GDP). Furthermore,

the country heavily depended on imports of many essential goods (e. g. food and petroleum), while the mining sector (crude oil and natural gas) dominated exports. In this context, it is important to emphasize that the hydrocarbon rents constituted the backbone of Yemen's political and economic systems, with other sectors heavily depending on the trickle-down effects of oil rents (World Bank 2015).

Table 2.1: Yemen: supply, demand, and trade structure, 2014

| Sector | Share of GDP, % | Share of absorption, % | Export share of sectoral output, % | Import share of sectoral absorption, % |
|-------------------------------|-----------------|------------------------|------------------------------------|--|
| Crops | 7.8 | 8.3 | 8.8 | 26 |
| Livestock | 3.4 | 4.6 | 1.8 | 1.3 |
| Other agriculture * | 1.4 | 1.4 | 35.1 | 2.5 |
| Mining | 23 | 1.5 | 56.7 | 27.8 |
| Food processing | 6.5 | 20.7 | 9.9 | 26 |
| Other manufacturing | 1.7 | 15.2 | 10.6 | 67.7 |
| Utilities | 1.6 | 1.5 | - | - |
| Construction | 3.1 | 8.6 | - | 3.7 |
| Wholesale and retail trade | 16.7 | 10.7 | - | - |
| Transportation and storage | 8.8 | 9.4 | 5.5 | 27.3 |
| Housing | 3.9 | 1.9 | 39.7 | 6.7 |
| Information and communication | 1.7 | 1.3 | - | - |
| Business services | 3 | 3.1 | 15 | 39.5 |
| Other private services | 5.9 | 4.4 | - | 6.5 |
| Public goods and services | 11.4 | 7.5 | 3.1 | - |
| Total | 100 | 100 | 15.3 | 22.9 |

Source: Own calculations based on Raouf et al. (2019).

Note: * 'Other agriculture' is primarily capture fisheries (95%), with some forestry (5%).

The structure of factor payments in Yemen was also typical for low-income countries (Table 2.2). The economy was labor-intensive, with labor contributing 60.7% of GDP at factor cost. While capital-value added share was 34.5%, more than its half (18.9%) was associated with the mining sector. As in most countries, urban households enjoyed higher incomes than rural residents (Table 2.3). Per-capita consumption of urban households was 72.6% higher, and the poverty incidence in urban areas was 2.5 times lower than in rural communities. These disparities can be partly explained by different income sources and educational differences between urban and rural households. Yemen's urbanization was low, with 71% of the Yemeni population living in rural areas.

Table 2.2: Yemen: structure of factor payments, 2014

| Factor | Share of GDP, % | Share of factor income, rural households,% | Share of factor income, urban households,% |
|---------------------|-----------------|--|--|
| Labor - uneducated | 22.1 | 32.1 | 18.4 |
| Labor - secondary | 9.2 | 12.7 | 8.8 |
| Labor - tertiary | 29.4 | 22.9 | 56 |
| Land | 4.8 | 7.3 | 3.6 |
| Capital - crops | 0.5 | 1 | 0.2 |
| Capital - livestock | 0.4 | 0.7 | 0 |
| Capital - mining | 18.9 | 23.3 | 13.1 |
| Capital - other | 14.8 | | |

Source: Own calculations based on Raouf et al. (2019).

Table 2.3: Yemen: households' poverty and expenditure, 2014

| Household | Population, millions | Poverty prevalence, % | Per-capita expenditure, '000 Yemeni Rial (YER) |
|-----------|----------------------|-----------------------|--|
| Rural | 18.5 | 59.2 | 194.4 |
| Urban | 7.8 | 23.9 | 335.4 |
| Total | 26.2 | 48.6 | 236 |

Source: Own calculations based on Raouf et al. (2019) and Government of Yemen (2014).

In summary, Yemen was already among the world’s poorest countries in 2014, with an annual GDP per capita of United States Dollar (USD) 1,351 (290,000 YER), and almost half of the population living below the poverty line.

2.2.2 Integrating information on conflict-related shocks into the model

We begin our estimations with the compilation of the fragmented estimations made by various international organizations on the conflict-related economic shocks (Table 2.4). The shocks are assumed to be directly or indirectly associated with the armed conflict and estimated as a percentage change by 2020 to the levels of 2014.

Table 2.4: Yemen: available estimates on the conflict-related shocks, 2020 vs. 2014 in %.

| Type | Sources | Sector / Shock type | Total % change by 2020 (wrt 2014 level) |
|---|--------------------|---|---|
| Physical destruction of the capital assets* | World Bank (2019a) | Housing (capital stock) | -13.8 |
| | | Utilities, transport, public sector (capital stock) | -11.6 |
| Disruptions in the agriculture | FAO (2018b) | Crops (production) | -38 |
| | | Livestock (production) | -41 |
| Disruptions in mining | World Bank (2020e) | Production | -50 |
| | World Bank (2020a) | World Market Prices (crude oil) | -58 |
| Financing of the current account deficit | IMF (2020) | USD inflows | -48.5 |

Note: *we use the cost-based assessments of the DNA report (replacing destroyed capital assets are as-sessed at 100%, partially damaged capital assets are assessed at 40%). Detailed information is given in Appendix 2.A.

Physical destruction of capital assets. The World Bank (2019a) report relies primarily on remote data sources, including satellite imagery and social media analytics, and provided a cost-based assessment of the capital assets damages in the largest 16 urban centers.

Disruptions in agriculture. FAO (2018b) uses a different approach and directly estimates production reduction in the crop and livestock sectors. The report emphasizes the deterioration of the public sector and overall economic disorganization as the leading cause of the country’s agricultural degradation. In particular, in the context of regular droughts, flash floods, and

water scarcity typical for the country, FAO (2018b) emphasizes the conflict-related degradation of the government's water management services, irrigation, control of plant pests and diseases, and other public services. In the livestock sector, the conflict caused the displacement of herds of agropastoral households, reduced veterinary services, and led to the spread of endemic diseases.

Disruptions in the mining sector. Like FAO (2018b), the World Bank 2018 (Policy Note 2) highlights Yemen's institutional deterioration as the main reason for the hydrocarbon sector's halt. The report emphasizes tremendously increased operating costs of the mining companies due to continuous insecurity, increased compensation needs, and backlog in infrastructural maintenance. All these factors forced companies, including state-owned enterprises, to virtually halt operations with the outbreak of violence in 2015. However, according to the latest available data, production of hydrocarbons begun to be revived in recent years (primarily due to resuming of operations by Yemen's state-owned hydrocarbon enterprises) and reached 50% of the pre-conflict production level by the beginning of 2020 (World Bank 2020e). However, the industry's longer-term revival is highly uncertain due to the recent unprecedented shocks on the global energy markets (World Bank 2020a; 2020c), which raises doubts about the sustainability of production plans to increase output.

Financing of the current account deficit. Given the problems of the hydrocarbon sector, official assistance through grants and loans is a critical source of foreign exchange in the import-dependent Yemeni economy (World Bank 2019c). By the end of 2020, the USD 2 billion Saudi Arabian emergency assistance is near depletion, and other large inflows of official assistance are not (yet) announced (World Bank 2020f). We use the latest available data and projections by the IMF (2020) and estimate the current account deficit changes over 2014-2020.

The compiled information on the conflict shocks is then integrated into the Yemeni CGE model (Table 2.5). We use the standard recursive-dynamic CGE model developed by the International Food Policy Research Institute (IFPRI) and adjust it to reflect specific shock transmission channels of the Yemeni economy. In particular, the estimates of the physical destruction of the capital assets in housing, utilities, transport, and the public sectors are expressed in our model as a shock that decreases capital production factors. Consequently, the reduction of their output is endogenous and defined via the Constant Elasticity of Substitution (CES) production function. To model disruptions in agriculture and mining, we fix their output through the Leontief function and assume underutilization of respective capital assets. Furthermore, we simulate the observed drop of oil prices in the world markets and the drop of foreign assistance inflows. Finally, in line with the expectations about increased

(formal) unemployment and land use reduction (World Bank 2019a; FAO 2018b), labor and land production factors are allowed to be unemployed in our model. While official estimates on unemployment and agricultural land use are not available, we expect that together with reduced capital, underutilization of land and labor factors will significantly affect GDP and households' welfare.

Table 2.5: Yemen: functional forms and closures of the CGE model.

| Block | Category | Form / closure |
|------------|--------------------|--|
| Production | Primary factors | CES or Leontief (mining and agriculture) |
| | Intermediates | Leontief |
| | Top of technology | Leontief |
| Households | Consumption | Linear Expenditure System (LES) |
| Trade | Import | CES |
| | Export | Constant Elasticity of Transformation (CET) |
| Closures | Numeraire | Consumer Price Index (domestic producers price level is flexible) |
| | Government | Fixed government tax rates with (dis)savings adjusting to available net revenues |
| | Savings/Investment | Neoclassical closure (the sum of total savings defines investment) |
| | Rest of the World | The nominal exchange rate is flexible while the current account balance and world market prices are given exogenously (conflict shocks for mining) |
| | Factors | Capital is immobile across sectors and given exogenously (conflict shocks for housing, utilities, transport, and the public sectors); Labor and land might be unemployed |

Source: Own compilation based on Diao and Thurlow (2012). Details are in Appendix 2.B.

It is important to mention that our model simulations are based on the latest available information on conflict shocks. Several other important but not yet quantitatively formulated factors are not taken into account in our model. Among others, these factors include the COVID-19 pandemic and fluctuations in remittances, human capital depreciation due to

malnutrition, diseases, or increased qat³ consumption (UNICEF 2021; Tshiband 2019).

2.2.3 Modeling the uncertainty of post-conflict reconstruction

We use the standard five-year planning horizon (World Bank 2017b, 2017a) and assume that the country’s reconstruction can start in 2021. We also assume that reconstruction is financed directly by the international community, bypassing the government budget and without repatriating profits. This assumption is justified since most of the finance and required assets likely to be provided directly by international partners and organizations in line with the past recovery financing experience in Yemen (e. g. FAO 2018b; World Bank 2019a). At the same time, we refrain from associating the magnitude of the policy interventions with their monetary costs. While FAO (2018b) and World Bank (2019a) provide sector-specific estimates of the necessary reconstruction funds, these estimates are subject to further elaborations⁴, and the actual financing needs to restore production in the mining sector are not well understood.

As Yemen’s reconstruction prospects remain highly uncertain (World Bank 2020f), we use the method of SSA that allows us to reflect post-conflict uncertainty. SSA is becoming popular in the recent CGE-based studies as it addresses the topical problem of parameter uncertainty in CGE modeling. Most importantly, SSA implies treating parameters of interest as random variables that are sampled from assumed or estimated distributions. The method produces varying endogenous variables, whose variations are analyzed instead of point estimates produced by standard CGE scenarios (see e. g. Webster et al. 2008; Phimister and Roberts 2017; Chatzivasileiadis et al. 2018).

Table 2.6 describes the set of model parameters representing the reconstruction phase in our analysis. Given the lack of data, we assume uniform distributions and sample each parameter from the 0-1 range, where 0 corresponds to stagnation (no change since 2020), and 1 corresponds to complete recovery to the pre-conflict level of 2014 by 2025.

Besides conflict shocks, we also consider the country’s potential for qualitative improvements. In a pre-war study, the World Bank analyzed Yemen’s institutions and highlighted reforms that can boost growth by removing constraints in productivity growth, investment, and labor reallocation (see World Bank 2015 for details). Our analysis represents these fac-

3. Addictive flowering plant that contains psychoactive agents.

4. For example, the DNA study by the World Bank (2019a) concentrated solely on the largest 16 urban centers, for which reconstruction needs are estimated to reach USD 14 billion; however, extrapolated to the entire country, total reconstruction needs are projected to reach USD 32 billion.

Table 2.6: Yemen: CGE parameters of the reconstruction period (values by 2025).

| Name | Variable | Min | Max |
|--------------------------|-------------|------------|--|
| Physical damages | <i>dest</i> | 2020 level | complete recovery to 2014 level |
| Agriculture | <i>agri</i> | 2020 level | complete recovery to 2014 level |
| Mining | <i>mini</i> | 2020 level | complete recovery to 2014 level |
| Current account | <i>fsav</i> | 2020 level | complete recovery to 2014 level |
| Oil world market prices | <i>prwo</i> | 2020 level | complete recovery to 2014 level |
| Qualitative improvements | <i>inst</i> | 2020 level | 1 % p.a. Total Factor Productivity (TFP) growth +100% to capital investment effectiveness +100% to productivity elasticities |

Source: Own compilation.

Assumptions: *prwo* is independent; all other parameters are perfectly correlated.

tors through umbrella parameter *ins* that encompasses CGE parameters representing TFP, the transformation of investment into new capital stock, and production elasticities of substitution. We assume that *inst* = 0 corresponds to no TFP growth, no improvements in capital investment, and pre-war production elasticities of substitution (see Table 2.10 in Appendix); *inst* = 1 corresponds to 1% of annual of TFP growth and 100% increase of model parameters that represent the transformation of capital investment into new capital stock and production elasticities of substitution.

Furthermore, in order to identify the contribution of each policy to the total reconstruction uncertainty, we define six sample-scenarios:

1. only *dest* parameters are sampled, all other reconstruction parameters are fixed at the conflict level of 2020 (various scenarios of reconstruction of physically destroyed capital are considered);
2. only *dest* and *agri* parameters are sampled, all other reconstruction parameters are fixed at the conflict level of 2020 (various scenarios that assume both reconstructions of physically destroyed capital assets and agriculture are considered);
3. same as sample (2) + parameter *mini* (recovery of mining);
4. same as sample (3) + parameter *fsav* (foreign assistance recovery);
5. same as sample (4) + parameter *inst* (qualitative improvements);

6. same as sample (5) + parameter *prwo* (world market prices of hydrocarbons);

For each of the defined sample-scenarios, we sample parameters from respective dimensions of the multivariate uniform distribution specified in Table 2.6, each with a sample size of 100 simulations. To technically perform the sampling, we use the R-package ‘EnvStats’ by Millard (2013)⁵.

2.3 Results

2.3.1 Conflict phase, 2015 to 2020

This section discusses the simulation results for the conflict period. Tables 2.7 and 2.8 present the decomposition of losses of the economic sectors and household welfare over the conflict phase (percentage change with respect to the pre-war levels of 2014 by the year 2020).

Our results suggest an overall GDP loss of 36.0% (Table 2.7), which corresponds well with some of the World Bank’s more anecdotal-based estimates⁶. The loss of production factors in sectors affected by the conflict directly contributed to the loss of GDP and household welfare. However, the indirect economywide repercussions had more pronounced effects on the country. According to our estimates, the physical destruction of capital assets in housing, utilities, transport, and the public sector contributed to only 0.6% of total GDP reduction over 2015-2020. The most severe economic losses were associated with disruptions in the mining and agriculture sectors. The direct conflict-related reduction of the value-added in mining and agriculture constituted 11.5 and 4.4% of GDP⁷, but the economywide repercussions associated with these sectors contributed to 20.9 and 9.4% of GDP losses, respectively. Reduced foreign assistance to finance the current account deficit contributed to another 5.1% of GDP loss.

Model results at the sector level suggest that fishery (part of the ‘other agriculture’ sub-sector) and manufacturing (food and non-food) were the most resilient sectors during the conflict. These sectors were the sole recipients of the country’s remaining income, and other eco-

5. We use Latin Hypercube Sampling (LHS) method. See Millard (2013) for details.

6. Initial estimates suggested Yemen’s GDP contracted by more than 50% during the conflict (World Bank 2018); however, later the estimate was reduced to 39% (World Bank 2019b), and in late-2018, Yemen’s economy began to show signs of stabilization and demonstrated moderate growth in 2019 (World Bank 2019c).

7. GDP shares in 2014: 7.8% crops; 3.4% livestock; 23% mining (see Table 2.1); the total reduction of production (by 2020 wrt 2014): crops: 38%, livestock: 41%; mining: 50%. Direct conflict-related reduction of the value-added (by 2020 wrt 2014): agriculture: $7.8\% \cdot (0.38) + 3.4\% \cdot (0.41) = 4.36\%$; mining: $23\% \cdot (0.5) = 11.5\%$.

conomic activity in the country plummeted. While food is essential for household consumption (as is evident in the low-income elasticities of demand, see Table 2.10 in Appendix), Yemen's rudimentary manufacturing sector benefited from constrained imports due to foreign exchange shortages and supplied intermediates for the remaining economy. Other economic activity, especially non-essential services, experienced the most severe GDP losses due to economywide spillovers associated with reduced household and government income. In turn, the construction sector that could have absorbed economic shocks, collapsed, following a sharp increase in the government budget deficit and shrinking investment demand.

Table 2.7: Yemen: decomposition of the economic losses, 2020 vs. 2014 in %

| Sector | Total | Destruction | Agriculture | Mining | Current account |
|-------------------------------|------------|-------------|-------------|------------|-----------------|
| Total GDP | -36 | -0.6 | -9.4 | -20.9 | -5.1 |
| Crops* | -38 | 0 | -38 | 0 | 0 |
| Livestock* | -41 | 0 | -41 | 0 | 0 |
| Other agriculture | 5.6 | -0.7 | -1.4 | 2.9 | 5 |
| Mining* | -50 | 0 | 0 | -50 | 0 |
| Food manufacturing | -1.6 | -0.4 | -1.6 | -0.5 | 0.8 |
| Other manufacturing | 0.9 | -0.8 | -1.5 | 5.4 | -2.2 |
| Utilities | -31.8 | -1.1 | -15.3 | -11.5 | -3.9 |
| Construction | -69.5 | -1.6 | -7.7 | -31.3 | -28.9 |
| Wholesale and retail trade | -31.5 | -0.5 | -11.3 | -13.6 | -6.2 |
| Transportation and storage | -46.5 | -1.4 | -10.2 | -22 | -12.9 |
| Housing | -42.4 | -4.3 | -8.2 | -20.7 | -9.2 |
| Information and communication | -73.8 | -0.9 | -14.3 | -36.8 | -21.8 |
| Business services | -36.1 | -1.1 | -5.1 | -17.2 | -12.7 |
| Other private services | -69.2 | -0.5 | -15 | -37.9 | -15.7 |
| Real investment | -78.5 | -1.8 | -8 | -34.8 | -33.8 |
| Government budget deficit | 77.4 | 4.2 | 13.3 | 52.6 | 7.3 |
| Real exchange rate** | 8.3 | -0.7 | 3.4 | 0.4 | 5.3 |

Source: Yemen CGE model.

Notes:*The production of the sectors is fixed (conflict shocks).

**The simulations do not consider currency devaluation caused by monetary policy actions.

In terms of distributional impacts, the model results indicate that rural and urban residents experienced relatively similar losses in their welfare, with an overall reduction of per-capita consumption of 43.2% and the national poverty level increasing from 48.6% in 2014 to 79.9%

Table 2.8: Yemen: decomposition of the household losses, 2020 vs. 2014 in %

| Sector | Total | Destruction | Agriculture | Mining | Current account |
|-----------------------------|-------|-------------|-------------|--------|-----------------|
| Per-capita real consumption | -43.2 | -12.8 | -8.5 | -17.2 | -4.7 |
| Rural | -42.1 | -8.4 | -9.8 | -18.7 | -5.2 |
| Urban | -47.1 | -21.8 | -6.6 | -14.8 | -4 |
| Poverty level* - national | 79.9 | 55.6 | 7.5 | 13.5 | 3.3 |
| Rural | 89.1 | 64.8 | 8.5 | 13 | 2.8 |
| Urban | 61.7 | 37.4 | 5.5 | 14.4 | 4.4 |
| Rural labor income | -39.2 | -0.3 | -13.3 | -17.6 | -8 |
| Rural capital income | -45.3 | -0.9 | -2.3 | -43.1 | 1.0 |
| Rural land income | -38 | 0 | -38 | 0 | 0 |
| Urban labor income | -35.4 | 0.4 | -10.4 | -18.9 | -6.5 |
| Urban capital income | -55.3 | 0 | -2.7 | -53.8 | -55.3 |
| Urban land income | -38 | 0 | -38 | -38 | -38 |

Source: Yemen CGE model.

Notes:*Poverty headcount by 2020.

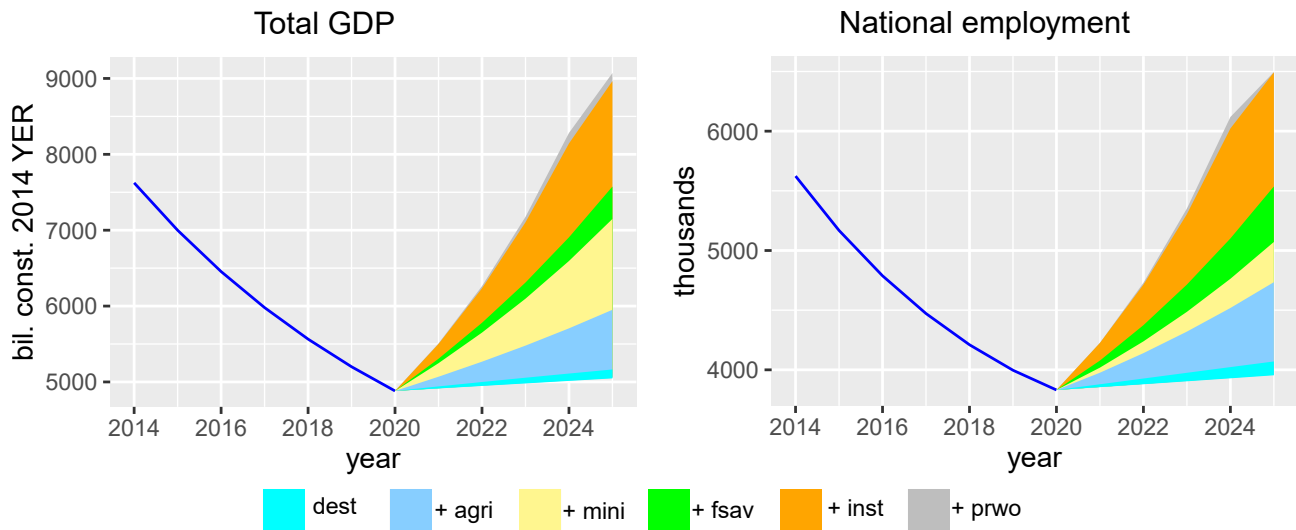
by 2020. At the same time, the urban population experienced a more significant relative increase in poverty prevalence than did the rural population – the poverty headcount rose by half for the rural population (from 59.2 to 89.1%), while for the urban population, it more than doubled (from 23.9 to 61.7%). However, as poverty in rural areas was much higher than in cities before the conflict, the situation in rural areas is particularly devastating, with nine out of ten rural Yemenis living below the poverty line.

2.3.2 Post-conflict recovery phase, 2021 to 2025

Having estimated the impact of the conflict shocks on the Yemeni economy, in this section, we analyze its potential recovery scenarios. Figures 2.1 and 2.2 and Table 2.9 present the spectrum of the country's reconstruction trajectories, where we investigate the importance of each policy in the total post-conflict uncertainty in line with the samples defined in Subsection 2.2.3.

The range of Yemen's possible recovery trajectories varies significantly. Under the worst-case scenario that assumes no reconstruction of the conflict damages, real GDP over 2020-2025 is expected to grow on average by 0.7% per year (Table 2.9). However, given the projected

Figure 2.1: Yemen: real GDP and employment estimates, 2014-25.



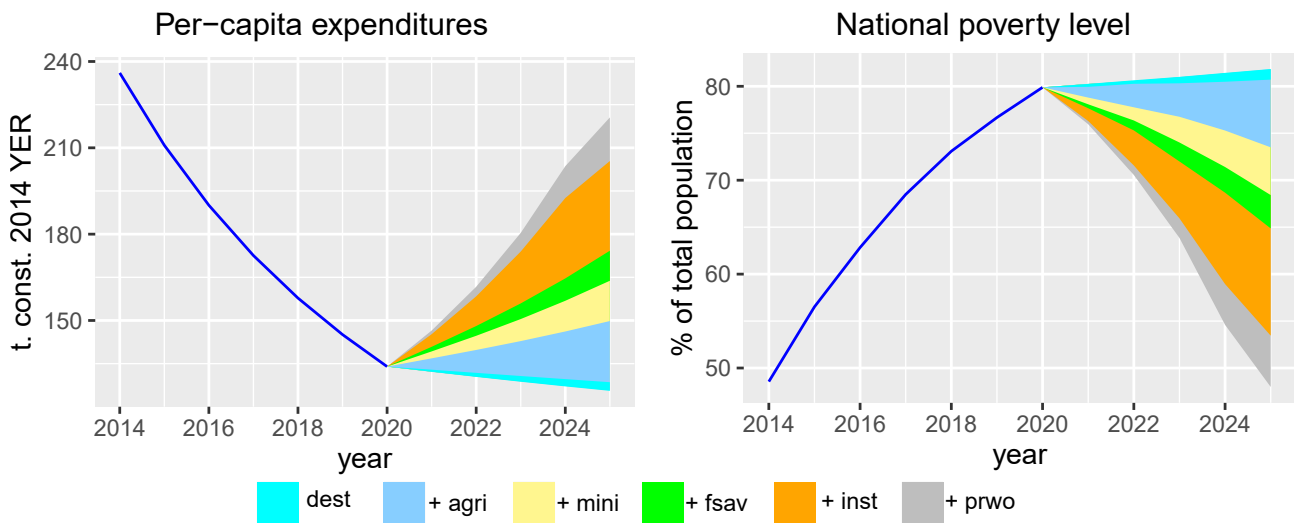
Source: Yemen CGE model.

Table 2.9: Yemen: sectoral GDP (p.a. growth rates with respect to estimated 2020 levels).

| Sector | worst | dest | & agri | & mini | & fsav | & inst | & prwo |
|---------------------|-------|------|--------|--------|--------|--------|--------|
| Total GDP | 0.7 | 1.1 | 4 | 7.9 | 9.2 | 12.9 | 13.2 |
| Agriculture | 0.3 | 0.3 | 8.9 | 8.9 | 8.9 | 10.2 | 9.9 |
| Mining | 0 | 0 | 0 | 14.9 | 14.9 | 14.9 | 14.9 |
| Food manufacturing | 1.1 | 1 | 1.2 | 1.5 | 2 | 6.4 | 5.8 |
| Other manufacturing | 1.6 | 1.3 | 1.6 | 2.1 | 3.5 | 12.4 | 8.8 |
| Utilities | 0.5 | 0.6 | 5.5 | 6.5 | 7.3 | 10.1 | 10.9 |
| Construction | 1.1 | -3.2 | 3.1 | 8.4 | 19.8 | 25.5 | 28.9 |
| Services | 0.9 | 1.8 | 4.6 | 6.3 | 8.2 | 13.6 | 14.3 |

Source: Yemen CGE model.

Figure 2.2: Yemen: per-capita expenditures and poverty headcount estimates, 2014-25.



Source: Yemen CGE model.

growth of the population (see Table 2.11 in Appendix), the per-capita and poverty indicators are expected to deteriorate further (e.g., see the lowest trajectory of per-capita consumption in Figure 2.2). The reconstruction of the physically destroyed capital assets can provide only +0.4% of average annual GDP growth (Table 2.9), which is not enough to achieve positive per-capita growth rates (see the bounds of *dest* in Figure 2.2). With the additional reconstruction of agricultural activities, household income can be stopped from further deterioration (see *+agri* in Figure 2.2). While the complete reconstruction of agriculture to its pre-conflict levels can provide +2.9% of annual GDP growth (Table 2.9), the mining sector's revival is the most effective way for economic recovery even at the current meager world market prices. If the mining sector production reaches 100% of its pre-conflict level, it can provide +3.9% of annual GDP growth (Table 2.9). However, given the importance of agriculture for household incomes, compared to mining, its revival has a more significant effect on the real per-capita consumption (approximately +3.1% of annual growth for agriculture compared to +1.8% for mining, see *+agri* and *+mini* in Figure 2.2). The recovery of foreign assistance inflows to finance the current account deficit can provide another +1.3% of annual real GDP growth (Table 2.9), which is still insufficient to reach pre-war GDP by 2025 (see *+fsav* upper bounds in Figure 2.1). If the country succeeds in the ultimate phase-off of all conflict-related shocks, its economy can be expected to grow very fast (on average, 9.2% per year, see *fsav* in Table 2.9), but given

the growth of population, it will still be far away from the pre-war income and poverty levels (see *+fsav* bounds in Figure 2.2).

Nevertheless, the improvements in productivity, investment, and technological flexibility can boost the economy by another 3.7% of annual GDP growth, with manufacturing and service sectors being the primary recipients of the qualitative economic shift (Table 2.9, *inst*). Only under qualitative improvements that lead to booming secondary and tertiary sectors, the country reaches its potential GDP growth rates, with the labor supply being restricted by population growth rates (see *+inst* upper bounds in Figure 2.1). Yet, according to our estimates, the country reaches its pre-war poverty level by 2025 only in those cases that on top of the best-case reconstruction scenarios assume recovery of the oil world markets (see *+prwo* bounds in Figure 2.2).

2.4 Summary and Conclusion

In this paper we have applied an economywide CGE modeling approach to determine the impact of war in Yemen on its economy and households. For this purpose, we have compiled publically available, albeit fragmented sector-focused data and estimates from various international organizations and integrated them into a CGE model calibrated to the pre-war year of 2014.

Our simulation-based findings suggest that the most severe economic and welfare losses are associated with conflict-related disruptions in the mining and agriculture sectors. These two key sectors' repercussions sent devastating shockwaves throughout the economy, contributing to 20.9 and 9.4% of GDP loss of the total estimated contraction of 36% of GDP between 2015-2020. Consequently, recovery of these sectors' activities should receive the highest priority as their recovery is estimated to produce the fastest way for the country's socio-economic revival. At the same time, our estimates suggest that even if Yemen succeeded in offsetting all conflict-related shocks, reaching the pre-conflict economic and poverty status quo is very unlikely without institutional reforms and qualitative improvements in productivity, investment, and technological flexibility. In addition to a significant boost of the recovery pace, qualitative improvements can positively affect the economy's structure and divert its reliance on the hydrocarbon rents in the post-conflict era. However, as the country could not implement such reforms for decades before the conflict (World Bank 2015), such scenarios seem to be optimistic in the short-run and in light of the recent COVID-19 crisis and human capital depreciation factors not accounted for

in our model. Given the established interrelationship between poverty and armed conflicts (see e. g. Stewart 2002; Ikejiaku 2009; Braithwaite et al. 2014), our findings thus suggest that stabilization of the country in the longer term will require additional assistance beyond the reconstruction of the damaged assets and sectors.

In the context of the Recovery and Peacebuilding Assessment conducted after the conflict (World Bank 2019a), our simulation-based methodology can be used in countries with circumstances similar to the current fragile situation in Yemen. Simulation-based estimates can serve as the first important step for understanding the reconstruction potential and stabilization prospects of a country and thus complement the arsenal of other methods and models feasible at the later stage of post-conflict development.

2.A Calculation of the physical destruction of the capital assets

DNA reports conducted by the World Bank are not fully publicly disclosed (e. g. Bayoumy 2016; World Bank 2017b). However, the reports' most critical excerpts are stated in publicly disclosed Country Engagement note (World Bank 2019a: 7). In particular, the note states that:

- the housing sector suffered the worst damage, with 32% of houses partially damaged and 1% destroyed;
- education, health, transport, water supply, sanitation, and hygiene sectors experienced damage ranging from 27 to 31%.

We then use the methodological conventions of standard DNA of the World Bank, according to which the costs of replacing destroyed assets are assessed at 100%, while those for partially damaged assets are assessed at 40% (World Bank 2017a: 5). Thus, we assume that the housing sector's capital stock was reduced by $(32 \times 0.40) + (1 \times 1.00) = 13.8\%$. For the costs of replacing destroyed assets for utilities, in the transport sector, and the public sector, we use the median of the disclosed range of damage (27 to 31%) and assume that 29% of the capital of these sectors was damaged, resulting in an 11.6% capital loss (29×0.40) .

2.B Yemen CGE model

We use the standard IFPRI CGE model developed by Löfgren et al. (2002) and Diao and Thurlow (2012). General mathematical statements of model equations are similar to those of the Egypt model (Chapter 1).

Table 2.10: Yemen: CGE model parameters.

| Sector | Production elasticities | Trade elasticities | Income elasticities of demand | |
|-------------------------------|-------------------------|--------------------|-------------------------------|---------------|
| | | | Rural h-holds | Urban h-holds |
| Crops | Leontief | - | 0.3 | 0.3 |
| Livestock | Leontief | - | 1 | 0.6 |
| Other agriculture | 0.2 | 1.3 | 1 | 0.6 |
| Mining | Leontief | - | 1.8 | 2.3 |
| Food processing | 1.1 | 3.13 | 0.6 | 0.5 |
| Other manufacturing | 1.3 | 3.1 | 1.5 | 1.7 |
| Utilities | 1.3 | - | 0.9 | 0.7 |
| Construction | 1.7 | 1.9 | 1 | 0.8 |
| Wholesale and retail trade | 1.3 | - | 2.1 | 2 |
| Transportation and storage | 1.3 | 1.9 | 2.1 | 2 |
| Housing | 1.3 | 1.9 | 2.4 | 1.9 |
| Information and communication | 1.3 | - | 2.4 | 1.9 |
| Business services | 1.3 | 1.9 | 2.4 | 1.9 |
| Other private services | 1.3 | 1.9 | 2.4 | 1.9 |
| Public goods and services | 1.3 | 1.9 | - | - |
| Frisch parameter (LES) | - | - | -5.5 | -4.5 |

Source: Aguiar et al. 2016 (production and trade); Breisinger et al. 2011 (income); Ramprakash et al. 1979 (Frisch).

As the country moves from an emergency mode to a development mode, we adjust the model closures defined in Table 2.5. For the period 2020-2025, we assume that for the non-controlled sectors, the newly generated capital (depends on the investment in the previous year) is mobile across sectors, and its distribution depends on the patterns of capital rent distribution paid by each sector (see the ‘putty clay’ assumption in Diao and Thurlow 2012 for more details). We also assume that until reaching the upper threshold of the available labor force, labor factors’

supply is perfectly elastic; after reaching respective threshold levels, labor factors' growth is restricted by the population growth, and the markets adjust through varying wages.

Table 2.11: Yemen: population projections, rural and urban, 2015-25.

| Type | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|-----------------|------|------|------|------|------|------|------|------|------|------|------|
| Total growth, % | 2.4 | 2.4 | 2.3 | 2.2 | 2.2 | 2.1 | 2.1 | 2 | 2 | 1.9 | 1.9 |
| Rural growth, % | 1.6 | 1.5 | 1.4 | 1.4 | 1.3 | 1.2 | 1.2 | 1.1 | 1 | 1 | 0.9 |
| Urban growth, % | 4.4 | 4.3 | 4.2 | 4.1 | 4.1 | 4 | 3.9 | 3.9 | 3.8 | 3.7 | 3.6 |
| Total, millions | 26.9 | 27.5 | 28.1 | 28.8 | 29.4 | 30 | 30.6 | 31.2 | 31.9 | 32.5 | 33.1 |
| Rural, millions | 18.8 | 19.1 | 19.3 | 19.6 | 19.9 | 20.1 | 20.3 | 20.5 | 20.8 | 21 | 21.1 |
| Urban, millions | 8.1 | 8.4 | 8.8 | 9.2 | 9.5 | 9.9 | 10.3 | 10.7 | 11.1 | 11.5 | 11.9 |

Source: UN 2019.

Table 2.12: Yemen: labor supply upper thresholds, thousands of workers, 2015-25

| Type | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Rural uneducated | 979 | 994 | 1,008 | 1,022 | 1,035 | 1,048 | 1,060 | 1,071 | 1,082 | 1,092 | 1,102 |
| Rural secondary | 2,916 | 2,960 | 3,002 | 3,043 | 3,082 | 3,119 | 3,155 | 3,189 | 3,222 | 3,252 | 3,282 |
| Rural tertiary | 131 | 133 | 135 | 136 | 138 | 140 | 141 | 143 | 144 | 146 | 147 |
| Urban uneducated | 422 | 440 | 459 | 478 | 497 | 517 | 537 | 558 | 579 | 600 | 622 |
| Urban secondary | 1,256 | 1,310 | 1,365 | 1,422 | 1,479 | 1,538 | 1,599 | 1,660 | 1,723 | 1,787 | 1,852 |
| Urban tertiary | 56 | 59 | 61 | 64 | 66 | 69 | 72 | 74 | 77 | 80 | 83 |

Source: World Bank 2020d (labor force by skill), and UN 2019 (rural and urban population).

Chapter 3

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 CGE 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.

3.1 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 CGE modeling (Dixon and Rimmer 2016; Taylor 2016; Henning et al. 2018). This type of modeling 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 (PM) 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, I suggest analyzing policy options from the risk perspective, with indicators of policy impact variation caused by parameter uncertainty being used as volatility/risk metrics. Like in portfolio theory, then 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; Markowitz 1959; Sharpe 1994). To my knowledge, this is the first paper that suggests the use of portfolio theory in CGE-based studies.

1. For 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.

I apply the 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 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. Therefore, to explicitly account for the world market uncertainty when analyzing Senegal's agricultural value chains, I use portfolio management methods. As a domain of endogenous policy outcomes, I consider the Poverty-Growth Elasticities (PGE) of ten primary agricultural sectors, and as a domain of uncertain model parameters, I 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, I 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.), I 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, I sample mixed-policy scenarios and estimate the PGE of all policy scenarios under various RoW scenarios.

I 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 the costs of expected return. I 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), portfolio management principles' suggested application can be particularly beneficial for Senegal's practical policymaking.

The rest of this paper proceeds as follows. Section 3.2 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 3.3 describes the application to the analysis of the Senegalese pro-poor agricultural value chains. Finally, section 3.4 highlights the potential implications for policy analysis and concludes.

3.2 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 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) and 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, its peculiarity is the suggestion to integrate SSA methods into the portfolio management framework.

The 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 and 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, I 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 significantly 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 the scope of this paper. In the application to CGE-based analysis of agricultural value chains in Senegal, I use simple portfolio theory concepts defined in Markowitz (1952), Markowitz (1959), Sharpe (1994), and Jorion (2006). To represent risk/return trade-offs, for each policy option, I calculate the average value of policy impact (represents expected policy return), the standard deviation of policy impact (represents the volatility/risk of a policy), and minimum policy impact (represents the worst-case policy return). Furthermore, much like diversified portfolios in finance, I consider diversified (mixed) policies. I 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 the 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 poli-

cymakers. In this context, this 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).

3.3 Agricultural policy in Senegal under the world market uncertainty

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

I use the recursive-dynamic CGE model of the IFPRI developed by Löfgren et al. (2002) and Diao and Thurlow (2012) and the 2015 SAM constructed by Randriamamonjy and Thurlow (2019). I select five years as the simulation horizon (2020-2024)² and tailor the SAM and model to reflect specific adjustment possibilities of the Senegalese economy in the medium-term (see appendix 3.A for more details).

As a set of policy parameters, I consider the TFP growth of ten primary agriculture sectors (table 3.1, columns 1-2). TFP 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, TFP 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.

Following Wiebelt et al. (2020), who conducted the standard CGE-based policy analysis of the Senegalese agricultural value chains, I define standard TFP sectoral scenarios such that 1% growth of total agriculture by 2024 is achieved uniquely by respective sectors (table 3.1, column 6). Then, obtained policy impact estimates represent sectors' effectiveness in poverty reduction per 1 percent of agricultural growth. Therefore, I define policy impact estimates under standard

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

3. Per-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).

Table 3.1: Senegal, PM: considered agricultural sectors.

| Sector | Short | GDP, % | Export in output, % | Import in consumption, % | p.a.TFP growth | Stan- dard PGE | Rank |
|--------------------|-------|--------|---------------------------|--------------------------------|-------------------|----------------------|------|
| [1] | [2] | [3] | [4] | [5] | [6] | [7] | [8] |
| Sorghum and 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: Calculations based on Randriamamonjy and Thurlow (2019) and Senegal CGE model.

TFP sectoral scenarios as (semi) Poverty-Growth elasticities (PGE, table 3.1, column 7⁴) and rank sectors (table 3.1, column 8). I 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.

3.3.2 Uncertain model parameters

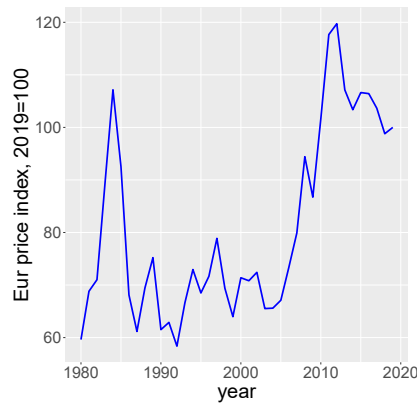
The rice sector's estimated high effectiveness can be primarily attributed to its trade intensiveness (table 3.1, columns 4-5). The increased output should be absorbed by domestic or external demand, and the trade intensive rice sector benefits from import substitution or export expansion opportunities, 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

4. In order to operate with the term 'return' in the meaning similar to finance, I 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.

the agricultural markets (e. g. 1985-1992 or 2011-2020, see figure 3.1), 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 3.1: Price index of agricultural commodities



See Appendix 3.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 3.2). 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 2020a; FAO 2011), the standard assumption about constant world market prices becomes particularly weak, and the 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, I consider world 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

Table 3.2: Senegal, PM: linkages between agroprocessing and primary agriculture.

| Sector | Intermediate costs, % | of which primary agriculture, % |
|----------------------------|-----------------------|---------------------------------|
| 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: Calculations based on Randriamamonjy and Thurlow (2019).

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 2020a; FAO 2011). Therefore, in addition to the price indices, I use the current account deficit estimates by the IMF (2020) to represent the uncertainty in RoW (table 3.3).

Table 3.3: Senegal, PM: 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 mineral 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 3.A.3 for sources and details.

3.3.3 Systematic Sensitivity Analysis

Next, I consider standard sectoral PGE, but allow for the variation of RoW parameters. To sample RoW scenarios, I follow Webster et al. (2008) and use the Latin Hypercube Sampling from a multivariate Gaussian distribution. First, I estimate the mean and the variance of the Gaussian distribution (see appendix 3.B for details) and treat sampled parameters as possible

RoW scenarios (table 3.4). Then, I calculate PGE and rank the poverty reduction effectiveness of agricultural sectors for each sampled RoW scenario (table 3.5).

Table 3.4: Senegal, PM: sampled RoW scenarios.

| Scenario | pw_agri | pw_MUVi | pw_ener | pw_fert | pw_mtmm | 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: Author's compilation. See appendix 3.B for details.

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. 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 3.1, column 7), demonstrates its robustness and is ranked as a second or third best policy option under the majority of scenarios.

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.

3.3.4 Portfolio management methods

Having established the inability of standard tools to define optimal policy under the RoW uncertainty, I refer to portfolio management methods and perform the comparative analysis of

Table 3.5: Senegal, PM: sectoral ranking and PGE under different RoW scenarios.

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

Source: Calculations based on Senegal CGE model.

policy options based on portfolio management principles.

In the context of my case study, besides the standard comparison of sectors, consideration of mixed policies is necessary. By design of the 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, I 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 3.C 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.

I 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 such 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, I 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 information and estimation, I 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, I do not use advanced mathematical finance

methods that involve analyzing return distributions and applying the latest available modern portfolio theory methods. To represent risk/return trade-off, I use simple metrics such as the average value of PGE (represents expected return, E), standard deviation of PGE (represents the volatility of expected return, σ), or minimum value of PGE (represents the worst-case expected return of a policy, min).

Table 3.6: Senegal, PM: top five policies based on expected return $E(PGE)$.

| Policy | Weights/composition | | | | | | | | | | E | σ | 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: Calculations based on Senegal CGE model.

Table 3.7: Senegal, PM: top five policies based on worst-case return $min(PGE)$.

| Policy | Weights/composition | | | | | | | | | | min | E | σ |
|--------|---------------------|------|------|------|------|------|------|------|------|------|-------|------|----------|
| | 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: Calculations based on Senegal CGE model.

Table 3.8: Senegal, PM: top five policies based on Sharpe ratio $E(PGE)/\sigma(PGE)$.

| Policy | Weights/composition | | | | | | | | | | Sharpe | E | σ |
|--------|---------------------|------|------|------|------|------|------|------|------|------|--------|------|----------|
| | 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: Calculations based on Senegal CGE model.

Table 3.6 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 σ). 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 3.5). 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 3.7). This criterion is a simplified version of the Value at Risk indicator used in finance to represent the risk of loss for investments (Jorion 2006). 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 I consider is the Sharpe ratio (expected return E / standard deviation σ , table 3.8) - 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, $\sigma(PGE) \in [0; 0.1]$), 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.

3.4 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 be insufficient to define optimal policy intervention. If none of the policy options is robustly superior, I 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, I 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, I apply portfolio management methods and analyze the spectrum of agricultural policy options from a risk and return perspective. 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, the method can be especially useful in such models as it allows applying commonly known portfolio management principles when it is necessary to select a policy based on the risk/return trade-offs in a highly uncertain environment.

3.A Senegal CGE model

3.A.1 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, I perform the following adjustments:

- I 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 emphasizing 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.

3.A.2 Functional forms and closures

I define functional forms and closure rules for the Senegalese CGE model based on the standard IFPRI CGE model by Löfgren et al. (2002) and Diao and Thurlow (2012). General mathematical statements of model equations are similar to those of the Egypt model (Chapter 1).

Table 3.9: Senegal, PM: CGE functional forms and closures.

| Block | Category | Form / closure (endogenous variables) |
|------------|--------------------|--|
| Production | Value-added | CES |
| | Intermediate | Leontief |
| | Top of technology | Leontief |
| Trade | Import | CES |
| | Export | CET |
| Households | Consumption | 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 |

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

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

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

3.A.3 Sources used to define model parameters

Used SAM and selected functional forms and closures define the set of CGE parameters, and I use different sources, estimates, and approximations to assign fixed parameter values.

- I use approximations and assumptions when the necessary estimates are not available. For example, I use Aguiar et al. (2016) to define values of elasticity parameters;
- based on the observed productivity decline over 2006-2015 (see IMF 2017b for more details), I assume zero productivity growth for all non-policy sectors;
- I use Euro as a trade currency and convert USD 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 3.10: Senegal, PM: sources used to define CGE parameters.

| Parameter | Used sources |
|-----------------------------------|--|
| Non-policy TFP | Own assumption based on IMF (2017b) |
| Factor supply | ILO (2020) for labor; FAO (2020b) for land; Feenstra et al. (2015) for economywide capital |
| Population | UN (2019) |
| 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) and King and Byerlee (1978) |
| Frisch parameters | Own estimates based on ANSD (2013), World Bank (2020d), and Ramprakash et al. (1979) |

3.B Sampling RoW scenarios

- I use the same sources as in 3.A.3 and construct the historical sample of p.a. growth rates throughout 1980-2019 and estimate moments of the multivariate Gaussian distribution (Table 3.11);
- I use LHS 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, I truncate 0.1 percentiles from left and right.

Table 3.11: Senegal, PM: means, standard deviations and correlations for RoW scenarios.

| | 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 |

3.C Sampling of mixed-policy scenarios

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

$$\sum_{i=1}^{10} share_i tfp_i = tfp_{tot} \quad \text{subject to } tfp_i > 0 \quad (3.1)$$

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 I assume that the sample size of 1000 scenarios is sufficient to cover the parameter space of potential policy options.

Chapter 4

The Role of Global Climate Change in Structural Transformation of Sub-Saharan Africa: Case Study of Senegal

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Abstract

With increasing evidence that rural households in sSA opt for deagrarianization as an adaptation strategy to climate change, it is becoming important to understand the role of GCC in ongoing structural transformation processes in these countries. We use Senegal as a case study country and analyze how various GCC scenarios affect the country’s economic sectors, households’ welfare, and structural transformation patterns. Our simulation results suggest that GCC can increase the country’s deagrarianization pace, with industrial and service sectors in the capital Dakar being the most important destinations of the former agricultural labor force. Although unplanned urbanization caused by GCC smoothes its overall negative impact and decreases spatial income disparities, uncontrolled deagrarianization is also associated with negative externalities. Previous growth-focused studies suggest that services partaking in labor deagrarianization can hamper country’s long-term growth prospects. Our results suggest that

productivity increase of service sector can reduce its labor demand and thus redirect part of the former agricultural labor force towards industrial sectors.

Keywords: CGE modeling; climate change; deagrarianization; urbanization.

4.1 Introduction

With the growing certainty in various GCC projections and scenarios, quantification of GCC-associated economic and social consequences is becoming a top priority of researchers and policymakers worldwide. Due to the natural relationship of climate characteristics and agriculture (Dell et al. 2014), vulnerable agriculture-dependent countries and regions receive particular attention (Mertz et al. 2009). Significant efforts have been made to quantify GCC scenarios' impact and explore agriculture-focused adaptation strategies in various developing countries and regions (e. g. Kurukulasuriya et al. 2006; Mendelsohn 2008; Calzadilla et al. 2013; Arndt and Thurlow 2014; Wiebelt et al. 2015; Siddig et al. 2020). While these studies provide important insights on GCC-associated economic and social consequences, surprisingly little attention has been given to climate change in the context of ongoing structural transformation processes in developing countries.

GCC-associated challenges in sSA represent particular research interests. For decades it has been observed that sSA countries do not follow classic structural transformation patterns¹. Bryceson (1996) is among the first to cite statistical evidence and notes that despite industrializing a little, sSA is becoming less rural in character. She emphasizes that the industrial sector, being easily outcompeted by developed countries, is not the primary driver of rural exodus and urbanization. She suggests applying the distinct concept of 'deagrarianization' for sSA and using a sectoral perspective to analyze off-farm activity diversification of rural households. In more recent studies, McMillan et al. (2014) and Rodrik (2015, 2016) also apply a sectoral approach and similarly note industrialization problems in sSA countries. With increasing evidence that rural households in sSA opt for deagrarianization and rural outmigration as adaptation strategies to GCC (Mertz et al. 2008; Connolly-Boutin and Smit 2015), understanding economic transformation patterns of these countries becomes even more important. How can various GCC scenarios affect fundamental economic structure and labor reallocation? Which economic regions and sectors suffer, and which might eventually benefit from the structural

1. See Syrquin (1988) and Herrendorf et al. (2014) for overviews on the topic.

transformation? What policies might be necessary to influence these processes? This paper attempts to answer these and related questions based on the case study of GCC in Senegal.

Like many other sSA countries, Senegal is characterized by very uneven economic and social development, with the capital Dakar being more developed and wealthier than other provinces. The country has been experiencing a rural exodus since the 1960s, with most of the provincial migrants joining the non-official urban sectors (Goldsmith 2004; WB 2018). Although historical evidence suggests that rural outmigration decisions are more complex and might include non-income factors (e. g. Brockerhoff 1990), the search for a better job and income remains the self-declared primary driver of rural exodus in Senegal (FAO 2018a, 2020a). In the context of the lingering significance of agriculture for most of Senegal’s rural population (USAID 2017), GCC thus can be expected to trigger the country’s deagrarianization and affect the fundamental structure of its economy.

To model GCC’s impact on the Senegalese economy, we use biophysical and economic workhorse models developed by the IFPRI. We use the IFPRI’s International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model to produce GCC scenarios that affect the country through agricultural productivity and world market prices. Then IMPACT GCC scenarios are passed on to the IFPRI-type CGE model designed for the Senegalese economy.

Our simulation results demonstrate that although GCC’s overall impact is expected to be relatively moderate, it can still impact economic structure and contribute to existing regional imbalances. Agriculture, being already significantly less productive than other sectors², is directly exposed to the GCC-associated productivity shocks and becomes even more ineffective. We expect labor to be pushed out of agriculture and into both industry and services. This effect is the most significant for uneducated labor, which is intensively employed in Senegalese agriculture. Rural households are expected to deagrarianize either by joining nonagricultural sectors in their provinces or, depending on the interregional mobility, offer their labor in the other regions with higher wages. The most developed and the least agricultural, the Dakar region suffers only from the indirect, general income losses, and its activities are expected to be the most attractive destinations for the former agricultural labor force. Provincial industrial and service activities that could have grown due to local deagrarianization, with increasing interregional labor mobility, become less attractive than wealthier Dakarian counterparts. As

2. The average farmer is more than six times less productive than the average counterpart in the rest of the economy (Seck 2016)

a result, the capital Dakar can become even more economically important at other regions' expense.

Although urbanization resulting from non-interventional policy smoothes the overall negative impact of GCC and decreases spatial income disparities, previous growth-focused studies suggest that policy interventions should be considered too. McMillan et al. (2014) and Rodrik (2015, 2016) argue that in sSA rural labor movements towards unproductive and informal urban services is growth-reducing phenomenon that blocks off rapid industry-led growth and transformation similar to South Asian countries. In this context, services partaking in Senegal's deagrarianization can hamper its long-term growth prospects, and we additionally conduct simulations to analyze potential policies to influence these processes. Our results suggest that productivity increase of services sector can reduce its labor demand and thus redirect part of the former agricultural labor force towards industrial sectors. Although not being optimal policy in terms of immediate growth effects (compared to a productivity increase of industrial sectors themselves), productivity boost of services can essentially push uneducated labor towards industry and pave the way for rapid growth through industrialization.

The rest of this paper proceeds as follows. Section 4.2 provides an overview of the existing economic and social status quo and outlines GCC scenarios' major shock transmission channels that impact the Senegalese economy. Section 4.3 presents simulation results and analyzes scenarios of Senegal's economic transformation. Section 4.4 highlights the potential policy implications and concludes.

4.2 Vulnerability of the Senegalese economy to GCC

4.2.1 Economic and social status-quo

We begin our analysis by investigating pre-existing vulnerabilities of the Senegalese economy to GCC. As our primary data input, we use the SAM³ constructed by Randriamamonjy and Thurlow (2019). The SAM represents the state of the Senegalese economy in 2015, and, unlike standard national SAMs, it represents activities, households, and factors on the regional level (Table 4.1). Thus, our SAM allows us to account for each region's economic and social specifics

3. The SAM (available from the authors upon request.) uses macro- and micro-level data such as national accounts, input-output tables, household surveys and consistently represents a detailed snapshot of the economy for selected year. See Breisinger et al. (2009) for detailed explanation of the concept.

Table 4.1: Senegal, GCC: mapping between administrative and SAM regions.



| Administrative | SAM region |
|---|------------|
| Dakar | Dakar |
| Thiès, Diourbel | Thi_Dio |
| Louga, Kaolack, Fatick, Kaffrine | Center |
| Saint-Louis, Matam | North |
| Ziguinchor, Sédhiou, Kolda, Kédougou, Tambacounda | South |

and conduct our analysis on both regional and national levels.

Senegal has economic structure similar to other least developed countries (Schwab and Sala-i-Martin 2015). In particular, the country has a high share of primary sectors (18.7% of GDP is primary agriculture and mining, see Table 4.2), low industrialization (14% of GDP), and high reliance on imported industrial products (33% of consumption, of which one third is imported). At the same time, on the regional level, these patterns are not homogeneous. In particular, our SAM captures the more developed status of the capital Dakar, and its neighboring regions (Thi_Dio), where most of the economic activity is represented by the secondary and tertiary sectors. Other regions (Center, North, and South) heavily rely on primary agriculture (GDP share of agriculture varies from 40 to 60%) and are underdeveloped even by the national standards.

Similar developmental disparities can be observed in the regional breakdown of the household types (Table 4.3). The share of non-urban residents is significantly higher in the rural provinces (Center, North, and South), where the households involved in farming activities vary from 48.8 to 71.5%. The latest FAO survey conducted in 2020 reveals that most of these households are small-scale subsistence farmers who rely on informal family labor (FAO 2020a). As a result, already in 2015, Senegal is characterized by significant income disparities across its regions. The poverty line in Dakar is almost two times higher than in rural areas, and even with that, the (weighted) average poverty incidence among farmers is 64% compared to only 26% in Dakar (ANSD 2013).

Table 4.2: Senegal, GCC: economic structure, 2015.

| | Total, % | of which (within), % | | | | | | |
|------------------|----------|----------------------|-------|-------|-------|-------|-------|------|
| | | crops | oagr | mini | agpr | oind | serv | padm |
| National GDP | 100.00 | 9.26 | 6.20 | 3.17 | 9.38 | 14.08 | 52.34 | 5.57 |
| Dakar | 55.34 | 0.73 | 0.44 | 2.18 | 8.68 | 16.86 | 63.91 | 7.21 |
| Thi_Dio | 17.22 | 5.49 | 5.10 | 5.24 | 10.15 | 16.59 | 53.99 | 3.44 |
| Center | 9.05 | 38.47 | 20.48 | 1.70 | 5.26 | 6.21 | 26.14 | 1.73 |
| North | 10.10 | 21.03 | 18.58 | 6.56 | 16.57 | 8.67 | 23.12 | 5.47 |
| South | 8.29 | 27.76 | 16.23 | 2.97 | 8.19 | 5.58 | 35.86 | 3.41 |
| Export in output | 10.27 | 7.36 | 2.38 | 23.84 | 15.83 | 14.15 | 7.65 | - |
| Consumption | 100.00 | 7.68 | 4.20 | 2.86 | 14.35 | 32.74 | 34.51 | 3.66 |
| of which import | 18.21 | 19.52 | 0.37 | 38.51 | 14.05 | 32.60 | 8.42 | - |

Note: crops = crops production; oagr = other agriculture (livestock, fishery, forestry); mini=mining; agpr = agroprocessing; oind = (other) industry; serv = services; padm = public administration.

Source: Calculations based on Randriamamonjy and Thurlow (2019).

Table 4.3: Senegal, GCC: households structure, 2015.

| | Total, % | Population | | | % below poverty line | | | |
|----------|----------|-------------|-------|-------|----------------------|-------|-------|-------|
| | | of which, % | | | All | URB | FAR | NFR |
| | | URB | FAR | NFR | | | | |
| National | 100.00 | 43.79 | 46.04 | 10.16 | 46.71 | 33.03 | 64.42 | 36.91 |
| Dakar | 23.68 | 100.00 | 0.00 | 0.00 | 26.10 | 26.10 | - | - |
| Thi_Dio | 24.65 | 28.26 | 55.80 | 15.94 | 45.04 | 31.15 | 64.01 | 31.40 |
| Center | 10.78 | 35.83 | 48.83 | 15.35 | 41.60 | 50.10 | 41.00 | 28.23 |
| North | 21.36 | 19.09 | 71.44 | 9.46 | 54.19 | 31.09 | 63.46 | 41.52 |
| South | 19.53 | 26.67 | 60.24 | 13.09 | 68.45 | 55.94 | 74.62 | 61.96 |

Note 1: URB = urban households; FAR = rural farm households; NFR = rural non-farm households.

Note 2: Poverty lines (p.a. per-capita consumption per adult equivalent in constant 2015 thousand CFA francs): Dakar: 370; other urban: 295; rural: 221.

Source: Calculations based on Randriamamonjy and Thurlow (2019) and ANSD (2013).

4.2.2 Modeling GCC shocks and economic transformation

To produce the GCC scenarios that can affect the Senegalese economy, we use the IMPACT model developed by the IFPRI. For each of the three climate model scenarios used here, the IMPACT model produces estimates of region-specific crop productivity shocks and world market prices (detailed description of the model can be found in Calzadilla et al. 2013; Robinson et al. 2015).

Given our focus on the whole economy’s structural transformation, we have to extrapolate beyond IMPACT’s basic outputs. The IMPACT model focuses on the most common crops, and it does not produce GCC impact estimates for livestock and fishery, which constitute 40% of the primary agriculture in Senegal (see Table 4.2). At the same time, climate experts emphasize that these two agricultural sub-sectors will also be directly affected by GCC in Senegal. For the livestock, the impact is expected via heat stress and reduced productivity through reduced water and forage resources; for the fishery, the impact is expected via rising surface water temperatures and ocean acidification, altering species’ reproduction migration (USAID 2017). Furthermore, the IMPACT model does consider region-specific crops (e. g., cassava and other local fruits and vegetables). Therefore, given our focus on the fundamental structural transformation of the economy, we use the rule of thumb and produce region-specific GCC productivity shocks for the whole primary agriculture based on the weighted average IMPACT crop projections.

Table 4.4: Senegal, GCC: scenarios (total % change over 2015-50).

| Scenario | Agricultural productivity | | | | | Prices (world) | |
|----------|---------------------------|---------|--------|--------|--------|----------------|-------|
| | Dakar | Thi.Dio | Center | North | South | crops | oagr |
| No GCC | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.66 | 11.29 |
| GFDL | -15.01 | -15.01 | -11.59 | -4.56 | -4.84 | 28.31 | 11.94 |
| IPSI | -23.60 | -23.60 | -28.37 | -14.41 | -17.32 | 30.03 | 12.42 |
| HADGEM | -31.15 | -31.15 | -34.64 | -15.81 | -10.71 | 31.28 | 12.39 |

Note: No GCC = no-global-climate-change scenario; GFDL = **Geophysical Fluid Dynamics Laboratory Climate Model**; IPSL = **Institut Pierre Simon Laplace Earth System Model**; HADGEM = **Hadley Centre Global Environment Model**.

Source: Calculations based on the IMPACT model.

Then we use GCC scenarios (Table 4.4) and supply them into the IFPRI-type CGE model

of the Senegalese economy (Table 4.5)⁴. Similar to Wiebelt et al. (2013), Wiebelt et al. (2015), Arndt et al. (2015), and Siddig et al. (2020), and other authors who measure economywide repercussions of agricultural GCC shocks, we model GCC scenarios through the factor productivity parameters in the value-added production functions and model parameters that define the world market prices in the trade block of model equations. At the same time, our study is distinct from the literature strands because we focus on the country’s fundamental economic transformation resulting from GCC. We assume that deagrarianization will be the primary GCC adaptation strategy of rural households and suppose that sectoral and regional income differentials resulting from the agricultural productivity decline will shape the country’s economic transformation.

Table 4.5: Senegal, GCC: specification of CGE model.

| Block | Category | Functional form / closure (endogenous variables) |
|----------------------|-----------------------|---|
| Production (regions) | Value-added | CES. Elasticities: crops=0.24; oagr=0.24; mini=0.2; agpr= 1.12; oind=1.26; serv and padm=1.68. Source: Aguiar et al. (2016). |
| | Intermediates | Leontief |
| | Top of technology | Leontief |
| National market | Output by each region | CES |
| Trade | Import | CES |
| | Export | CET |
| Households | Consumption | LES |
| Closures | Numeraire | The exchange rate is the model numeraire; Consumer Price Index and domestic producers’ price level are flexible; |
| | Rest of the World | the current account balance and world market prices are exogenous; |
| | Government | Fixed government tax rates; (dis)savings adjust to net revenues; |
| | Savings/Investment | Neoclassical: fixed savings rate, endogenous investment |
| | Factors | Capital: ‘putty-clay’: newly generated capital is mobile and its distribution depends on the rents (\uparrow rents \Rightarrow \uparrow new capital, see Diao and Thurlow (2012) for more details); Labor and land: fully employed and mobile (within regions); interregional labor transformation via CET (below) |

Note: **GAMS** model code and other data available from the authors upon request.

The shock transmission channel is modeled as follows. First, we assume that GCC productivity decline in agriculture will affect capital and land production factors only. This assumption

4. The model is based on the standard recursive-dynamic CGE model of the IFPRI, which we tailor to reflect country-specific adjustment mechanisms. A detailed description of the IFPRI-type CGE model and its equations can be found in Löfgren et al. (2002) and Diao and Thurlow (2012) and in Chapter 1 (equations of the Egypt model).

is justified because, unlike specific land and capital production factors, the most significant agricultural labor is noneducated (see Table 4.6), meaning that it is relatively homogeneous, and its productivity losses due to intersectoral or interregional mobility are relatively low.

Table 4.6: Senegal, GCC: contribution of agricultural factors to GDP, %, 2015.

| | FLND | FCAP-c | FCAP-l | FLAB-n | LAB-p | FLAB-s | FLAB-t | Total agriculture |
|----------|-------|--------|--------|--------|-------|--------|--------|-------------------|
| Dakar | 0.36 | 0.34 | 0.14 | 0.28 | 0.04 | 0.01 | 0.00 | 1.17 |
| Thi_Dio | 2.81 | 3.97 | 1.08 | 2.22 | 0.38 | 0.12 | 0.01 | 10.59 |
| Center | 18.21 | 10.93 | 11.75 | 16.04 | 1.35 | 0.66 | 0.00 | 58.95 |
| North | 8.54 | 10.84 | 9.43 | 8.98 | 1.37 | 0.44 | 0.02 | 39.61 |
| South | 12.79 | 10.74 | 8.30 | 10.57 | 1.12 | 0.45 | 0.01 | 43.99 |
| National | 4.25 | 3.85 | 2.97 | 3.77 | 0.44 | 0.17 | 0.01 | 15.45 |

Note: FLND = agricultural land; FCAP-c=crops capital; FCAP-l=livestock capital; FLAB-n=non-educated labor; FLAB-p=primary educated labor; FLAB-s=secondary educated labor; FLAB-t=tertiary educated labor.

Source: Calculations based on Randriamamonjy and Thurlow (2019).

Then, agricultural assets' reduced productivity implies that agriculture receives less investment than other sectors (see 'putty clay' closure in Table 4.5). Given its rigid production function (very low CES elasticities, see Table 4.5), labor cannot substitute scarcer land and capital. Therefore, having less demand, agricultural labor is devalued and pushed out of agricultural activities. As other sectors with higher wages can employ released agricultural labor force, this shock transmission channel allows us to model the economic transformation.

The absorbents of deagrarianized labor can be either nonagricultural activities within the region or, conditional on the interregional mobility, activities in other regions with higher wages. We assume that the labor can be reallocated across the activities within their regions without any frictions (full employment and mobility assumption for region-specific labor factor, see Table 4.5). To model the interregional mobility of labor, we use a relatively straightforward approach and apply (volume-preserving) the CET function (see Dixon and Rimmer 2003, 2006; Mensbrugghe and Peters 2016). Under this approach, regions with higher wages attract more labor, and household costs associated with reallocating labor from one region to another are represented through exogenously specified elasticity parameters (the higher the elasticity, the higher is the mobility to regions with higher wages)⁵. Furthermore, as our model separates

5. It should be mentioned that upon the data availability, the interregional mobility of labor can be modeled

households and factors, we assume that households stay in their provinces, but they can receive factor income earned in the other regions. This mechanism can be interpreted as remittances sent to the family by internal labor migrants, and it allows us to take into account positive welfare effects for migrant-sending regions.

4.3 Scenarios of Senegals' economic transformation

Our simulation results demonstrate that GCC's overall economic impact is expected to be relatively low, with GDP losses reaching 2.08% under the worst-case HADGEM scenario (Table 4.7). At the same time, these losses are unevenly distributed across sectors and regions of the country. On a sectoral level, due to direct productivity losses, agriculture is expected to experience the worst economic decline. In turn, although not directly hit, downstream agro-processing also shrinks because its most essential intermediates - agricultural commodities - get more expensive due to domestic and world market price increase. With increasing GCC severity, the whole agribusiness sector becomes less effective and loses in the competition for production factors to other economic sectors. Under the assumption of interregional immobility of labor, the industrial sector is expected to be the primary beneficiary of the country's GCC-induced deagrarianization (Table 4.7). Compared to income-dependent services, the less elastic industrial sector additionally benefits from the depreciated real exchange rate⁶ and pulls production factors to itself. Consequently, besides GCC shocks, the regional losses largely depend on their economic structure. The most severe GDP losses are expected in the rural region Center, whose underdeveloped industrial sector cannot absorb the deagrarianized labor force and cushion GCC shocks. At the same time, Dakar and neighboring Thiès & Diourbel are the most industrialized and the least agrarian regions in the country, and despite having comparable shocks as Center (see Table 4.4), they are expected to be the most resilient to GCC.

However, the economic loss distribution is not fully mirrored in the households' welfare (Table 4.8). Like other case-country studies (e. g. Breisinger et al. 2013; Wiebelt et al. 2015), we find that farmers (households who own agricultural land) are not the main cost-bearers of GCC. Although all households suffer from increased agricultural prices (both domestic and

based on the econometric estimates of migration gravity equations, where besides wage/income differentials, the attractiveness of the region depends on distance, demography, and other non-monetary factors (see Borgy et al. (2010) and Luo et al. (2016) for details).

6. Real exchange rate in % vs No GCC by 2050 (no interregional mobility): GFDL-0.7; IPSL -1.56; HADGEM - 1.8.

Table 4.7: Senegal, GCC: GDP losses (% vs No GCC by 2050, no interregional mobility).

| Scenario | Total | by sectors | | | | | | by regions | | | | |
|----------|-------|------------|--------|------|--------|------|-------|------------|---------|--------|-------|-------|
| | | crops | oagr | mini | agpr | oind | serv | Dakar | Thi.Dio | Center | North | South |
| GFDL | -0.74 | -8.03 | -3.89 | 2.62 | -4.77 | 1.33 | -0.40 | -0.22 | -0.90 | -3.69 | -0.89 | -1.13 |
| IPSI | -1.86 | -20.80 | -9.62 | 5.59 | -9.35 | 2.47 | -0.89 | -0.56 | -1.52 | -9.37 | -2.75 | -3.98 |
| HADGEM | -2.08 | -22.88 | -10.90 | 6.29 | -10.61 | 2.75 | -0.99 | -0.67 | -2.01 | -11.77 | -2.99 | -2.13 |

Source: Calculations based on Senegal CGE model.

import), and reduce real consumption, farmers are expected to be less affected than urban and rural non-farm households. Despite reduced productivity, we expect factor remuneration of agricultural land to increase, especially in regions with a relatively mild productivity decrease (North and South). Land becomes a scarce and expensive production factor that cannot be easily substituted (very low CES elasticities, see Table 4.5). Therefore, landowners (farmers), unlike urban and landless rural households, can partly compensate for their consumption losses. However, because significant income disparities already characterize the country, residents of industrialized regions (Dakar, Thiès & Diourbel) are projected to be still much wealthier than their rural provincial compatriots.

Table 4.8: Senegal, GCC: households' losses (by 2050, no interregional mobility).

| Indicator | Scenario | National | URB | FAR | NFR | Dakar | Thi.Dio | Center | North | South |
|--|----------|----------|-------|-------|-------|-------|---------|--------|-------|-------|
| Real per capita consumption (vs. No GCC) | GFDL | -1.78 | -2.30 | 0.29 | -3.65 | -1.94 | -2.66 | -1.89 | -0.70 | -0.15 |
| | IPSI | -4.01 | -4.22 | -2.74 | -7.31 | -3.34 | -4.90 | -7.74 | -3.38 | -3.14 |
| | HADGEM | -4.53 | -4.77 | -3.13 | -7.99 | -3.78 | -5.78 | -10.08 | -3.79 | -1.45 |
| % below poverty line | No GCC | 36.14 | 23.80 | 53.72 | 22.66 | 11.82 | 27.49 | 38.83 | 45.49 | 64.85 |
| | GFDL | 37.64 | 25.66 | 54.11 | 26.29 | 12.14 | 31.07 | 41.74 | 45.86 | 65.62 |
| | IPSI | 40.67 | 27.81 | 57.59 | 30.66 | 12.14 | 34.98 | 48.13 | 49.23 | 68.95 |
| | HADGEM | 40.85 | 28.31 | 57.41 | 30.90 | 12.14 | 36.32 | 49.90 | 49.59 | 66.80 |

Source: Calculations based on Senegal CGE model.

GCC's uneven impact on the regional economies and persisting regional income disparities can facilitate interregional labor mobility. We expect that poorer less educated households of rural provinces will offer their labor in the regions with higher wages. To model these processes, we assume that each labor type's supply across the regions is distributed via the CET function with the elasticity values of 0.5 and 2. Given data absence, we assume that these arbitrarily chosen elasticity parameters represent scenarios of rigid and flexible responses to wage differentials across the regions (rigid=0.5; flexible=2). Due to this paper's size restrictions, we present the interregional labor mobility scenarios only for the most severe 'HADGEM' GCC

scenario.

According to our simulations, interregional labor mobility allows smoothing the GCC's overall negative economic impact (Table 4.9). This effect, however, is associated with growing economic imbalances across the country. With its highest wages, Dakar is expected to be the most significant labor-pulling region, and compared to the interregional labor immobility, the inflow of cheap labor boosts its economy. In contrast, the provincial economies become even more non-competitive and plummet. As a result, we expect Dakar to gain economic weight at the expense of other provinces and be the only region with positive growth rates.

Table 4.9: Senegal, GCC: regional GDP under interregional labor mobility (HADGEM, % vs No GCC by 2050).

| Region | GDP changes | | | GDP shares | | |
|----------|-------------|--------|----------|------------|--------|----------|
| | no | rigid | flexible | no | rigid | flexible |
| National | -2.08 | -1.75 | -1.69 | 100.00 | 100.00 | 100.00 |
| Dakar | -0.67 | 1.11 | 1.55 | 59.08 | 59.94 | 60.16 |
| Thi_Dio | -2.01 | -1.37 | -1.30 | 17.38 | 17.43 | 17.44 |
| Center | -11.77 | -16.85 | -18.05 | 6.92 | 6.50 | 6.41 |
| North | -2.99 | -5.09 | -5.66 | 9.31 | 9.07 | 9.01 |
| South | -2.13 | -5.23 | -6.15 | 7.31 | 7.05 | 6.98 |

Source: Calculations based on Senegal CGE model.

Redistribution analysis on a sectoral level (Table 4.10) reveals further important details. Provincial industrial and service sectors that could have benefited from the local deagrarianization, with increasing interregional labor mobility, are losing competitiveness to Dakar, where services and industrial sectors are expected to be the most important destinations for the former agricultural labor force. With increasing 'Dakarization', the pace of the country's deagrarianization can be almost doubled. Under the HADGEM GCC scenario with no interregional mobility, only 9.8% (152.95 thousand, see Figure 4.1) of the noneducated labor force is leaving agricultural activities; however, with increasing interregional mobility, Dakarian industry and services absorb the former agricultural labor force at a larger scale, and agriculture is losing 18% (275.85 thousand, see Figure 4.1) of its most crucial labor factor.

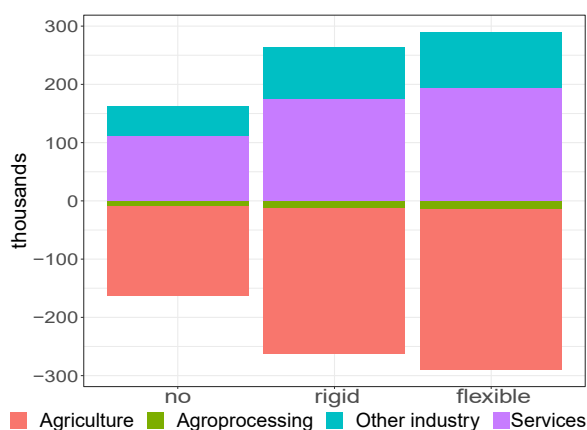
'Dakarization' of the country is also expected to smooth spatial income disparities (Table 4.11). In particular, poor rural households can improve their well-being by offering their labor factors in rich Dakar and repatriating profits back home. Rural regions can also benefit because

Table 4.10: Senegal, GCC: sectoral GDP under interregional labor mobility (HADGEM, % vs No GCC by 2050).

| Sector | no | rigid | flexible | Sector | no | rigid | flexible |
|----------------|--------|--------|----------|----------------|-------|-------|----------|
| Agriculture | -15.87 | -16.95 | -17.32 | Other industry | 3.38 | 4.21 | 4.41 |
| Dakar | -23.86 | -21.96 | -21.19 | Dakar | 3.63 | 5.24 | 5.65 |
| Thi_Dio | -23.48 | -22.23 | -21.78 | Thi_Dio | 3.31 | 4.10 | 4.26 |
| Center | -27.12 | -29.93 | -30.90 | Center | 2.06 | -1.02 | -1.77 |
| North | -7.62 | -8.08 | -8.26 | North | 3.21 | 2.07 | 1.74 |
| South | -3.93 | -4.90 | -5.25 | South | 1.65 | -0.49 | -1.20 |
| Agroprocessing | -10.61 | -11.82 | -12.22 | Services | -0.91 | -0.34 | -0.21 |
| Dakar | -9.60 | -10.25 | -10.54 | Dakar | -1.33 | 0.78 | 1.30 |
| Thi_Dio | -9.70 | -10.28 | -10.50 | Thi_Dio | -1.35 | -0.74 | -0.74 |
| Center | -13.19 | -16.90 | -17.75 | Center | 4.28 | -4.99 | -6.75 |
| North | -13.04 | -15.48 | -16.12 | North | 0.64 | -3.84 | -4.98 |
| South | -14.00 | -17.18 | -18.09 | South | -0.35 | -5.38 | -6.82 |

Source: Calculations based on Senegal CGE model.

Figure 4.1: GCC in Senegal: deagrarization of non-educated labor (HADGEM, diff vs No GCC by 2050).



Notes:

- using nationwide estimates of labor force by the ILO 2020 (non-educated labor in 2015: 2,171.20 thousand);
- assuming 2.37% of p.a. growth rate (based on population growth projections by the UN 2019 and assuming proportional growth of labor factors).

Source: Calculations based on Senegal CGE model.

the outflow of the labor to Dakar eases the pressure on local wages (e. g., almost a quarter of labor factor income of the region 'Center' is expected to be earned in Dakar). However, the massive inflow of labor from the provinces to Dakar can suppress the Dakarian wages and, thus, negatively affect the income growth of Dakarian households. Nevertheless, even in this case, Dakar will be the richest in the country, with significantly lower poverty rates than in other regions.

Table 4.11: Senegal, GCC: households' welfare under interregional labor mobility (HADGEM by 2050).

| | Real per capita cons (% diff. vs. No GCC) | | | % below poverty line (level) | | | Share of 'foreign' labor income | |
|---------|--|-------|----------|---------------------------------|-------|----------|------------------------------------|----------|
| | no | rigid | flexible | no | rigid | flexible | rigid | flexible |
| Dakar | -3.78 | -5.23 | -5.62 | 12.14 | 12.54 | 12.54 | 0 | 0 |
| Thi_Dio | -5.78 | -5.66 | -5.56 | 36.32 | 35.65 | 35.65 | 0.00 | 0.22 |
| Center | -10.08 | -4.26 | -3.21 | 49.90 | 40.83 | 39.05 | 19.68 | 22.01 |
| North | -3.79 | -0.95 | -0.24 | 49.59 | 44.90 | 44.44 | 8.06 | 9.91 |
| South | -1.45 | 2.26 | 3.20 | 66.80 | 63.42 | 62.61 | 12.43 | 15.11 |

Source: Calculations based on Senegal CGE model.

Although urbanization and 'Dakarization' of the country resulting from non-interventional policy smooth the overall negative impact of GCC and decrease spatial income disparities, adjacent studies suggest that further consideration of policy interventions is necessary. In particular, the most recent growth-focused literature strands argue that uncontrolled labor movement in sSA can have long-term growth repercussions that cannot be directly accounted for in our model. For instance, McMillan et al. (2014) find that, unlike in Asian countries, structural change in sSA from 1990 to 2000 was growth-reducing, with labor moving towards mostly informal urban services. The authors find evidence of a potential turnaround after 2000 and express cautious optimism about African growth prospects through industry-led structural change. Similarly, Rodrik (2016) emphasizes that unproductive and informal urban services are major destinations for rural-urban migrants in sSA. He analyzes various growth options, and in the context of poor industrialization pace, expects mediocre long-term growth rates in sSA of a maximum of 2% per capita p.a.

Given this context, the expected deagrarianization of Senegal towards the services can be concerning. Being the largest sector in the country (almost 58% of the country's GDP in 2015, see Table 4.2), the services sector can absorb more agricultural labor than the industry (in

absolute numbers, see Figure 4.1). More important, however, is that the lion's share of mostly uneducated agricultural labor is likely to join trade and transport services that are notoriously known for their informality (depending on interregional flexibility, the share of the labor force absorbed by these subsectors varies from 73 to 83% of the total labor force absorbed by services). Given this context, we also conduct a brief analysis of the potential policy interventions that can reduce services' partaking in the country's deagrarianization.

As a set of potential policy interventions, we consider TFP growth of the nonagricultural sectors (aggregate nonagricultural industry and aggregate services on the regional level). We assume that considered sectors are technologically homogenous and have equal costs of TFP increase (for the same money, sectors of the same size should receive an equal TFP boost). This is a rather strong assumption, but at least on an aggregated level it allows us to conduct coarse comparisons of policy interventions. To set values of TFP policy parameters, we assume that an additional 1% of TFP growth of the whole economy is achieved only by considered sector and treat obtained results as comparable sectoral policy elasticities. As a set of policy outcomes, we focus on noneducated labor employment and the overall impact on real per-capita consumption for all households.

Table 4.12: Senegal, GCC: TFP sectoral elasticities (% vs. HADGEM flexible by 2050).

| | TFP boost of the industrial sector in | | | | |
|--|---------------------------------------|---------|--------|-------|-------|
| | Dakar | Thi_Dio | Center | South | North |
| Non-educated labor, total industry (non ag) | -1.96 | -2.04 | -1.77 | -2.01 | -2.01 |
| Non-educated labor, total services | 1.12 | 1.06 | 0.61 | 0.66 | 0.74 |
| Real per-capita consumption (total households) | 2.08 | 2.11 | 1.06 | 0.92 | 1.36 |
| | TFP boost of the services sector in | | | | |
| | Dakar | Thi_Dio | Center | South | North |
| Non-educated labor, total industry (non ag) | 1.17 | 1.09 | 1.38 | 1.05 | 1.36 |
| Non-educated labor, total services | -0.74 | -0.77 | -0.92 | -0.70 | -0.90 |
| Real per-capita consumption (total households) | 1.40 | 1.14 | 1.10 | 1.10 | 1.10 |

Note: p.a. TFP growth rates:

Industry (non agr.): Dakar=0.29; Thi_Dio= 0.86; Center=3.34; North= 2.20; South=3.34;

Services: Dakar=0.08; Thi_Dio= 0.29; Center=1.01; North= 1.02; South=0.83;

Source: Calculations based on Senegal CGE model.

Our simulation results (Table 4.12) demonstrate that increasing productivity of a sector leads to own factor demand reduction and diverts noneducated labor to competing sectors (in-

creased productivity of industrial sectors will push noneducated labor towards services and vice versa). In terms of immediately observable income growth, investing in raising the productivity of Dakar's industrial sectors seems to deliver the highest policy return. At the same time, this policy is also associated with the highest increase of undesirable services' absorption of noneducated labor.

All in all, these findings align with the recently emerged concept of 'premature deindustrialization'. Rodrik (2015) investigates transformation patterns of modern developing economies and shows that increasing industrial productivity leads to low-skill employment reduction, which is part of the broader growth-reducing phenomenon of 'premature deindustrialization'. According to Rodrik (2015), low-income countries like Senegal should avoid premature deindustrialization because industrialization, especially through organized, formal manufacturing, is associated with the economy-wide productivity spillovers, making it the most potent engine of long-term growth. In this context, although our CGE model is not growth-focused⁷, our outcome variables still serve as proxies to reflect an unavoidable trade-off between short and long-term growth prospects faced by the policymakers in the context of forthcoming labor deagrification. From one side, the immediately observable multiplicative effect of boosting the productivity of industrial sectors appears to be higher than that of services. At the same time, as former agricultural labor then is pushed out of industry towards services, this policy contributes to the deindustrialization of Senegal, which, according to Rodrik (2015), will reduce the country's potent for future economic growth. On the other side, boosting the productivity of services, although less effective immediately, pushes uneducated labor towards industry, thus, paving the way for rapid future growth through industrialization.

Nevertheless, it must also be noted that our findings on policy interventions should be treated cautiously because of the coarse and ad-hoc nature of our simulations and corresponding assumptions. A more nuanced analysis of policy interventions (such as detailization on a sub-sectoral level) and consideration of other important factors (such as trade or budgeting⁸) might be necessary in future elaborations and extensions.

7. Our model has endogenized capital accumulation, but other growth determinants such TFP growth are given exogenously (Hicks neutral rate of technical change, see Löfgren et al. 2002; Diao and Thurlow 2012).

8. For instance, in the recent work, Diao and McMillan (2018) adjust the Lewis Model to explain SSA's growth patterns. They find that structural transformation, besides agricultural and nonagricultural productivity, depends on the terms of trade and sources of public investment to enhance productivity growth. The authors show that when TFP growth is financed through foreign inflows, it can cause significant real exchange rate appreciation leading to an undesirable boom of less tradable sectors and contraction of more tradable sectors.

4.4 Conclusion

In this paper, we investigate the potential role of GCC in the structural transformation processes in sSA. We use Senegal as a case study country and analyze how various GCC scenarios might affect its economy, household welfare, and labor reallocation across sectors and regions.

Our simulation results suggest that GCC's overall impact is expected to be moderate, with overall GDP losses reaching 2.08% under the worst-case scenario. At the same time, the losses are unevenly distributed across sectors and regions, and GCC can significantly impact country's economic structure and increase existing regional imbalances. As directly hit agriculture becomes less efficient and non-competitive, uneducated labor that constitutes the lion's share of the agricultural labor force will deagrarianize and join other economic activities. The most developed and the least rural Dakar region is the most resilient to GCC shocks, and its economy is expected to outcompete provincial nonagricultural sectors and attract former agricultural labor from all provinces. The pulling power of the large Dakarian economy, with increasing interregional mobility, can double the pace of country's deagrarianization and contribute to internal migration.

Although expected urbanization and 'Dakarization' of the country allow alleviating negative consequences of GCC, nonintervention policy is also associated with potentially negative repercussions. In particular, the urban services' absorption of mostly uneducated agricultural labor can slow industrialization and hamper the country's long-term growth prospects. One of the policy options that can push the former agricultural labor force from the services to industry can be a productivity boost that reduces services demand for unskilled labor. This option, however, appears to be not an optimal policy in terms of immediate policy returns, as boosting the productivity of Dakar's industrial sectors is likely to outperform similar policies in any service sector across the country.

Our approach and findings thus contribute to defining the best policies in the context of forthcoming GCC and labor deagrarianization in sSA. Besides the more refined approach to the potential policy instruments themselves, future work in this direction might also require taking into account the multidimensional nature of the national goals, which besides standard growth and poverty reduction targets, can distinctly highlight such aspects as regional development, inclusive provincial growth, or internal migration reduction.

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Affirmation

I hereby affirm that I have completed my doctoral thesis entitled, ‘Aspects of Designing Sustainable Development Policies in Developing Countries’ entirely on my own and unassisted, and that I have explicitly marked all of the quotes I have used from other authors as well as those passages in my work that are extremely close to the thoughts presented by other authors, and listed the sources in accordance with the regulations I have been given.

Ich erkläre hiermit, dass ich meine Doktorarbeit ‘Aspects of Designing Sustainable Development Policies in Developing Countries’ selbstständig und ohne fremde Hilfe angefertigt habe und dass ich als Koautor maßgeblich zu den weiteren Fachartikeln beigetragen habe. Alle von anderen Autoren wörtlich übernommenen Stellen, wie auch die sich an die Gedanken anderer Autoren eng anlehnenden Ausführungen der aufgeführten Beiträge wurden besonders gekennzeichnet und die Quellen nach den mir angegebenen Richtlinien zitiert.

Kiel, 25.06.2021



Askar Mukashov