The Economic Impact of Climate Change in Burkina Faso

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Abstract

The paper assesses the economic impact of climate change in Burkina Faso through the lens of a quantitative spatial model that incorporates multiple regions, sectors and crops. The model allows for several channels of transmission of climate change—change in temperatures and precipitation, crop yields, and labor productivity—and multiple margins of adaptation—switching crops, migration across regions and from/to urban areas. Calibrated to match aggregate-, region- and crop-level data, the model predicts that GDP would decrease by 0.20 to 3.25% in the RCP 2.6 and RCP 6 respectively at the 2050 horizon, mainly due to declining labor productivity, but with substantial heterogeneity across regions and crops. Adaptation margins mitigate the cost of climate change by 13.5% but most of these gains are offset by the decreasing land sizes implied by movements in population to more productive areas. The scarcity of land also implies that the cost of climate change is magnified by expected growth in population.

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1 Introduction

Climate change is poised to exert a profound impact on Burkina Faso, particularly affecting its agricultural sector. With current agricultural productivity already trailing the Sub-Saharan average, the country faces heightened vulnerability to more frequent extreme weather events, increased heat, and diminished precipitation. Given the predominance of rainfed agriculture, the confluence of rising temperatures and dwindling water resources threatens to further depress crop yields, with divergent consequences across regions and crops. Climate change will also negatively impact households' labor productivity and affect those who raise livestock and who will face increased risk of animal death and malnutrition. The escalating frequency of extreme weather phenomena, including droughts and poor harvests, amplifies the likelihood of significant income losses. In a country where the majority of the population relies on subsistence farming for its own consumption, this could further worsen chronic food insecurity (World Bank 2022).[1]

In this paper, we assess the economic impact of climate change in Burkina Faso through the lens of a quantitative spatial model that incorporates multiple regions, sectors and crops. The model allows for several channels of transmission of climate change—change in temperatures and precipitation, crop yields, and labor productivity—and multiple margins of adaptation—switching crops, migration across regions and from/to urban areas—which are important to accurately quantify the long-run effects of climate change. We calibrate the model using region-, sector- and crop-level data in Burkina Faso in the last decade, and the FAO-GAEZ projections about climate change under different scenarios.

We start by introducing a multi-region, -sector, -crop model to analyze the economic and migration impacts of climate change and the role of adaptation strategies. The 13 different regions, which correspond to the administrative "regions" in Burkina Faso, differ exogeneously in their climate conditions, the yields of different crops the available land and the productivity of labor in cities. In each region, there are rural and urban areas. In rural areas, households work in the primary sector as farmers, and their income is derived from the sale of crops they grow using land

[1] The prevalence of undernourishment, defined as the population consuming an insufficient number of calories to cover their energy requirement for a healthy life, remains elevated in Burkina Faso. After a slow secular decline until about 2013, it has since risen to the highest level in over two decades.

and their labor. Farmers choose which crop to grow among cotton, groundnut, cowpea, millet, rice, maize, and sorghum, based on expected income and costs of production. Those living in urban areas work in the secondary and tertiary sectors and earn a wage which is related to the local exogenous labor productivity.

Climate change exerts its influence on the economy through three channels. Firstly, it impacts crop yields by altering agro-climatic conditions, encompassing changes in average temperatures and water availability. Second, the escalation of heat levels poses challenges for people to work outside and negatively impact workers' health, adversely affecting labor supply. Finally, it affects the "amenity" value of different regions, rendering some areas uninhabitable due to excessive heat or scarcity of water, thereby impeding human survival. These three effects are not uniform and the model allows for heterogeneous changes across crops and regions. While we focus on these tangible impacts, it necessarily abstracts from several other potential channels that are inherently complex to quantify. These include long-term accumulation of human capital, adverse health outcomes for infants and heightened risk of pandemics (Dasgupta and Robinson 2023), escalating risks of conflicts exacerbated by the fragile institutional and security context (Larémont 2021), and the destruction of infrastructures (World Bank 2022).

The model embeds key strategies households have in Burkina Faso to adapt to climate change. There are three main margins of adaptation in the economy. First households can decide to switch to crops whose productivity is less negatively affected by climate change. Second, they have the flexibility to relocate to urban centers, where opportunities in the secondary or tertiary sectors offer alternative avenues for livelihood. Finally, they can opt to migrate to another region with superior amenities, better crop yields or higher urban wages, or any combination of the three.

The model is estimated to match aggregate-, region- and crop-level data. More specifically, we exactly match the observed migration patterns across each pair of regions, the current urbanization rate in each region, the observed yields and production of each crop in each region, and land availability using public data from the INSD. Using the consumer expenditure survey of 2018 (INSD), we calibrate the consumption basket to match the expenditure share on different crops and the average income of farmers and households living in urban areas. The elasticity of substitution across crops is estimated using the observed response of land used for each crop to exogenous changes in international crop prices. The households' migration and sectoral elasticities are taken from the literature.

Our main counterfactual looks at the economic and migration impact of climate change at the 2050 horizon. The model simulations are based on the projections from the FAO-GAEZ dataset. This dataset contains projections for yields of the main crops in Burkina Faso, as well as average temperatures and precipitation, under different scenarios, for different underlying ecological models and at a very granular level. We construct average yields at the region and crop level, and average temperature and precipitation at the region level, in 2050. Together with population forecasts from the UN World Population Prospects, these are the main inputs in our counterfactual exercises. The simulated steady-state equilibrium predicts a new spatial distribution of economic activity and population, a different urbanization rate in each region, and different production of crops in each region.

In our baseline counterfactual, we find that GDP would decrease by 0.20 and 3.25% in the RCP 2.6 and RCP 6 respectively at the 2050 horizon, and that the decline in labor productivity and supply is the dominant channel. These aggregate figures hide substantial heterogeneity across regions: GDP per capita decreases by about 15, 10 and 22% in the Centre-Nord, Nord and Sahel respectively and increase in Cascades, Hauts-Bassins and Sud-Ouest. Additionally, the model predicts substantial migration of population from regions experiencing declines in yields and/or in amenities—Centre- Nord, Est, Nord and Sahel—to those experiencing increases in yields—Cascades, Hauts- Bassins, Sud-Ouest. Finally, the model also predicts a substantial change in the mix of crops grown in Burkina Faso: the shares of pearl millet and maize increase by 3 and 1 percentage points respectively, and the shares of cowpea, groundnut and rice decrease by 2, 1, and 1.5 percentage points respectively.

We use the model to quantify the role of adaptation strategies in mitigating the negative impacts of climate change. These adaptation strategies include switching crops, moving to a more attractive region, or opting out of farming altogether and moving to a city. Our findings indicate that while these adaptive measures offer some relief, their impact remains moderate. Accounting for these adaptation margins results in a 13.5% reduction in the overall cost of climate change relative to a baseline scenario without adaptation. Notably, migration to regions exhibiting higher economic growth prospects emerges as the most influential adaptation strategy, followed by switching to crops that benefit from climate change. Regions such as Cascades, Centre-Ouest, Centre-Sud, Hauts-Bassins, and Sud-Ouest stand to gain the most from these adaptation strategies, underscoring the regional variability in adaptive potential and economic resilience.

Importantly, we uncover a more surprising result: most of the gains from adaptation are offset by the decreasing average land sizes per farmer. This reduction is primarily driven by population migrations towards regions with higher productivity and the concurrent increase in the proportion of individuals engaged in agriculture. This highlights the importance of taking into account the endogenous land size decision, population migration and the scarcity of land when evaluating the cost of climate change.

We then delve deeper into the role of population growth, forecasted to increase from about 22 in 2022 to 40.5 million by 2050, and how it interacts with climate change in shaping the economy and migration patterns. In line with the findings by Henderson et al. (2024) we find that population growth is predicted to have a larger negative impact on GDP per capita than climate change. Moreover, our analysis underscores the significance of accounting for their interaction: ignoring their interplay would lead to underestimating the cost of climate change by about 18% due to the decrease in land available for agriculture. It is thus important to consider them jointly when quantifying the impact of climate change when land is scarce.

Finally we look at the role of agricultural policies in lifting productivity in the primary sector and mitigating the effect of climate change. Low agricultural productivity is a key impediment to improving living standards in Burkina Faso. Many obstacles impede agriculture productivity, including low use of fertilizers, mechanized equipment and irrigated land, even relative to Sub-Saharan averages. We thus leverage our model to simulate the effect of increasing crop yields consistent with higher input use as defined in the FAO-GAEZ dataset. Our findings reveal that aggregate GDP could surge by 292 and 320% in the RCP 2.6 and 6 respectively. These results suggest that improving agricultural productivity has the potential to outweigh the detrimental impacts of climate change and should therefore remain a key policy priority in Burkina Faso.

The paper contributes to the literature quantifying the economist costs of climate change. There is a large empirical literature estimating damage functions, either by exploiting weather events (Dell, Jones, and Olken 2012) or using cross-sectional variation (Nordhaus 2006). There is also a model-based literature quantifying the cost of climate change starting with Fankhauser (1994), Nordhaus (1994) and Tobey, Reilly, and Kane (1992) for a general equilibrium approach to the effect on agricultural production and consumption. We build on a recent set of studies that have provided novel insights about the implications of climate change for migration (Benveniste, Oppenheimer, and Fleurbaey 2022) and incorporated the analysis of climate change in quantitative spatial economic models (Desmet and Rossi-Hansberg 2015).

The most closely related paper is Conte (2023) who developed a model with migration and trade frictions and several crops across Sub-Saharan African. Our focus specifically on Burkina Faso enables us to offer a more detailed and granular analysis across several dimensions. Unlike this paper, who consider crops widely grown across Africa overall (cassava, maize, millet, rice, sorghum, and wheat), we include all important crops in Burkina Faso (cotton, cowpea, groundnut, maize, millet, rice, sorghum). Our model incorporates a richer set of channels through which climate change affects the economy beyond crop yields: lower labor productivity and supply from higher temperatures, which turns out to be a dominant channel, and changing amenity values of different regions. We also allow for a land size decision by farmers which we tightly discipline using empirical evidence, and which emerges as a crucial determinant in assessing the costs of climate change. We also highlight the importance of jointly considering population growth and climate change. In addition, we enhance the precision of our calibration by using recent survey data to inform income differentials between urban and rural areas within each region, a departure from Conte (2023), who relies on model-generated grid-level GDP estimates.[2]

Our investigation of the role of population growth connects our paper to the literature analyzing the effects of natural resource congestion due to population growth, going back to Malthus (1798), Hardin (1968) and more recently Acemoglu and Johnson (2007). Like Henderson et al. (2024) we find larger costs of population growth than climate change, and we highlight the importance of considering

[2]We closely relate to the last World Bank's Country Climate and Development Report for the Sahel which also simulates the impact of climate change in Burkina Faso with a calibrated agent-based model including several adaption strategies (World Bank 2022).

the interaction between these two phenomena when quantifying their individual impact.

The remainder of the paper is organized as follows. Section 2 introduces a tractable model with multiple regions, sectors and crops and climate change. Section 3 presents the data sources and main moments used in the paper and section 4 explains our estimation strategy. Section 5 uses the calibrated model to simulate the effect of climate change, the role of different adaptation channels and of population growth. Section 6 concludes.

2 A Model with Multiple Regions, Sectors and Crops and Climate Change

Environment Time is discrete and runs to infinity, $t = 0, 1....$ The economy is populated by a continuum of individuals of mass N_t and indexed by $i \in [0, 1]$. There are $J = 13$ regions indexed by $j \in \{1...J\}$. In each region, there are rural and urban areas. In rural areas, households work in the primary sector ($s = 1$) as farmers. Their income is derived from the sale of crops they grow. Those living in urban areas work in the secondary and tertiary sectors, which we group and denote $s = 2$. Workers in urban areas earn a wage w_j, which is exogenous and specific to the region.

Regions differ in four exogenous dimensions: (i) their wage and productivity in the urban areas w_j, (ii) the yields of different crops per unit of land $\mathbf{z}_{j1t} = \{z_{j11t}, z_{j12t}, ...z_{j1Ct}\}$, (iii) their local exogenous amenity, a_{jt}, which shapes the value of living in a region besides its economic fundamentals, (iv) their climate, including the average precipitation and temperatures.

Climate affects the economy through three channels. First it shapes yields by changing the environment, the temperatures and the water availability in which crops grow. Second, the escalation of heat levels poses challenges for people to work outside and negatively impact workers' health. As shown by empirical evidence, higher levels of heat is predicted to adversely affect labor supply and productivity. Third, it affects the amenity values of different regions: some regions may become too hot to live, or water may become scarce in some places making it difficult to meet basic needs. We will describe each channel in more details as we introduce the households' preferences and decisions.

In each period t, households make four consecutive decisions: first they choose to stay where they are or to migrate to another region; then they choose whether to move to rural areas to work as farmers or to an urban area to work in the secondary or tertiary sectors; then if they decide to farm they choose which crop they grow in this period and the size of land to cultivate; and finally all households choose their optimal consumption bundle. We now describe each decision one at a time, starting from the last one.

2.1 Households' preferences and consumption decisions

Households have Cobb-Douglas preferences over a bundle of goods produced in the primary sector $s = 1$ and the other sectors $s = 2$. The primary-sector good is itself a bundle over C' crops. The overall bundle can thus be written as follows: $\left(\Pi_{c=1}^{C'} c_{1ct}^{\alpha_{1c}}\right) c_{2t}^{1-\sum_c \alpha_{1c}}$. Households also value the local amenity in their region a_j, which depends to some extent on average temperatures (TMP), and water availability (PRC), $a_j = \bar{a}_j \text{TMP}_j^{\beta_T} \text{PRC}_j^{\beta_P}$. We estimate β_T, β_P when we calibrate the model in section 4.

In addition, we assume a convex utility cost associated with using farm lands, and that this cost is increasing in the local density of farmers $\frac{\gamma_{0j} N_{j1t}}{\bar{L}_j} \ell^{\gamma}$ where γ is the (exogenous) elasticity of utility cost to land use, $\bar{L}_j$ is the local supply of land and N_{j1t} is the mass of farmers—individuals working in sector $s = 1$—in region j. This cost captures in a simple way the notion that the use of land is subject to competition across different individuals and for different uses.[3] This microfoundation also helps us match the fact that regions with higher density of farmers have smaller average land size per farmers.

Denoting y the income of a household, p_{2t} the price of the good in the non-primary sector and p_{1ct} the price of crop c, the problem of a consumer is to maximize

[3]We depart from a more conventional way of modelling the allocation of land as a market outcome for two reasons: first we don't have data on land prices and rents, second the model would predict that the optimal land sizes depend on the crop chosen, but we only observe average land size in the data. In addition, this would imply that the marginal crop yields differ from the average crop yields, substantially complicating the estimation of the model. Our simple microfoundation generates an optimal land size that differs across region but is the same across crops within a region and that we can directly map to moments of the data.

the following flow utility value

$$u_{jst} = \max_{\{c_{1ct}\}_{c=1}^{C'}, c_{2t}, \ell} \log \left[a_{jt} \left(\Pi_{c=1}^{C'} c_{1ct}^{\alpha_{1c}} \right) c_{2t}^{1-\sum_c \alpha_{1c}} \right] - \frac{\gamma_{0j} N_{j1t}}{\bar{L}_j} \ell^{\gamma} 1_{s=1} \quad (1)$$

$$\text{such that} \quad y = \sum_{c=1}^{C'} \left[p_{1ct} c_{1ct} \right] + p_{2t} c_{2t}$$

Optimal consumption decisions. The first-order conditions to the previous problem imply that every household consumes a share α_{1c} of their income on crop c and a share $(1 - \sum_c \alpha_{1c})$ on the non-primary sector good:

$$c_{1ct} = \alpha_{1c} \frac{y}{p_{1ct}} \quad \text{and} \quad c_{st} = \left(1 - \sum_c \alpha_{1c} \right) \frac{y}{p_{st}} \quad (2)$$

Replacing the expressions given by (2) into the definition of the utility function and using the budget constraint gives the following indirect utility:

$$\bar{u}_{jt}(i) = \log \left[a_{jt} \Gamma_t y \right] - \frac{\gamma_{0j} N_{j1t}}{\bar{L}_j} \ell^{\gamma} 1_{s=1} \quad (3)$$

$$\text{with} \quad \Gamma_t = \left(\Pi_{c=1}^{C'} \left(\frac{\alpha_{1c}}{p_{1ct}} \right)^{\alpha_{1c}} \right) \left(\frac{\alpha_2}{p_{2t}} \right)^{1-\sum_c \alpha_{1c}}$$

2.2 Households crop and land decision

Farmers, those living in rural areas and working in the primary sector ($s = 1$), choose which crop to grow between $C = 7 < C'$ crops: cotton, groundnut, cowpea, millet, rice, maize, and sorghum. Their optimal choice is based on the comparison of the expected income and costs of growing different crops in their location.

The technology to grow any crops takes three inputs: labor, land ℓ and the agro-climatic environment which determines the overall crop yields vector $\mathbf{z}_{j1t}$. We assume that households supply inelastically h units of labor. Consistent with empirical evidence that hot temperatures are an obstacle to labor supply and productivity, we allow h to respond endogenously to average temperatures when we simulate the impact on climate change in section 5. While we normalize $h = 1$ for all individuals in the baseline equilibrium, we allow h to depend on TMP in the counterfactual. Since TMP varies by region only, we add a $j-$subscript on h in the equation below.

Finally, households endogenously choose how much land ℓ to use. This decision is the solution to a trade-off between higher crop production and higher utility cost of using land. The farmer's income is given by the profits from the sale of their crops:

$$y_{j1c} = p_{1ct} z_{j1ct} \times \ell \times h_j \tag{4}$$

where p_{1ct} is the price of crop c at time t.

Optimal land decision Given the log-linearity of utility in ℓ, the problem of choosing the optimal land size amounts to maximizing $\ln p_{1ct} z_{j1ct} \ell - \frac{\gamma_{0j} N_{j1t}}{\bar{L}_j} \ell^{\gamma}$. The optimal land size is given by the following expression:

$$\ell_{jt} = \left(\frac{\bar{L}_{jt}}{\gamma_{0j} \gamma N_{j1t}} \right)^{\frac{1}{\gamma}}.$$

An appealing feature and a reason why we chose the functional form of this expression is that the optimal land size depends only of the location j, for which we have data, and not on the specific crop grown, for which we don't have data. Substituting for ℓ in the expression for income given by (4), the farmers' utility is given by $\log \left[a_{jt} \Gamma_t p_{j1ct} z_{jct} \right] + \log \Omega_{jt} + \log h_j$ with $\Omega_{jt} = \left(\frac{\bar{L}_j}{\gamma_{0j} \gamma N_{j1t} e} \right)^{\frac{1}{\gamma}}$ where e is the Euler's number.

Optimal crop decision. When choosing the optimal crop to grow, a farmer weighs the yields and the cost of growing these crops, which we model as utility costs.[4] In addition, we allow households to differ in the costs they face to grow different crops. This heterogeneity allows us to capture the fact that not all farmers cultivate the same crop at any point in time and that several crops are grown in each region. More specifically, each household receives idiosyncratic vectors of i.i.d. ETV1 distributed shocks over crops, $\{\eta_{1ct}\}$. Each household i chooses the crop to cultivate to maximize

$$t_{j1t}(i) = \max_{c \in \{1,\ldots,C\}} \left\{ \log \left[a_{jt} \Gamma_t p_{j1ct} z_{jct} \right] + \log \Omega_{jt} + \log h_j - b_{j1c} + \eta_{1c}(i) \right\} \tag{5}$$

[4]A motivation for modeling these as utility costs is that we don't observe them in the data.

where b_{j1c} is the utility cost of growing crop c in location j. We call the expectation of t_{j1t} before the realization of the idiosyncratic shock $\bar{t}_{j1t} = E_{\eta_c} t_{j1ct}(i)$. It is given by

$$\bar{t}_{jst} = \sigma_c \log \sum_c \left(\frac{a_{jt} \Gamma_t y_{j1ct} \Omega_{jt} h_j}{\exp\{b_{j1c}\}} \right)^{1/\sigma_c} \tag{6}$$

and the share of workers in the primary sector who grow crop c in location j is given by

$$\pi_{j1ct} = \frac{\left(\frac{p_{1ct} z_{j1ct}}{\exp\{b_{j1c}\}} \right)^{1/\sigma_c}}{\sum_{c'=1}^{C} \left(\frac{p_{1ct} z_{j1ct}}{\exp\{b_{j1c'}\}} \right)^{1/\sigma_c}}. \tag{7}$$

2.3 Households sector decision

After choosing a region, individuals decide whether to move to an urban area or to work as farmers in the rural areas. If they move to a city, they work in the secondary and tertiary sector and earn an income that is specific to that region j and which is given by

$$y_{j2t} = w_j \times h_{jt}. \tag{8}$$

where h_{jt} is the labor supply/productivity which is normalized to 1 in the baseline equilibrium and which is allowed to decrease with the rise in heat levels in the counterfactual with climat echange. The wage w_j is exogenous and equal to the productivity of secondary and tertiary sectors in that region.

Individuals compare expected utilities derived from the income earned in each sector. If they become farmers, they can expect to receive utility given by $\bar{t}_{jt}$ in equation (6). In addition to comparing income levels, they also take into account the utility costs b_{js} of working in sector s, which are allowed to be heterogeneous across households. More specifically, we assume that each household receives a vector of i.i.d. shocks over sectors, which is realized only after they move to a region, $\{\eta_s\}$. These shocks are i.i.d. EVT1 distributed. We normalize this cost in agriculture to 0, $b_{j1} = 0$ for all j. Formally, the optimal sector decision of households is solution to: $T_{jt}(i) = \max_{s \in \{1,\ldots,S\}} \left\{ \bar{t}_{jt} - b_{j1} + \eta_1(i), \log \left[a_{jt} \Gamma_t y_{j2t} \right] - b_{j2} + \eta_2(i) \right\}$.

Given the distributional assumption on the shocks, the sectoral shares — the probability of an individual who is in j to work in sector s —are given by

$$\pi_{j1t} = \frac{\left(\sum_c \left(\frac{a_{jt}\Gamma_t p_{1ct} z_{jsct}\Omega_{jt}}{\exp\{b_{j1c}\}}\right)^{1/\sigma_c}\right)^{\sigma_c/\sigma_s}}{\left(\sum_c \left(\frac{a_{jt}\Gamma_t p_{1ct} z_{jsct}\Omega_{jt}}{\exp\{b_{j1c}\}}\right)^{1/\sigma_c}\right)^{\sigma_c/\sigma_s} + \left(\frac{a_{jt}\Gamma_t w_{jt}}{\exp\{b_{j2}\}}\right)^{1/\sigma_s}} \tag{9}$$

$$\pi_{j2t} = \frac{\left(\frac{a_{jt}\Gamma_t w_{jt}}{\exp\{b_{j2}\}}\right)^{1/\sigma_s}}{\left(\sum_c \left(\frac{a_{jt}\Gamma_t p_{1ct} z_{jsct}\Omega_{jt}}{\exp\{b_{j1c}\}}\right)^{1/\sigma_c}\right)^{\sigma_c/\sigma_s} + \left(\frac{a_{jt}\Gamma_t w_{jt}}{\exp\{b_{j2}\}}\right)^{1/\sigma_s}} \tag{10}$$

and the indirect utility before the realization of the sectoral idiosyncratic shock is given by

$$\bar{T}_{jt} = \sigma_s \ln\left(\left(\sum_c \left(\frac{a_{jt}\Gamma_t p_{1ct} z_{jsct}\Omega_{jt} h_j}{\exp\{b_{j1c}\}}\right)^{1/\sigma_c}\right)^{\sigma_c/\sigma_s} + \sum_{s>1}\left(\frac{a_{jt}\Gamma_t w_{jt} h_j}{\exp\{b_{js}\}}\right)^{1/\sigma_s}\right) \tag{11}$$

2.4 Households migration decision

At the beginning of each period t, individuals decide whether to stay or to relocate to another region. When making that decision, they compare the economic prospects of each location in terms of wages in urban areas and yields in rural areas as well as rural density captured by the term Ω_{jt}, and amenities a_{jt} . In addition, households receive an idiosyncratic vector of i.i.d. preference shocks over locations, $\{\varepsilon_{j,t}\}$. We assume that these shocks are i.i.d. EVT1 distributed across households. Importantly, migration is costly: moving from region j to region k entails a migration cost, m_{jk}, which we assume is exogenous and uniform, with $m_{jj} = 0$.

After the realization of the taste shock and the relocation decision to region d, the indirect utility is given by $U_{dt}(i) = \bar{T}_{dt} + \beta\bar{V}_{dt+1}$ where β is the time discount factor and $\bar{V}_{dt+1}$ is the expected value at the beginning of next period of an individual located in j defined below. The value of an agent currently located in the origin location o and deciding where to move after having received their preference shock for the locations is given by $V_{ot}(i) = \max_{d\in\{1,\ldots,J\}}\{U_{dt}(i) - m_{od} + \varepsilon_d(i)\}$.

Similarly, we define the expectation of V before the realization of the taste shock $\bar{V}_{dt} = E_{\varepsilon} V_{dt}(i)$. The households optimal behavior are summarized by the following migration shares —the probability of an individual who lived in o moving to d:

$$\pi_{odt} = \frac{\exp\left\{\left(U_{dt} - m_{od}\right)/\sigma_m\right\}}{\sum_{k=1}^{J} \exp\left\{\left(U_{kt} - m_{ok}\right)/\sigma_m\right\}}. \tag{12}$$

and the indirect utility is given by $\bar{V}_{ost} = \sigma_m \ln \sum_d \exp\left\{\left(U_{dst} - m_{od}\right)/\sigma_m\right\}$.

2.5 Laws of Motion of Population

Between period t and $t+1$, individuals reallocate across regions. Denoting N_{ot} the mass of individuals in location o at time t and N_{dt+1} the mass of individuals in location d at time $t+1$, the laws of motion are given by

$$N_{dt+1} = \sum_{o} \pi_{odt} N_{ot}$$

where π_{odt} is given by expression (12).

2.6 Market Clearing and Local Land Use

We assume that Burkina Faso is a small open economy and that prices of all goods are exogenous, both for agricultural products and secondary and tertiary goods. There is thus no domestic market clearing condition for these goods.

The demand for land coming from farmers growing different crops has to be consistent with the total land used L_{jt}:

$$L_{jt} = N_{jt} \pi_{j1t} \sum_{c} \pi_{j1ct} \ell_{jct} \tag{13}$$

3 Data and Sources

3.1 Crop yields and harvested land

The data for production and harvested land by region and by crop is collected annually by the National Statistical Agency, the INSD, and is available on their opendata platform.[5] The INSD has collected data from 1996 until 2021 on cotton, groundnut, cowpea, maize, rice, millet, and sorghum, which are also the main crops grown in Burkina Faso. Figure 1 shows that the mix of crops vary widely across regions and that sorghum is the most commonly cultivated one.

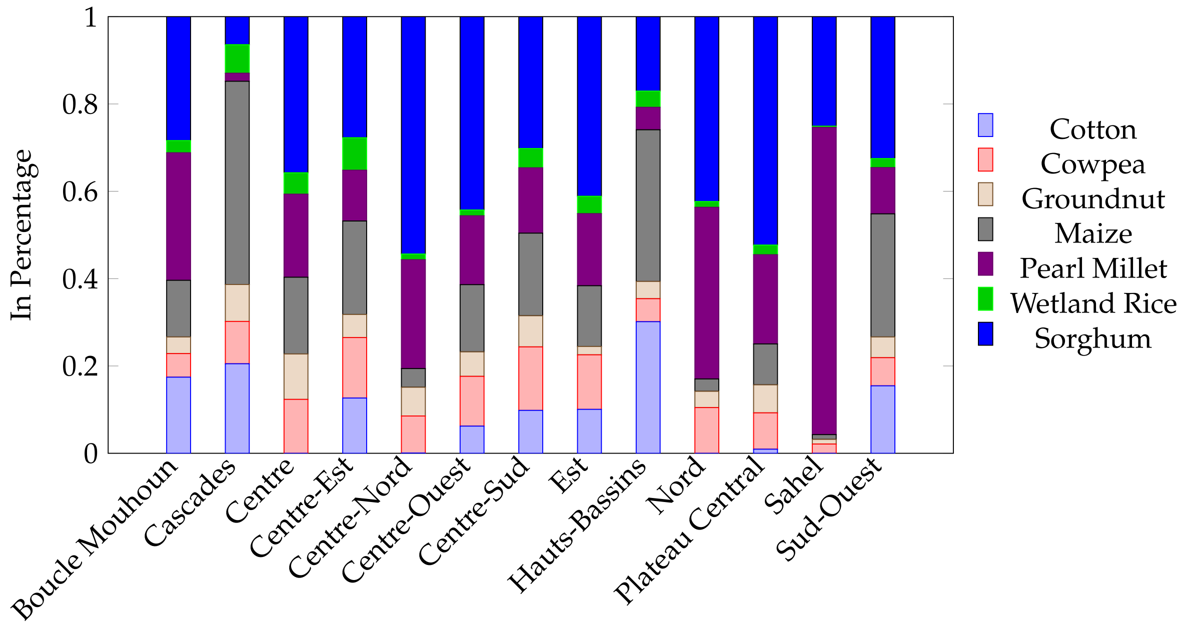

Figure 1: Shares of Each Crop in Harvested Land by Region

We compute yields as the ratio between production and land harvested. To smooth out yearly variation, we take the median value of each variable over the years 2013-2019. Figure 2 shows huge heterogeneity of yields across regions for the same crop, but also across crops.

[5] Here is a link to the website.

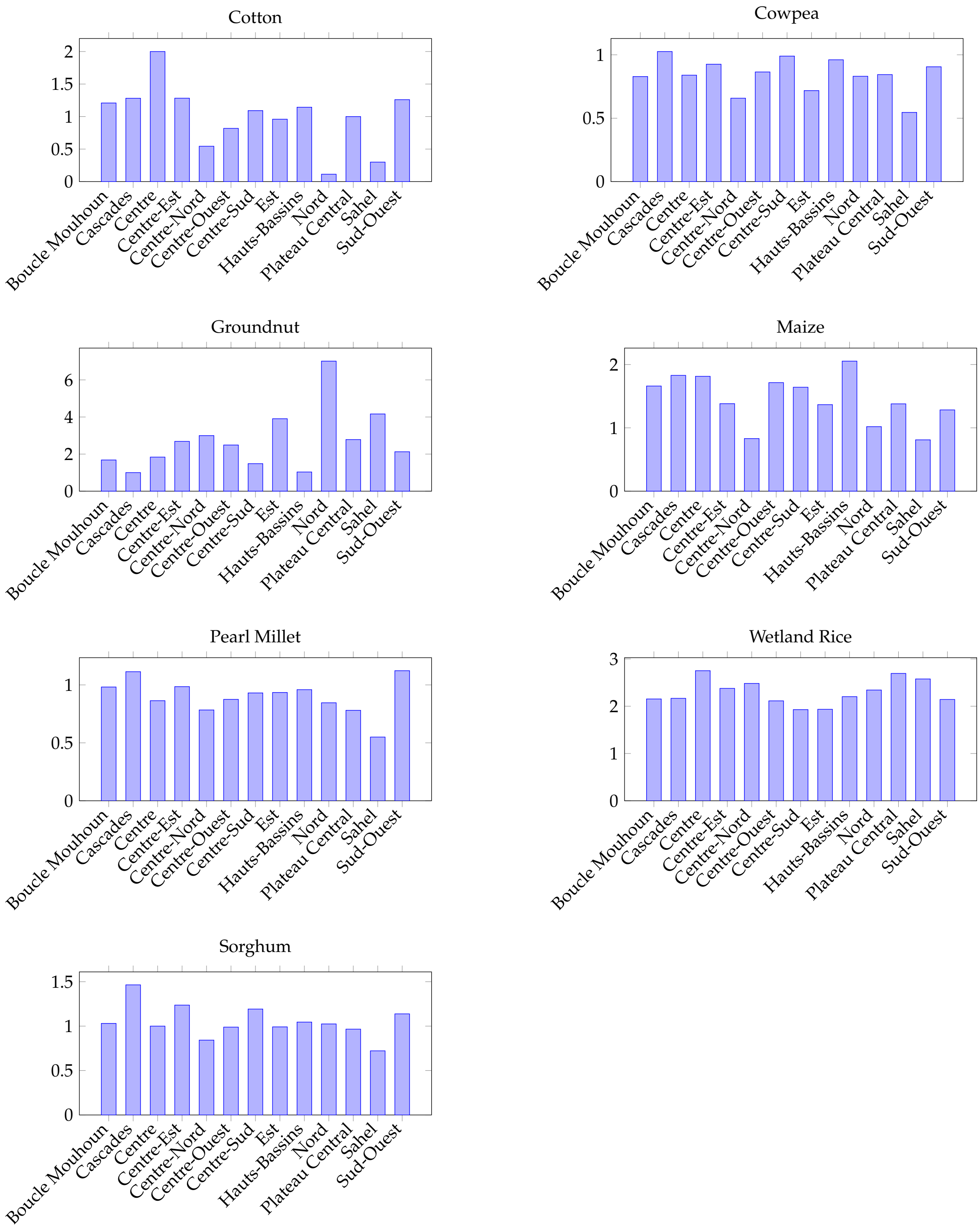

Figure 2: Yields of Main Crops by Region

3.2 Population and migration

Data for population in each region, by rural and urban areas and the matrix of migration flows across regions come from the 2019 Census, which is also publicly available on the INSD website or on IPUMS. The INSD reports two measures of migration: lifetime and seasonal. Given that we are interested in long-term migrations, we select the matrix of lifetime migrations.[6]

Figure 3 reports the share of urban population in each region, and the share of population in each region relative to the total population. The most populated area is the region Centre which includes the capital city, Ouagadougou. This also explains why this is the region with the highest share of urban population (about 80%).

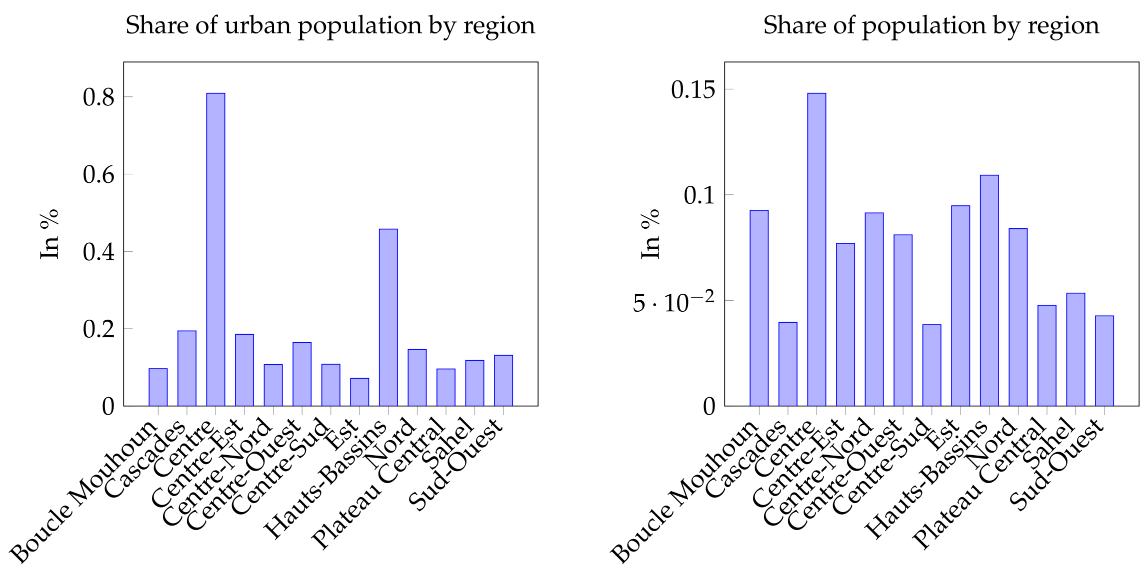

Figure 3: Population and Urban Population by Region

3.3 Average households income and consumption bundle

We use the 2018-2019 Survey of Households, "Enquête Harmonisée sur les Conditions de Vie des Ménages", which is publicly available on the World Bank micro-data website[7] to compute, for each region, the average consumption in rural and in urban

[6] The matrix of migration flows is in Table 6 in Appendix A.

[7] The data can be found here.

areas. These moments, which are reported in Figure 4, will be used later to calibrate productivity in urban areas. We also use this data to construct the consumption basket of households, by computing the share of consumption spent on each crop specifically and on non-agricultural products.

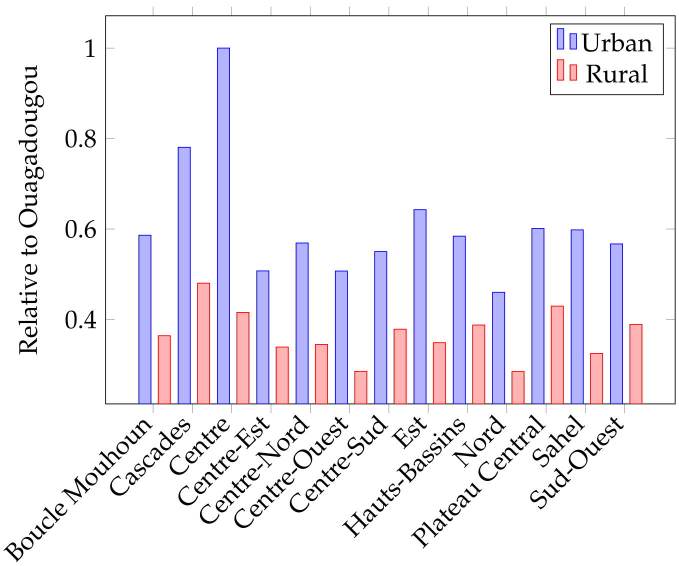

Figure 4: Average Income by Urban/Rural and by Region

3.4 Climate Variables and Yields Forecast

Historical averages and forecasts for the period 2030-2070 of mean temperatures and precipitation, and crop yields are obtained from FAO-GAEZ. The FAO-GAEZ is a framework and associated databases which evaluates suitability and production potentials for individual crop types under specific agro-ecological input and management conditions.[8]

Historical data for both climate variables come from the CRUTS model, for the period 1980-2010, and forecasts for the period 2030-2070 come from the same model. Forecasts about yields for all crops—cotton, groundnut, cowpea, maize, rice, millet, sorghum—are obtained from the same source. They correspond to attainable yields, or output density. The forecasts are based on the GFDL model.[9]

[8]The data is available here.

[9]Forecasts from CRUTS are not available.

For forecasts, we consider two different scenarios of climate change: RCP 2.6 and RCP 6.0. The Representative Concentration Pathway 2.6 is a "very stringent" pathway in which carbon dioxide (CO2) emissions start declining by 2020 and go to zero by 2100. In RCP 6, emissions peak around 2080, then decline. Together, they cover a wide range of realistic scenarios.

The raw data for climate variables and measures of crop yields is provided at the 5 arc-minute grid-cell level. We then aggregate it at the region level to obtain region-level average temperatures, precipitation, yields for different crops, both historically and at the 2030-2070 horizon in both scenarios.

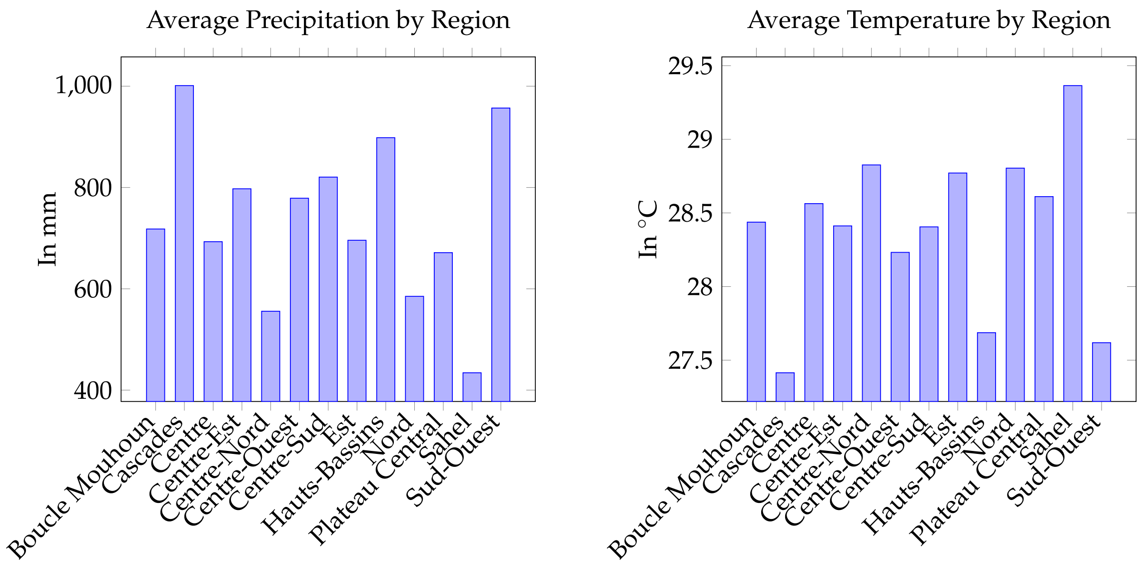

Figure 5: Average Precipitation and Temperatures by Region

3.5 Crop prices

Prices for millet, sorghum, rice and cotton are obtained from FRED, the St Louis Fed data website.

4 Estimation and Calibration

We now turn to the quantitative assessment of climate change in Burkina Faso. We start by carefully calibrating the model to match important country, sector, region and crop-level moments. A small subset of parameters are calibrated externally, and the rest is calibrated to match moments from the data.

4.1 External Calibration

Four parameters are calibrated externally: the time discount factor, the sectoral elasticity σ, the migration elasticity σ_m and the sensitivity of labor productivity and supply h to average temperatures, ζ.

Table 1: Externally Calibrated Parameters

Parameter	Description	Value	Source
β	Time discount factor	0.36	Standard
$1/\sigma$	Sector Elasticity	1	Authors calculation
$1/\sigma_m$	Migration Elasticity	5	Kleven et al. (2020)
ζ	Semi-elasticity of h to temperatures	.04	Lai et al. (2023)

Time discount factor, β. The first parameter we calibrate externally is the time discount factor, β. It matters especially for the migration decision, which is dynamic. Given that we are interested in long-term migrations, we choose a discount factor of $\beta = .36$ which corresponds to a conventional 4% annual discount rate at a 25 years horizon.

Migration and sectoral elasticity, $1/\sigma, 1/\sigma_m$. Following Clemens and Mendola (2020) which focuses on migration patterns in developing and low-income countries, we calibrate the elasticity to .2, which corresponds to $\sigma_m = 5$. This is within the wide range of estimates for migration elasticities across regions within country reviewed by Kleven et al. (2020) (between .1 and 2). Consistent with the fact that most estimates reviewed in this paper are for rich individuals in developed countries, which are arguably much more mobile, our parameter is at the lower end of this range.

It is difficult to find an estimate of the sectoral elasticity. The literature on labor supply elasticity focuses on the intensive and extensive margin of labor supply, but doesn't look at sectoral reallocation and the literature on urban-rural migration doesn't focus on estimating the elasticity to income differentials. Given this limitation, we follow the intuition that this elasticity should be higher than the migration elasticity .2, but lower than the crop elasticity 2.78, which we estimate later in this section. We thus set it equal to 1.

Sensitivity of h to average temperatures. Following the empirical literature, we assume that increases in average temperature imply a constant percentage point change in labor productivity and supply:

$$\frac{dh/h}{dTMP} = -\zeta = -\zeta_{productivity} - \zeta_{supply}$$

where TMP denotes average temperatures, $\zeta_{productivity}$ is the elasticity of labor productivity and ζ_{supply} is the elasticity of labor supply. To calibrate the semi-elasticity of labor productivity to temperatures $\zeta_{productivity}$, we follow the median estimate from the literature and set $\zeta = .03$ (Lai et al. 2023). We follow the same paper to calibrate the semi-elasticity of labor supply to temperatures and set $\zeta_{supply} = .01$, though more research is needed to estimate this parameter.

4.2 Internal Calibration Before Running the Model

The parameters we calibrate internally are as follows: the crops elasticity σ_c, the land use elasticity γ, the vectors of amenities a_{ot} and wages in the non-agricultural sector w_{o2}, yields for crops in each region z_{o1c}, the supply of land $\bar{L}_j$, and the migration, sectoral and crops costs m_{od}, b_s, b_{1c}. Table 2 reports the list of internally calibrated parameters together with the specific moment of the data that discipline each parameter. The table reports the value of parameters that are not region or crop-specific.

Elasticity of substitution across crops. We start by estimating the elasticity of substitution across different crops $1/\sigma_c$. Denoting L_{j1ct} the land devoted to crop c in region j, we have the following equilibrium condition

$$\frac{L_{j1ct}}{L_{j1c't}} = \frac{\pi^n_{j1ct}\ell_{jct}}{\pi^n_{j1c't}\ell_{jct}} = \frac{\left(\frac{p_{1c't}z_{osc't}}{\exp\{b_{o1c}\}}\right)^{1/\sigma_c}}{\left(\frac{p_{1c't}z_{osc't}}{\exp\{b_{o1c'}\}}\right)^{1/\sigma_c}} \tag{14}$$

Table 2: Internally Calibrated Parameters and Targeted Moments

Parameter	Description	Value	Targeted Moments
$1/\sigma_c$	Crop Elasticity	2.78	Reg. harvested land on crop prices
γ	Land use elasticity	7	Reg. of land size on rural density
a_{ot}	Amenities	-	Own migration share
w_{o2}	Productivity in cities	-	Consumption in cities
z_{o1c}	Crop yields	-	Crop yields
$\bar{L}_j$	Supply of land	-	Actual total area of region
γ_{0j}	j-specific cost of land	-	Average land size
b_{j1c}	Costs of crops	-	Harvested land in each crop/region
b_{js}	Sectoral costs	-	Urban population in each region
b_j	Migration cost	-	Bilateral migration flows

where π^n_{jct} is the share of farmers growing crop c in location j at time t and ℓ_{jct} is the land used by farmers cultivating crop c at time t in region j. The second equality stems from the result that land sizes are common across all crops in each region. Taking logs gives

$$\ln \frac{\pi_{j1ct}}{\pi_{j1c't}} = \frac{1}{\sigma_c}\left(\log p_{1ct} z_{jsct} - \log p_{1c't} z_{jsc't}\right) + \frac{1}{\sigma_c}(b_{j1c'} - b_{j1c}) \tag{15}$$

To control for region fixed-effects, and address the concern that yields z_{jsct} may be an omitted variable in the regression, we adopt the following local projection panel regression

$$\ln \frac{L_{j1ct+\tau}}{L_{j1c't+\tau}} = \alpha_j + \beta_c \ln \frac{p_{1ct}}{p_{1c't}} + X_{jct} + \epsilon_{jct} \tag{16}$$

with $\tau = 0, ..6$ and X_{jct} is a set of controls that includes two lags of relative prices of crop c. To further address potential concerns about the endogeneity of prices, and consistent with our assumption that Burkina Faso is a small open economy, we consider the crops that are widely traded on international market—rice, cotton, millet and maize—relative to sorghum, and we use international prices for these crops.

Given the slow reaction of farmers to prices, one may be worried that a static framework would underestimate the magnitude of the elasticities, potentially understating the strength of adaptation to climate change. An appealing aspect of using a local projection panel regression is that it allows for a persistent impact of prices on harvested land and can thus provide an estimate of the long-run elasticity of crops. We report the estimates for each crop and horizon in Table 3. To obtain the long-run elasticity, we sum the coefficients from $\tau = 0$ to $\tau = 5$ (last line of the Table). We finally take the average across crops in the last column and we find $1/\sigma_c = 2.78$ which implies $\sigma_c = .36$. This is consistent with the calibration by Conte (2023) and the estimates by Sotelo (2020).

Horizon	Cotton	Maize	Millet	Rice	Average
$\tau = 0$	-0.09	.21**	.14	1.04***	-
$\tau = 1$	.15	.17*	.59*	.58***	-
$\tau = 2$	.51**	.44***	.90***	.89***	-
$\tau = 3$	.10	.43***	.83**	.69***	-
$\tau = 4$	.09	.49***	.76***	.62***	-
$\tau = 5$	-.32	.41***	.66	.43***	-
Sum, $\tau = 0...5$	0.44	2.14	3.88	4.68	2.78

Table 3: Elasticity of relative harvested land to relative prices

Notes: Local projections of (log) relative harvested land on (log) relative prices, as shown in specification 16. Relative prices refer to relative international prices. Controls include two lags of relative prices.

Costs of different crops We now estimate the costs of growing different crops, b_{j1c}. Our approach is to match exactly the share of land devoted to each crop in each region. From equation (15), we have

$$b_{j1c'} - b_{j1c} = \sigma_c(\log L_{j1ct} - \log L_{j1c't}) - \left(\log p_{1ct}z_{jsct} - \log p_{1c't}z_{jsc't}\right)$$

The right-hand side variables are all observable: harvested land for each crop and region, prices and yields of different crops. We can thus calculate the difference in costs of growing any two crops $b_{j1c'} - b_{j1c}$. Given that we can identify only $C - 1$ costs, we normalize the cost associated to sorghum to 0 in all regions: $b_{sorghum} = 0$.

Land elasticity To estimate the land elasticity γ, we start from the model-implied optimal land size $\ell_j = \left(\frac{\bar{L}_{it}}{\gamma\gamma_{0j}N_{j1t}}\right)^{\frac{1}{\gamma}}$ which varies at the region level. This is a log-linear relationship between the average land size per farmer and the density of rural population. It is therefore natural to run a regression of the (log) harvested land per farmer over (log) total land relative to the population of farmers

$$\log \ell_j = \alpha + \beta \log \frac{N_{j1}}{\bar{L}_j} + \epsilon_j.$$

Using OLS, we find $\beta = -.143$ and the regression with region fixed-effects gives similar estimates. The elasticity γ is then simply equal to the inverse of the estimated coefficient from this regression: $\gamma = -\frac{1}{\beta} = 7$. Figure 12 in Appendix shows that the log-linear relationship offers a good fit of the empirical relationship between average land size per farmer and the density of rural population.

Land supply. We calibrate the land supply $\bar{L}_j$ to match the available land area in each region. To back out γ_{0j} we use the equilibrium expression for ℓ_j and the value of available land area for $\bar{L}_j$, average land size for ℓ_j and our estimated elasticity γ:

$$\gamma_{0j} = \frac{\bar{L}_j}{\gamma N_{j1t} \ell_j^{\gamma}}$$

Sectoral costs. We then recover the costs associated with working in the urban and in the rural sectors. Consistent with our previous strategy to recover the costs of crops, we take the ratio of the share of workers in urban areas and the share of farmers: $\frac{\pi_{jst}}{\pi_{j1t}} = \frac{1}{\sigma_s} \frac{w_{jst} / \exp\{b_{js}\}}{\left(\sum_c \left(\frac{p_{1ct} z_{o1ct} \Omega_{jt}}{\exp\{b_{o1c}\}}\right)^{1/\sigma_c}\right)^{\sigma_c}}$. Taking the log and isolating the difference in sectoral cost on the left-hand-side of the equation gives

$$b_{js} - b_{j11} = \ln \frac{w_{jst}}{\left(\sum_c \left(\frac{p_{1ct} z_{o1ct} \Omega_{jt}}{\exp\{b_{j1c} - b_{j11}\}}\right)^{1/\sigma_c}\right)^{\sigma_c}} - \sigma_s \ln \frac{\pi_{jst}}{\pi_{j1t}}$$

We then compute $\left(\sum_c \left(\frac{p_{1ct} z_{o1ct} \Omega_{jt}}{\exp\{b_{o1c}\}}\right)^{1/\sigma_c}\right)^{\sigma_c}$ in each region using our estimates of yields, the costs of growing different and our estimated Ω_j. Using the calibrated elasticity for σ_s, the observed wages in urban areas and share of people living in these areas in region we can compute $b_{js} - b_{j11}$. This is a set of J equations with

$2 \times J$ unknowns. We need to normalize J parameters, which we do by setting the cost of living in rural areas to 0, $b_{j11} = 0$ for all j.

Migration costs. To recover the migration costs, we use the matrix of migration from the Census 2019. We start from the equilibrium ratio of migration flows to destination d from two different origins o and o': $\frac{\pi_{odst}}{\pi_{o'dst}} = \frac{\exp\left\{\frac{m_{o'd}-m_{od}}{\sigma_m}\right\}\sum_{k=1}^{J}\exp\left\{\left(U_{kt}-m_{o'k}\right)/\sigma_m\right\}}{\sum_{k=1}^{J}\exp\left\{\frac{U_{kt}-m_{ok}}{\sigma_m}\right\}}$.

It turns out that the log of the ratio of this ratio between two destinations d and d' is simply a function of the migration elasticity and the migration elasticity:

$$\log \frac{\frac{\pi_{odt}}{\pi_{o'dt}}}{\frac{\pi_{od'st}}{\pi_{o'd'st}}} = \log \frac{\exp\left\{\left(m_{o'd} - m_{od}\right)/\sigma_m\right\}}{\exp\left\{\left(m_{o'd'} - m_{od'}\right)/\sigma_m\right\}} = \frac{1}{\sigma_m}\left[m_{o'd} - m_{od} - m_{o'd'} + m_{od'}\right] \quad (17)$$

Normalizing the cost of staying to 0, and imposing symmetry $m_{od} = m_{do}$, we can perfectly recover the matrix of migration cost.

4.3 Internal Calibration: Amenities

The last step of our calibration strategy requires running the model to estimate amenities internally.

Levels of amenities. We estimate the vector of amenities to match the share of stayers in each region, π_{oot}. The intuition is that more attractive places retain more people and have a higher own-migration share.[10] To estimate amenities we thus need to loop over guesses of vectors of amenities and compute the model until we find a set that is consistent with the observed diagonal of the matrix of migration flows.

Effects of Climate Change on Amenities. Climate change will impact the economy through different channels, including labor productivity and crop yields but also by changing how attractive each region is, even after controlling for these

[10] An alternative strategy would be to match the share of population in each region, but this would require in addition the assumption that the population distribution is in steady-state, which is not consistent with the empirical matrix of migration flows and the distribution of individuals across regions.

other factors. Consistent with our assumption that amenities depend on average temperatures TMP, and precipitation PRC in a log-linear way

$$\ln a_j = \ln \bar{a}_j + \beta_T \ln TMP_j + \beta_P \ln PRC_j + \epsilon_j$$

we estimate both coefficients β_T, β_P by regressing our estimated amenities on the climate variables from the FAO-GAEZ dataset, using OLS. Our findings, $\beta_T = -1.44$ and $\beta_P = 1.79$, are consistent with the intuition that individuals prefer locations with more tempered temperatures and where water is more easily available. We will then use these estimated coefficients to predict the effect of water availability and average temperatures on amenities in each region in different scenarios of climate change.

5 Aggregate and Spatial Impacts of Climate Change

In this section, we provide a quantitative assessment of the effects of climate change on the aggregate and spatial distribution of economic activities, crops and population in Burkina Faso. We also analyze the role of the main adaptation margins, and how population growth interacts with the impact of climate change.

5.1 Climate Change

Climate change will have a first order effect on average temperatures and precipitation, which are shown in Figure 6.[11] While all regions are likely to experience similar increases in average temperatures, changes in precipitation are more heterogeneous with some regions experiencing increases, like Cascades, Hauts-Bassins and Sud-Ouest, but with more uncertainty.

In the model, climate change affects the economy through three channels. First it shapes yields by changing the agro-climatic conditions, including temperatures and availability water, in which crops grow. As shown in Figure 7, the same regions that benefit from an increase in precipitation could experience an increase in average crop yields. Similarly crops will be affected differently: while rice, groundnut,

[11] Additional effects include more frequent extreme weather events.

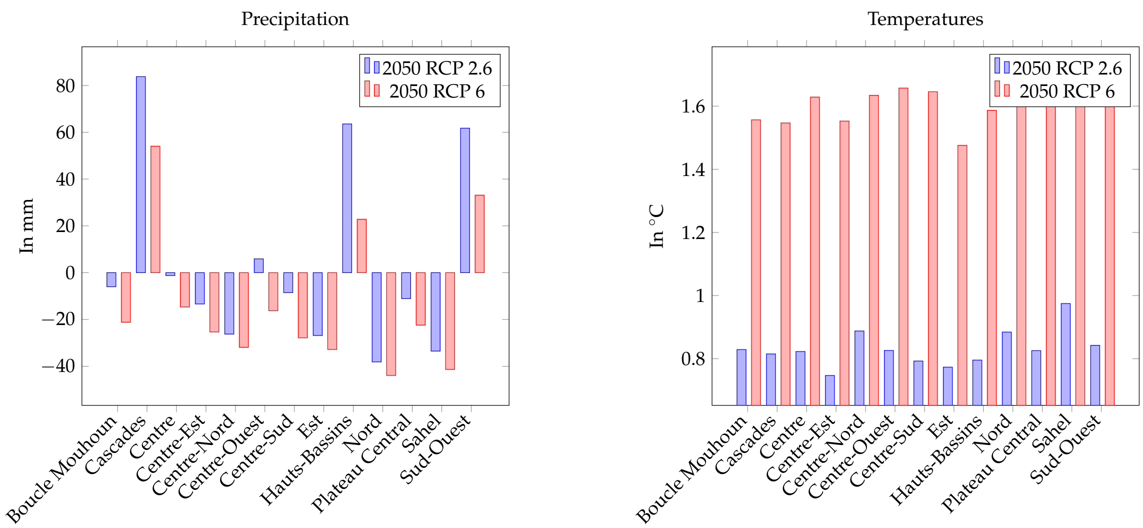

Figure 6: Change in Precipitation and Temperatures

cowpea suffer severely from climate change, cotton and maize are barely affected and sorghum and millet could experience increases in their yields.

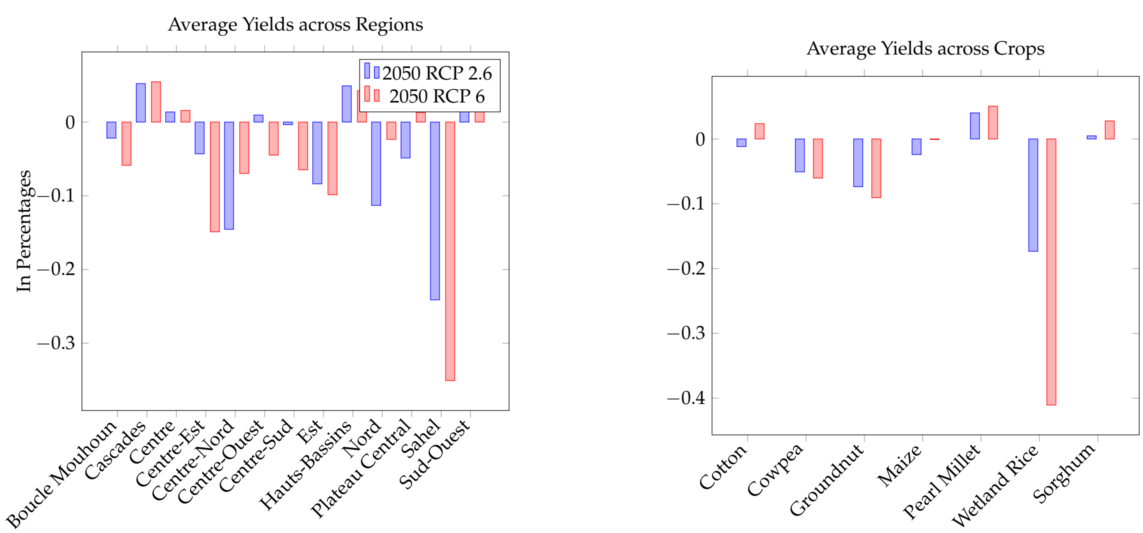

Figure 7: Change in Yields across Regions and Crops

Second, increasing heat levels will make it more difficult for people to work outside and negatively impact workers' health, which will result in lower labor productivity and supply. Given that the increase in average temperatures is quite homogeneous across regions and sectors, this channel will not generate heterogene-

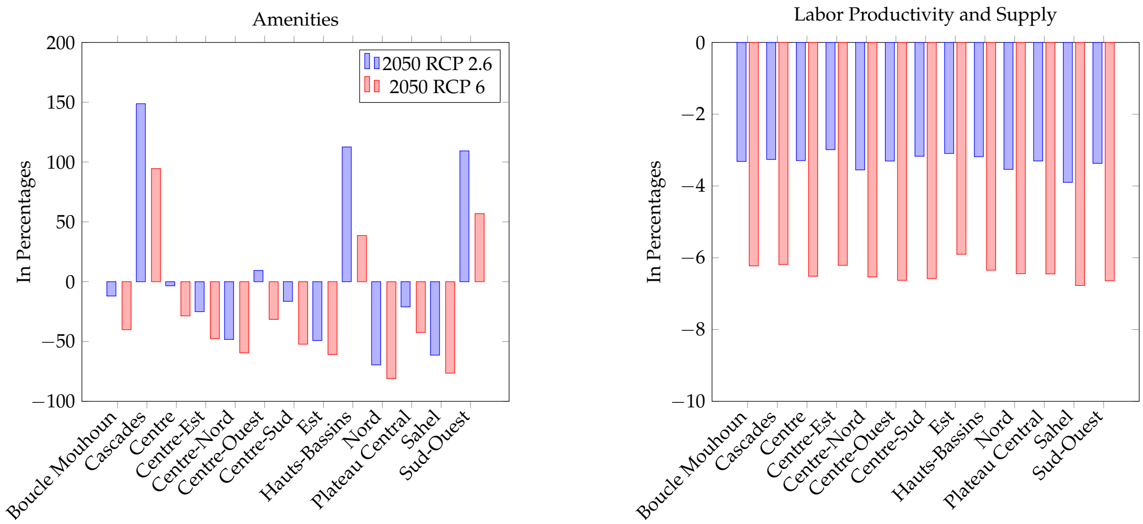

Figure 8: Change in Amenities and Labor Productivity due to Climate Change

ity across space and sectors but may still have large aggregate effects (see Figure 8).

Third, it affects the amenity values of different regions: some regions may become even hotter, or water may become scarcer in some places, making it difficult to survive there. As shown in Figure 8 the values of amenities decrease in most regions, with the exception of Cascades, Hauts-Bassins and Sud-Ouest because they receive more precipitation.

The model abstracts from channels that are potentially important but harder to quantify, including through the long-term accumulation of human capital, worse health outcomes for infants and risk of pandemics (Dasgupta and Robinson 2023), the risks of conflicts which are amplified in the fragile institutional and security context (Larémont 2021), and the destruction of infrastructures (World Bank 2022).

5.2 Main Results

We are now ready to compute the effects of climate change on aggregate GDP, by sectors and by regions, on migration patterns across regions and on crop specialization. To quantify these effects, we compare the steady-state in 2050 with climate change and population growth to another counterfactual steady-state without climate change but with population growth. Note that the equilibrium in the latter steady-state differ from the current level of GDP and distribution of population due to the changes implied by the increase in population and its endogenous redistribution across space.

As shown in the last column of Table 4, we find that GDP would decrease by 0.20 to 3.25% in the RCP 2.6 and RCP 6 respectively at the 2050 horizon. There is however substantial heterogeneity across regions: GDP per capita decreases by about 15, 10 and 22% in the Centre-Nord, Nord and Sahel respectively in the RCP as shown in the bottom left panel of Figure 9.[12] In the 2050 steady-state of the model with population growth but before accounting for climate change, a smaller share of the population live in these regions. The large decline in GDP per capita there due to climate change have therefore limited impact on aggregate GDP.

Turning to migration patterns, the model predicts substantial migration of population from regions experiencing declines in yields and/or in amenities—Centre-Nord, Est, Nord, Sahel—to those experiencing increases in yields—Cascades, Hauts-Bassins, Sud-Ouest—and amenities as shown in Figure 9 right panel. We also find that the share of urban population decreases by 1 and 1.5 percentages points respectively. There is however substantial heterogeneity across regions: regions that experience a strong decline in yields like the Sahel, Nord and Centre-Nord see an increase in the share of urban population (see Figure 9 left panel). The fact that the aggregate rate of urbanization decreases is mainly driven by the fact that the regions whose population increases are also those whose urbanization rate decreases—Cascades, Hauts-Bassins, Sud-Ouest.

Finally, the model also predicts a substantial change in the mix of crops grown in Burkina Faso. The shares of pearl millet and maize increase by 3 and 1 percentage points respectively, and the shares of cowpea, groundnut and rice decrease by 2, 1, and 1.5 percentage points respectively. The effect on sorghum and cotton depends on the scenario: as shown in the bottom right panel of Figure 9 harvested areas grow for these crops in the RCP 6 by around 1 p.p., but decline in the RP 2.6 by less than half a percentage point.

[12] We report GDP per capita to control for changes in the distribution of population across space. Changes in GDP across regions can be computed by adding changes in GDP per capital and in population across region using the top and bottom left panel of Figure 9 respectively.

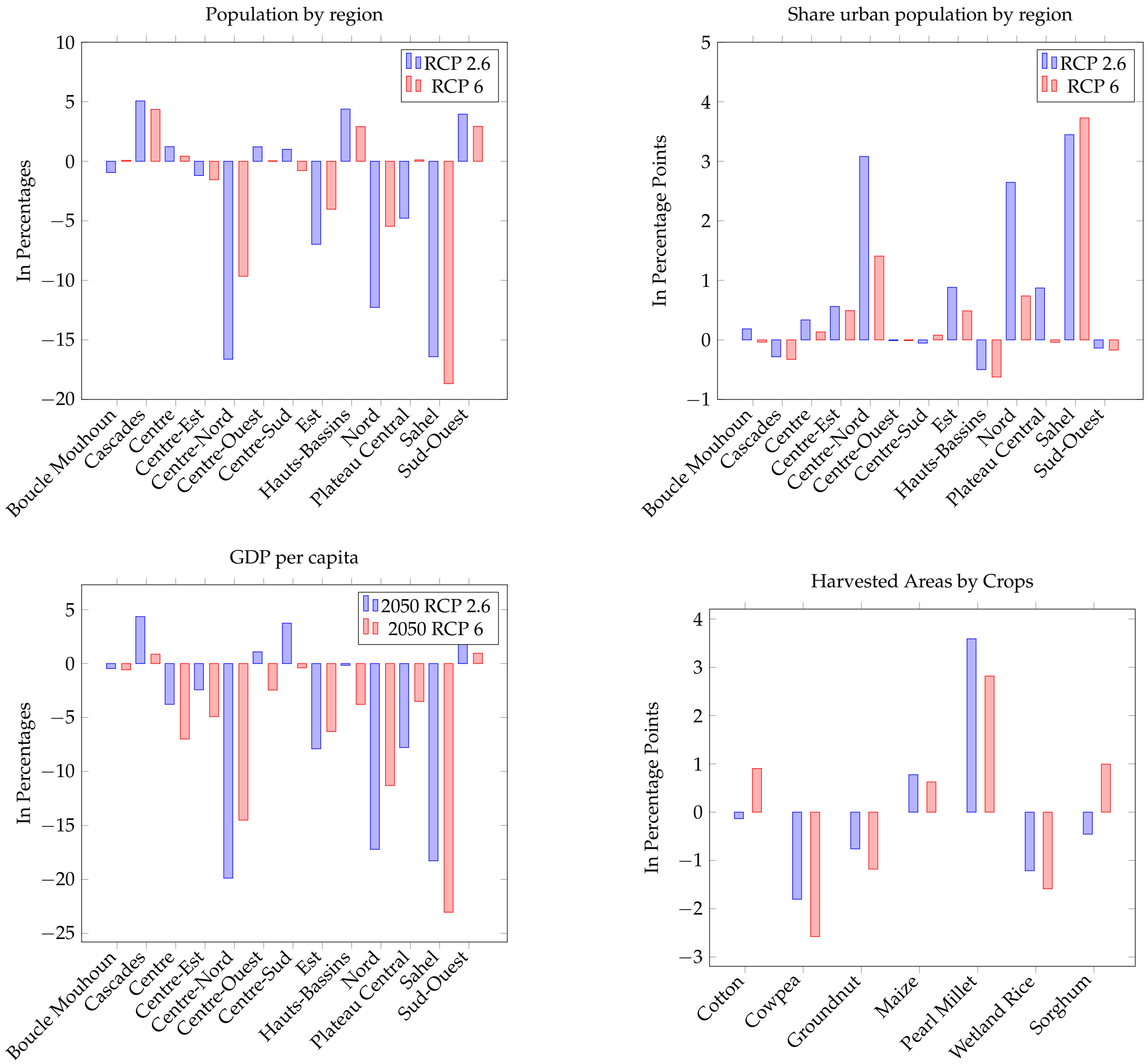

Figure 9: Changes in Population, GDP and Crops

5.3 Decomposition of GDP Changes: The Role of Adaptation Strategies

To better understand what drives aggregate changes in GDP and to quantify the strength of adaptation strategies we next propose a decomposition of total changes implied by climate change into different channels, which is shown in Table 4. The first two columns isolate the direct effect of climate change through labor productivity and supply (first column) and crop yields (second column), and before individuals can respond and adapt to these changes. The third column isolates the effect of switching crops. The fourth isolates the impact of migration—both to and from urban areas and across regions. We also isolate the effect changes in the land size in the last column, which itself depends on the equilibrium region-level density in rural areas.

Methodologically, our decomposition uses the following expression for aggregate GDP:

$$GDP = \sum_j L_j \left(\pi_{1j} h_j \sum_c \pi_{j1c} p_c z_{jc} \ell_j + \pi_{2j} h_j w_j \right).$$

We start from the level of GDP in the baseline steady-state without climate change but with population growth (GDP^{base}). We first compute the change in GDP implied by climate change if individuals couldn't adapt, starting with replacing labor productivity and supply h_j alone (first column) and then by replacing both the yields z_{jc} and the labor productivity and supply h_j by their value implied by climate change but keeping all other variables unchanged (second column). We denote the resulting level of aggregate output GDP^{no}.

The decrease in labor productivity and supply is the strongest channel through which climate change affects GDP. Quantitatively, we find that the change in labor productivity and supply alone decreases GDP by 3.26 and 6.29% in the RCP 2.6 and 6 respectively. The changes in crop yields lead to an increase in GDP, not a decrease. This is because the decline in crop yields in many regions is more than offset by the increase in yields in a select areas that are characterized by higher productivity and population density such as the Cascades, Hauts-Bassins and Sud-Ouest regions—as shown in the left panel of Figure 7.

We then turn to the effects of adaptation margins. To isolate the effect of switching crops, we replace the allocation of farmers and land across crops in each region π_{j1c} by their value in the steady-state with climate change (yields and productivity are also equal to their value implied by climate change) and we denote the associated output GDP^{crops}. To isolate the effect of migration, we replace the distribution of population across regions and across urban areas L_j, π_{1j}, π_{2j} by their value in the steady-state with climate change (GDP^{mig}). Finally, to isolate the effect of changes in land sizes, we replace land sizes ℓ_j by their value in the steady-state with climate change, GDP^{land}. This is by definition equal to GDP in the steady-state with climate change, GDP^{cc}.

Table 4: Decomposing the Role of Different Channels and Adaptation Margins

	No Adaptation		With Adaptation		Total
	Labor	+ Yields	+ Crop	+ Migration	+ Land
$\times 100$	$\ln\left(\frac{GDP^{lab}}{GDP^{base}}\right)$	$\ln\left(\frac{GDP^{no}}{GDP^{base}}\right)$	$\ln\left(\frac{GDP^{crop}}{GDP^{base}}\right)$	$\ln\left(\frac{GDP^{mig}}{GDP^{base}}\right)$	$\ln\left(\frac{GDP^{cc}}{GDP^{base}}\right)$
RCP 2.6	-3.26	-.80	-.76	.11	-.19
RCP 6	-6.39	-3.39	-3.21	-2.95	-3.25

Note: "Migration" includes migration to and from urban areas and across regions. Log-differences are multiplied by 100. RCP = representative concentration pathway.

Overall, our findings indicate that while these adaptive measures offer some relief, their impact remains moderate. Accounting for these adaptation margins results in a $(3.39 - 2.95)/3.25 = 13.5\%$ reduction in the overall cost of climate change relative to a baseline scenario without adaptation. Migration to regions with higher growth prospects is the most important adaptation margin in terms of its contribution to GDP (8%), followed by switching to crops that benefit from climate change (5.5%). Regions that benefit the most from these adaptation strategies include Cascades, Centre-Ouest, Centre-Sud, Hauts-Bassins and Sud-Ouest.

Most of these gains from adaptation are however offset by lower land sizes implied by movements in population to more productive areas of the country and the overall increase in the share of farmers. As shown in Figure 10, the regions whose population and share of farmers are predicted to increase (Cascades, Hauts-Bassins and Sud-Ouest) see a significant decrease in land sizes. On aggregate, we find that the land response accounts for 9% of the total negative effect of climate change, thus offsetting most of the gains from adaptation. This doesn't imply at all that adaptation are not important, but it highlights the need to consider carefully changes in land sizes implied by movement in population, when quantifying the strength of adaptation margins.

5.4 The Role of Population Growth

The population in Burkina Faso is growing at a fast pace and is expected to almost double from about 22 to 40.5 million by 2050. A larger population is likely to have

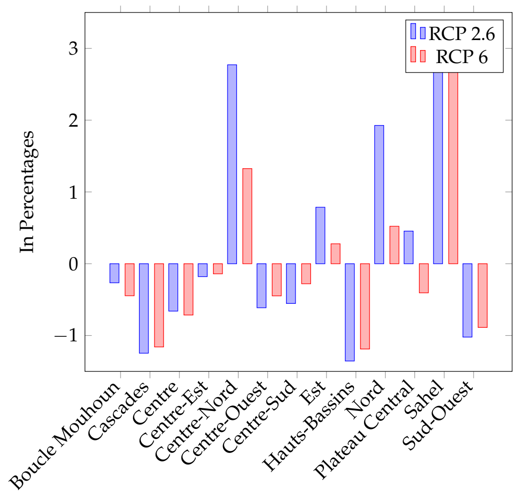

Figure 10: Changes in farm land sizes

large effects on the economy, including by putting pressure on land, and by leading individuals to migrate to cities and potentially to other regions.

In this section, we investigate two questions related to this large expected population growth. The first question is: how does the cost of climate change compare with the cost implied by population growth? To answer this question, we isolate the impact of population growth by simply simulating the impact of population growth alone, ignoring climate change. The second is: how does the cost of climate change itself is affected by population growth? We will do so by computing two new counterfactuals: the impact on GDP of population growth alone (ignoring climate change) and the impact of climate change if population remains the same as its current level. Results are displayed in Table 5.

Scenario	Pop Growth Only	CC only (2050 pop)	CC only (2020 pop)
RCP 2.6	-3.29	-.19	.21
RCP 6	-3.29	-3.3	-2.8

Table 5: Decomposition of the Impact of Population and Climate Change on GDP
Note: GDP refers to GDP per capita and controls for the change in population size.

Interestingly, the cost of population growth (3.29%) is of the same order of magnitude as the cost of climate change in the RCP 6 (3.3.%) but significantly larger than in the RCP 2.6 (-.19%). This finding echoes Henderson et al. (2024) which finds that in most areas in the world population growth is a bigger concern that climate change for maintaining standards of living.

Secondly, the cost of climate change is larger when looking at the economy with population growth (3.3% in the RCP 6) than without population growth (2.8% in the RCP 2.6), by about $(3.3 - 2.8)/2.8 = 17.8\%$. The intuition for this interaction is that climate change induces a smaller increase in urban population than in the baseline without (i.e. more individuals stay in rural areas), but the increase in population puts pressure on land, which forces farmers to cut the size of their plot, thus lowering GDP.

The interaction between these two phenomena is thus quantitatively important. This result highlights the need to consider jointly changes in population and climate to properly quantify the cost of climate change.

5.5 Policy Counterfactuals

Finally we look at the role of agricultural policies in lifting productivity in the primary sector and mitigating the effect of climate change. Low agricultural productivity is a key impediment to lifting conditions of living and food security in Burkina Faso. While productivity in agriculture, measured as the value of production per farmer, has caught up to the average level in Sub-Saharan Africa in recent decades, it has recently remained stagnant and very low relative to advanced economies as shown on the left panel in Figure 11.

Several obstacles impede agriculture productivity. The use of fertilizers and of mechanized equipment is lower than in the rest of SSA, and the proportion of irrigated land is about four times smaller than the regional average; and all of these metrics in Burkina Faso are only a small fraction of those in AEs, as shown on the right panel in Figure 11.

To quantify the benefits of improving agricultural productivity in mitigating the effects of climate change, we now propose a model-based counterfactual where we change yields z_{jct} to their levels if farmers were using a greater quantity and quality of inputs. This measure of "high input" yields is directly provided and defined in the FAO-GAEZ dataset. Note that these increase in yields are assumed to be exogenous and we thus abstract from the cost of using more and better inputs for farmers.

Consistent with the very large gap in productivity and input use relative to

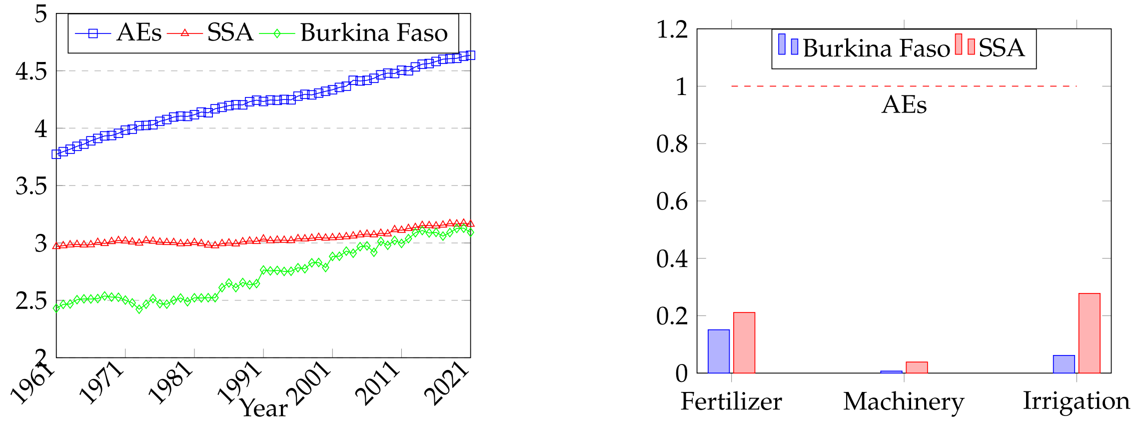

Figure 11: Agricultural Productivity and Input Use

advanced economies documented in Figure 11, we find that aggregate GDP could dramatically rise by 292% and 320% in the RCP 2.6 and 6, respectively, relative to a steady-state with low input use. These figures should be seen as upper bound since we abstract from the cost of using more and better inputs. Nonetheless, the impact of more intensive use of inputs far outweighs the cost of climate change and population growth together. It clearly suggests that use of fertilizers, investment in equipment and irrigation infrastructures are key priorities to improve agricultural productivity, as they would increase agricultural production, and lift standards of living.

6 Conclusion

Climate change is likely to have a large impact on Burkina Faso. The paper assesses the economic impact of climate change in Burkina Faso through the lens of a quantitative spatial model that incorporates multiple regions, sectors and crops. The model allows for several channels of transmission of climate change—change in temperatures and precipitation, crop yields, and labor productivity—and multiple margins of adaptation—switching crops, migration across regions and from/to urban areas. Calibrating the model to match aggregate-, region- and crop-level data, we find that GDP would decrease by 0.20 to 3.25% in the RCP 2.6 and RCP 6 respectively at the 2050 horizon, with substantial heterogeneity across regions and crops. Adaptation margins mitigate the cost of climate change by 13.5% but most of these gains are offset by the decreasing land sizes implied by movements in population to more productive areas. Relatedly, given the scarcity of land, we find that it is important to consider the interaction of climate change with population growth when assessing the cost of the former.

Future research should assess the role of human capital accumulation as an additional adaptation strategies and a lever of policy action in mitigating the cost of climate change, lifting agricultural productivity and fostering development. In addition, it would be interesting to extend the model to allow for climate change to affect the variability of rain and temperatures. This would in turn change the variance of crop yields, and the optimal crop and location decision of individuals, if farmers are risk-averse. By elucidating these dimensions, future studies can contribute to a more comprehensive understanding of the multifaceted impacts of climate change and inform policy interventions aimed at enhancing resilience and sustainability in economies dominated by rainfed agriculture.

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Appendix

A Additional data

Table 6: Migration Matrix

	From												
To	BM	Cascades	Centre	CE	CN	CO	CS	Est	HB	Nord	PC	Sahel	SO
BM	0.9236	0.0038	0.0042	0.0015	0.0047	0.0080	0.0022	0.0008	0.0095	0.0128	0.0019	0.0044	0.0035
Cascades	0.0056	0.9375	0.0025	0.0013	0.0039	0.0031	0.0011	0.0008	0.0126	0.0068	0.0017	0.0039	0.0073
Centre	0.0282	0.0181	0.9366	0.0427	0.0410	0.0564	0.1464	0.0185	0.0378	0.0472	0.1084	0.0256	0.0234
CE	0.0006	0.0007	0.0041	0.9292	0.0046	0.0012	0.0032	0.0048	0.0010	0.0007	0.0079	0.0011	0.0007
CN	0.0008	0.0012	0.0040	0.0015	0.8905	0.0017	0.0021	0.0018	0.0015	0.0027	0.0046	0.0195	0.0012
CO	0.0050	0.0025	0.0094	0.0023	0.0133	0.9022	0.0081	0.0015	0.0041	0.0090	0.0091	0.0048	0.0045
CS	0.0005	0.0004	0.0064	0.0028	0.0065	0.0019	0.8262	0.0006	0.0008	0.0006	0.0043	0.0009	0.0006
Est	0.0007	0.0006	0.0029	0.0065	0.0037	0.0011	0.0009	0.9642	0.0011	0.0008	0.0017	0.0020	0.0006
HB	0.0267	0.0264	0.0125	0.0050	0.0109	0.0123	0.0044	0.0026	0.9191	0.0245	0.0050	0.0087	0.0194
Nord	0.0030	0.0020	0.0046	0.0009	0.0057	0.0037	0.0015	0.0006	0.0025	0.8864	0.0023	0.0086	0.0014
PC	0.0007	0.0005	0.0076	0.0044	0.0080	0.0039	0.0019	0.0011	0.0009	0.0027	0.8494	0.0025	0.0007
Sahel	0.0005	0.0006	0.0016	0.0005	0.0029	0.0011	0.0006	0.0012	0.0007	0.0011	0.0011	0.9145	0.0006
SO	0.0040	0.0058	0.0035	0.0015	0.0042	0.0036	0.0016	0.0013	0.0083	0.0048	0.0027	0.0035	0.9362

BM = Boucle du Mouhoun, CE = Centre-Est, CN = Centre-Nord, CS = Centre-Sud, HB = Hauts-Bassins, PC = Plateau Central

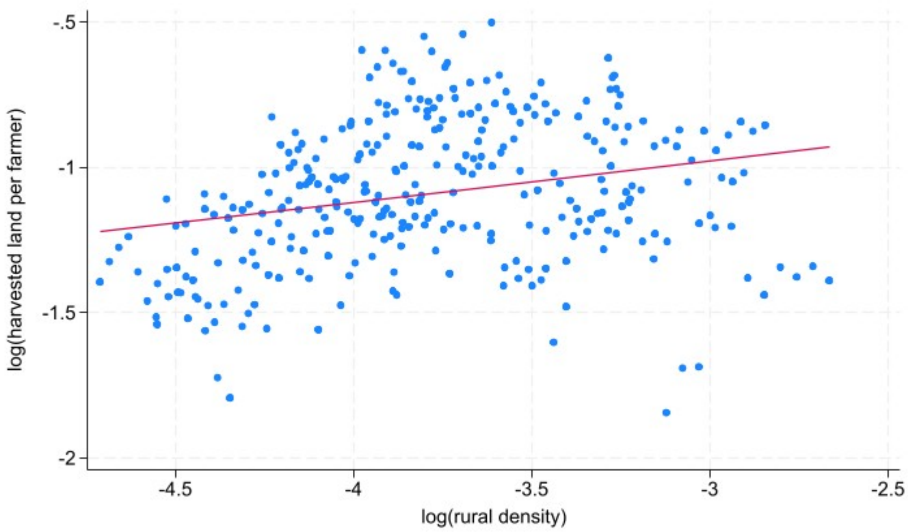

Figure 12: Harvested land per farmer and rural density