Policy Research Working Paper 10740

The Macroeconomic Impact of Climate Shocks in Uruguay

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WORLD BANK GROUP
Macroeconomics, Trade and Investment Global Practice
March 2024

Policy Research Working Paper 10740

Abstract

Uruguay is an economy that is vulnerable to precipitation patterns, as evidenced during the country's historic 2022/23 drought. Yet, and despite its rich macroeconomic and climate data environment, the country does not have a consistent macroeconomic model to address the aggregate impact of climate shocks, let alone the expected additional impact from climate change. This paper intends to fill this gap by integrating climate shocks into the World Bank's Macro-Fiscal Model, its workhorse structural macroeconomic projection model. Building on existing country studies on the sectoral effects of droughts and floods, the analysis finds that the volatility of a simulated Uruguayan economy only subject to historical climate shocks reaches 22 percent of the historical volatility of gross domestic product. Moreover, as climate shocks are only one of many shocks that can simultaneously affect an economy, incorporating exogenous macroeconomic shocks into historical climate shocks exacerbates volatility and increases potential losses. Gross domestic product can fall by 2.3 percent under a combined negative climate and macroeconomic shock of the type witnessed once every six years on average, and 4.1 percent under a once-in-40-years combined negative shock. Climate change compounds these effects going forward, worsening the magnitude of the downside risks from droughts by between 18 and 30 percent, although estimates incorporating climate change are subject to large uncertainty. The order of magnitude of these effects calls for a more systematic consideration of climate shocks in macroeconomic projections and fiscal risk assessments for Uruguay.

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The Macroeconomic Impact of Climate Shocks in Uruguay

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Keywords: Uruguay; macro-structural model; climate shocks; droughts; floods; climate change.

JEL Classification: C10, C50, E37, Q54

[§] World Bank; Macroeconomics, Trade and Investment Global Practice. This paper was produced under the guidance of Doerte Doemeland. The short-term distributional analysis was jointly developed with Lourdes Rodriguez Chamussy and Diego Tuzman Fernandez from the Poverty and Equity Global Practice. The team would like to thank Marianne Fay, Dirk Heine, Mariana Conte Grand, Ana Bucher, Lucia Spinelli, Florencia Balestro, Carlos Costa, Julieta Schiro, Andrew Burns, Charl Jooste, Edward Bresnyan, Pedro Valdivia, and Florent McIsaac, who provided valuable feedback and advice at different stages of the study, and Marielena Perez for her research assistance. This study benefited from a close collaboration with Uruguayan technical teams at the Ministry of Finance and the Ministry of Livestock, Agriculture, and Fishing. The team would like to thank the following current and former government officials which helped improve the study, none of whom should be held accountable for any mistakes or misinterpretations. At the Ministry of Finance (in alphabetical order): Marcelo Caffera, Juan Chaves, Lucia Heguy, Juan Labat, Gabriela Miraballes, Victoria Novas, Maria Luisa Olivera, Nicole Perelmuter, Maria Tornaria, Carolina Steneri. At the Ministry of Livestock, Agriculture, and Fishing: Ángela Cortelezzi and Veronica Duran.

1. Introduction

Uruguay, a relatively small country of approximately 3.4 million people in South America, has historically stood up in the region for its high income per capita, egalitarian society, low poverty levels, and strong social compact. After two decades of continuous economic growth only interrupted by the COVID-19 pandemic, the country ranks first in Latin America in terms of GDP per capita and currently enjoys the lowest sovereign country spreads in the region. Uruguay has relatively high levels of welfare, as measured by indicators such as the Human Development Index, has virtually eradicated extreme poverty, and is known for its political and institutional stability.

Natural capital lies at the core of Uruguay's wealth and culture. Uruguay has historically relied on livestock and agriculture (L&A) as the foundation of its economic activity and national identity. By the mid-20th century, one-third of GDP was directly accounted for by L&A, with industry and services splitting the other portion equally (Bertino and Tajam, 1999). As the country advanced in its development process, a slow but steady structural transformation process saw the emergence of services and the fall in the direct contribution of L&A, which currently accounts for approximately 6.3 percent of GDP. However, this significantly underestimates the macroeconomic relevance of natural capital for Uruguay. First, it does not account for L&A's backward and forward linkages along value chains, with many services (transport, logistics, related commerce, etc.) and manufacturing industries (leather, foodstuff, etc.) tightly linked to the primary sector. Second, L&A and related activities contribute to a large share of the country's exports of goods. Third, other natural capital-based activities play a significant role in Uruguay's economy, such as electricity generation (close to fully renewable in Uruguay) or tourism. The country's national motto, *Uruguay Natural*, pays tribute to this legacy.

Uruguay's economy is thus particularly vulnerable to certain climate shocks, notably those linked to precipitation patterns. For example, the Ministry of Livestock, Agriculture and Fishing (MGAP) estimates US$1.8 billion in direct losses from livestock, agriculture, and the dairy industry from the 2022-23 drought, trumping the large losses from the 2017/18 agricultural campaign (MEF 2023). Floods trigger productive losses (crop yields and pastures) and damage to the capital stock (transport infrastructure). Aside from their direct impact, these losses and damages trickle down to the rest of the economy, further affecting economic activity, external and fiscal accounts, and incomes. Climate change could exacerbate the already large impacts of these shocks, as they increase their frequency and intensity.

Climate shocks should therefore be analyzed under the same light as other macro-relevant shocks. Standard sensitivity exercises to baseline macroeconomic projections and risk assessments usually - and rightly - recognize the relevance of terms of trade shocks, international interest rate movements, or fluctuations in the demand from trade partners for macroeconomic outcomes. A fall in the terms of trade, for example, usually induces a worsening of external accounts, a real exchange rate depreciation, and a fall in GDP, the scale of which depends on the persistence of the shock. Climate shocks, despite their evident relevance for many countries, are not usually mainstreamed in macroeconomic analysis. Moreover, the compound effects of climate and standard macroeconomic shocks are seldom addressed.

We assess the macroeconomic impact of the most relevant climate shocks affecting Uruguay´s economy, using the wide availability of country-specific data and background analysis. Using a macro-structural projection model customized to Uruguay (MFMOD UY) and expanded to account for climate shocks, this paper isolates the main transmission channels of droughts and floods on aggregate macroeconomic outcomes. This allows us to quantify the second-round effects of climate shocks and the induced adjustment dynamics of the main macro variables. In addition, we simulate climate shocks jointly with standard macroeconomic shocks to address their compound effects. To do so, the study exploits the stochastic characteristics of climate shocks, as well as the joint distribution of standard macroeconomic shocks. This paper benefits from relevant background data and analytical studies related to climate shocks and their impacts available for Uruguay, which provide historical estimates of direct losses and stochastic projections of climate shocks under different climate scenarios.

The contribution of this study is threefold. First, and more specific to Uruguay, a comprehensive macroeconomic assessment of climate shocks was missing, despite the rich background data and analytics about the historical and expected direct effects of climate shocks in the country. Second, we develop an innovative and detailed approximation to the modeling of droughts, whose transmission mechanisms to aggregate outcomes are often oversimplified. This is particularly important for Uruguay, given its economic structure, but also has potential implications for other countries in Latin America that share its dependence on L&A. Third, of a more general nature, macroeconomic analyses that incorporate the effects of climate shocks do not usually address how they interact with more standard macroeconomic shocks, and thus understate their implied downside risks. Our approach allows for the simultaneous simulation of standard macro shocks (interest rates, external demand, etc.) and climate shocks, hence providing insight into how they jointly affect macroeconomic volatility.

We find that climate shocks have relevant and persistent effects on aggregate variables. Droughts in particular represent large and persistent shocks to economic activity and fiscal balances. However, this effect is dynamically complex. Incorporating the temporal pattern of production losses in historical droughts in Uruguay, and linkages between the L&A sector, other productive sectors, and the demand side of the economy, our modeled results imply that indirect effects magnify the direct impact of a drought on economic activity by around 50 percent in the year of occurrence. For the 2022/23 drought, this translates into a 2.8 percent fall in GDP accounting for direct and indirect effects. Given the persistent effect of climate shocks on economic activity, particularly on livestock, GDP, fiscal outcomes, and exports are still lower than in the baseline scenario of no climate shocks the year after the drought. We find small but persistent distributional effects in the short term, with a 0.5 percentage point increase in poverty levels on impact.

The volatility of a simulated Uruguayan economy only subject to climate shocks reaches 22 percent of historical GDP volatility. Average real GDP is estimated to fall by up to 0.4 percent because of continued historical climate shocks, and by up to 2.3 percent as a result of one-in-40 years climate shocks. Exports are affected disproportionately, as climate shocks affect activities overrepresented in the export basket. The impact of climate shocks on fiscal accounts is also relevant, reducing the fiscal balance (as a percentage of GDP) by up to 0.5 percentage points for climate shocks that historically occurred once every 40 years. Our results suggest that future changes in the Uruguayan climate associated with higher emissions concentration pathways would tend to worsen the magnitude of the downside risks from droughts by between 18 and 30 percent, and from floods by between 57 and 212 percent. Climate change estimates are subject to large uncertainty given the dispersion of the model's projected precipitation patterns for Uruguay.

These climate effects are compounded by macroeconomic shocks. Climate shocks do not occur in a vacuum but are only one of many shocks that can simultaneously affect an economy. Incorporating exogenous macroeconomic shocks to historic climate shocks exacerbates volatility and increases potential losses. GDP volatility roughly doubles compared to the climate shocks-only scenario. GDP can fall by 2.3 percent under a combined negative climate and macroeconomic shock of the type witnessed once every 6 years, on average, and 4.1 percent under a once-in-40-years combined negative shock. This affects downside risks for the fiscal balance, which can worsen around 0.8 percentage point of GDP and 1.5 percentage points of GDP, respectively.

The rest of this paper is organized as follows. Section 2 provides some background on Uruguay's structural characteristics and recent macroeconomic performance. Section 3 describes the main transmission channels of climate shocks to the Uruguayan economy. Section 4 presents the analytical approach used to assess the macroeconomic impact of climate shocks. Section 5 presents the data and background analytics used to inform this study and perform the quantitative exercises. Section 6 describes and presents the main results of the study. Section 7 lays out broad development policy implications.

2. A primer on Uruguay: A service economy rooted in its natural capital

Economic Structure

Uruguay is a relatively small and prosperous country located in South America, with a population of approximately 3.4 million people. Although at US$71.4 billion its gross domestic product (GDP) is orders of magnitude smaller than that of neighboring Brazil and Argentina, Uruguay is a high-income country, with relatively low poverty, low levels of inequality, and a strong social compact. As most modern economies, Uruguay is heavily reliant on the service sector, which accounts for approximately 67 percent of GDP. However, L&A is a significant contributor to the country's economy –directly accounting for approximately 6.3 percent of GDP and with large spillover effects on manufacturing and services– and a disproportionately high contributor to export revenues.

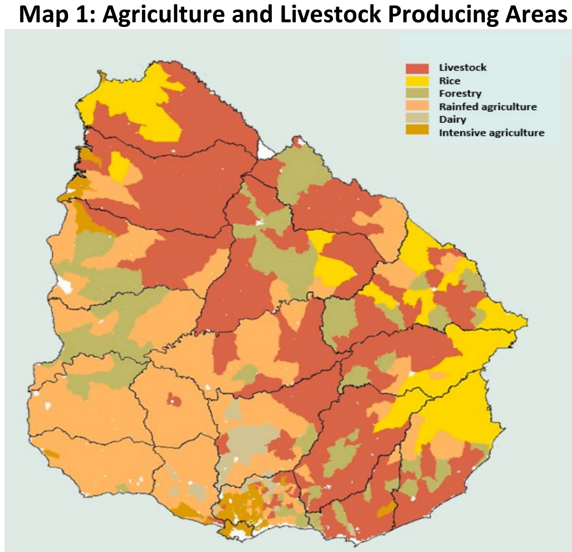
The 2002 crisis ushered in the country's longest economic growth spell, leveraged by a period of exceptional agricultural commodity prices. Between 2002 and 2019, Uruguay experienced a 153 percent increase in GDP per capita adjusted for real purchasing power parity (PPP). This growth positioned Uruguay as the third-highest performer in the region, only trailing behind Panama and Peru. This robust economic performance was driven by a combination of factors, including the commodity superboom and the successful implementation of post-2002 crisis reforms aimed at enhancing the country's macroeconomic and fiscal policy framework. Welfare indicators improved significantly in the period, with the population under the national poverty line reaching a record low of 7.9 percent in 2017.

Economic growth decelerated significantly as the commodity price boom waned and in the face of adverse weather events, stressing the importance of natural capital for the country's economic performance. GDP growth decelerated from an average of 5.1 percent between 2003 and 2014 to 0.9 percent between 2015 and 2019. With the deceleration of growth, improvements in poverty and inequality experienced in the first subperiod came to a halt, and showed an incipient reversal starting in 2017. Public finances deteriorated slowly as well, as tax revenue decelerated with lower GDP growth and health and social security spending increased. The COVID-19 pandemic added to the challenges, and further exposed external vulnerabilities.

Uruguayan beef exports are perhaps the most recognizable natural capital-related activity. Livestock production is a significant part of Uruguay's primary sector, with cattle being the largest contributor. In 2021, there were almost 12 million head of cattle in the country. Uruguay is known for its high-quality grass-fed beef, which is exported to several countries, including the United States, China, and the European Union. Other livestock production includes sheep, goats, and pigs. Dairy is also an important sector in Uruguay, producing enough milk to supply about 20 million people. Uruguay's dairy industry is mainly focused on the production of cheese, yogurt, and milk powder. The dairy sector is also a major employer in the country, providing jobs for thousands of people.

Uruguay is also an important producer of crops, especially soybeans, maize, wheat, barley, and rice, mostly destined to global markets. The country's climate and soil conditions are favorable for extensive rainfed agriculture, particularly in the southwestern portion of the country (Map 1). Soybeans are the most significant crop in terms of production and export earnings, followed by rice, wheat, maize, and barley. In recent years, there has been a significant increase in the surface area planted with eucalyptus, which is used by three pulp mills to produce and export cellulose. Uruguay has also been making strides in organic agriculture, with an increasing number of farmers adopting sustainable farming practices. Looking at major sectors within the primary sector, production is comprised of 44 percent crops, 40.5 percent livestock (meat), and 15.5 percent dairy[2] (Figure 1). The country's main trading partners are China, Brazil, and the United States. L&A and related products (excluding wood and paper) make up more than 65 percent of merchandise exports (Figure 2).

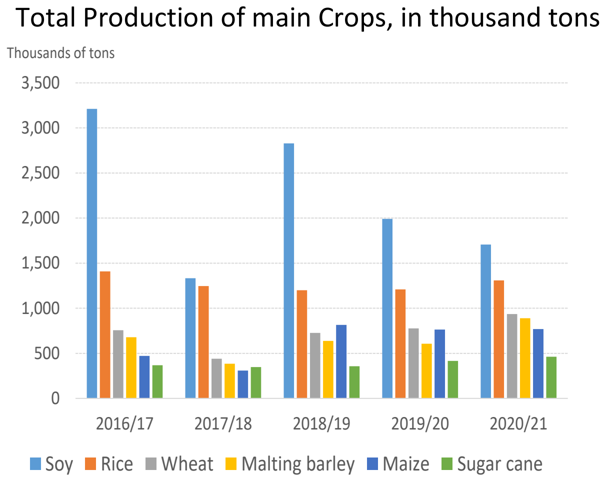
Map 1: Agriculture and Livestock Producing Areas

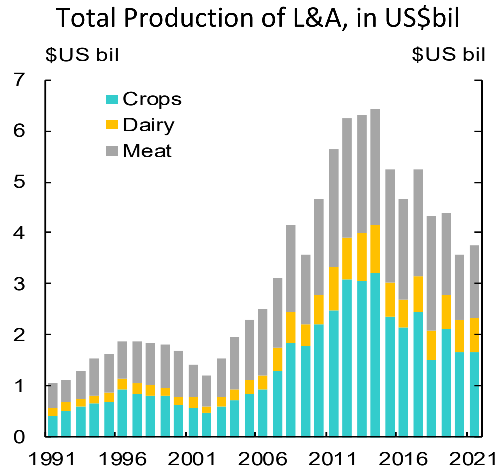


Source: MGAP (2015)

[2] Five-year average to 2021.

Figure 1: Agricultural production in Uruguay

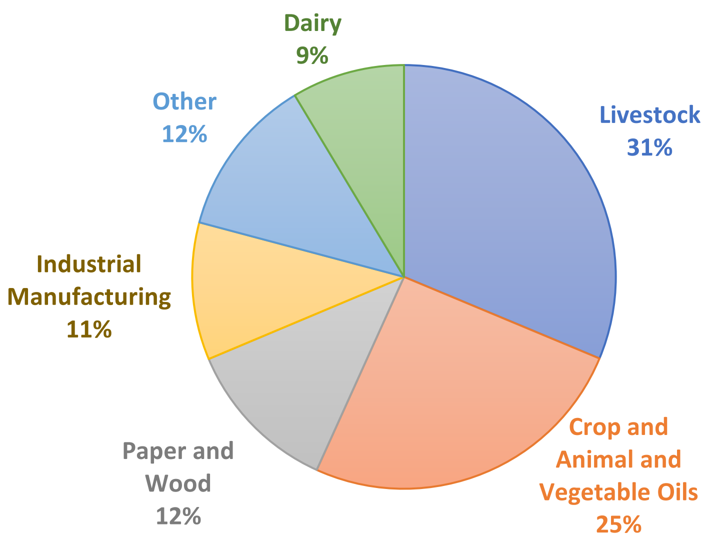




Source: Food and Agriculture Organization of the United Nations.

Also linked to its natural capital, tourism, and more recently processed foods and wines, are an important source of export revenue. Uruguay's service exports have historically been dominated by tourism, mostly linked to inbound travelers from Argentina -and more recently Brazil- towards its beaches. Many resort cities and villages along its 220 kilometers of Atlantic coast become tourism hotspots during the summer months, notably Punta del Este, a high-end destination with a mix wide natural beaches, coastal forests, and modern amenities. Wineries are becoming a complementary touristic attraction, and more generally a staple export industry, making headway into international markets with the flagship Tannat reds. Software development and other ICT-related activities have become an increasingly important engine of export growth in recent years, reaching US$980 million in 2022.

Figure 2: Uruguay merchandise export composition



Source: Based on Uruguay XXI.
Notes: Average from 2019-2022.

Fiscal Accounts

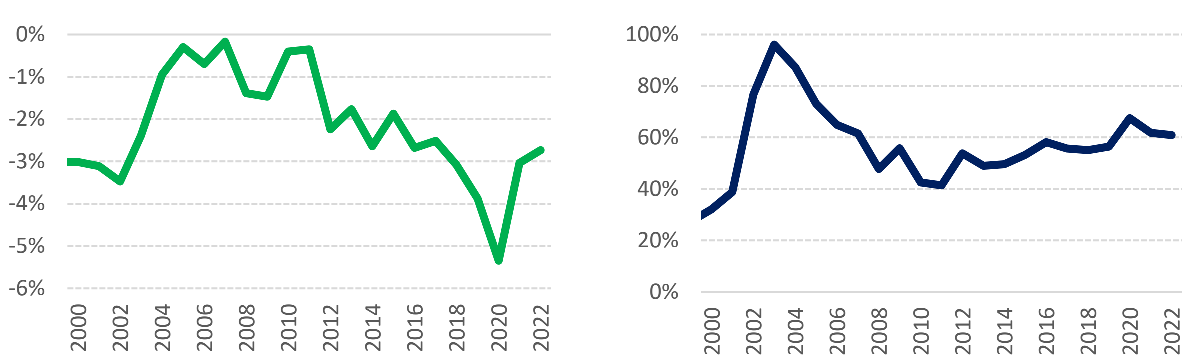
Following the 2002 economic crisis, Uruguay made significant progress in improving its fiscal framework and outcomes. Starting in the mid-20th century, fiscal imbalances and the monetization of deficits resulted in chronically high inflation and nominal volatility, while Uruguay's economy diverged from the frontier. Inflation returned to single-digit figures only in the 1990s, as fiscal imbalances moderated and the monetization of deficits was phased out.[3] Fiscal outcomes improved after the 2002 crisis, underpinned by prudent macroeconomic and fiscal policies, sound debt management, and robust economic growth.[4] The gross debt of the non-financial public sector, which spiked to 96.1 percent of GDP in 2003 following the depreciation of the Uruguayan peso, fell to a low of 53.8 percent in 2012 (Figure 3). The improvement in fiscal accounts stalled with the deceleration of growth in 2015, and the COVID-19 pandemic added to the challenges. Debt increased to 67.6 percent in 2020, driven also by the depreciation of the Uruguayan peso (about half of public debt is nominated in US dollars).

Despite the growth slowdown since 2015 and COVID-19 challenges, Uruguay emerged from the pandemic as the country with the lowest sovereign spreads of the region. Uruguay implemented a reform agenda to enhance the macro-fiscal framework, which included a structural balance fiscal rule, an expenditure ceiling linked to potential GDP growth, the establishment of an independent committee of experts to provide inputs to estimate the structural balance, and an independent advisory fiscal council. At the same time, it rationalized spending not directly linked to the pandemic, such as public wages, to buffer the negative impact on fiscal accounts. In addition, a reform to improve the long-term sustainability of the pension system was approved in 2023. As the post-pandemic recovery went underway, Uruguay found itself as the country with the lowest sovereign spreads of the region, and improved credit ratings from the main credit agencies.

Figure 3: Uruguay's fiscal outcomes

a) Fiscal Balance of the non-monetary public sector
In percent of GDP

b) Debt-to-GDP ratio of the non-monetary public sector
In percent of GDP



Source: World Bank database, based on BCU and MEF

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[3] Marandino and Oddone (2022).
[4] See World Bank Group (2022) for more details.

3. Given its economic structure, Uruguay is vulnerable to climate shocks

A growing literature has provided characterizations of the risks that climate can create for the economy, as well as their associated channels (see, for example, Dunz and Power (2021) for a paper with a fiscal perspective). These risks are typically categorized into physical and transition risks. Physical risks are those associated with climate outcomes, either current or future, in which case there is a dependency on the projected path of greenhouse gases concentrations. Physical risks can be either acute, when they are driven by specific events like droughts or hurricanes, or chronic, when they reflect longer term patterns such as changing temperatures or sea level variations. Transition risks, on the other hand, are those associated with the reduction of greenhouse gas emissions and the corresponding transformation of technologies, regulations, and social habits.

Uruguay, given its economic structure, is vulnerable to a complex set of climate-related risk drivers, including both physical and transition risks. A full evaluation of these risks is beyond the scope of this paper. For example, the effects of droughts on drinking water quality and availability, the impact of heat waves on aggregate productivity, or the risks of climate change to the tourism and hydroelectric generation sectors are not assessed in this study. We also do not consider transition risks that arise because of fast decarbonization in Uruguay´s markets, including through changes in trade policies or consumer habits.

Our focus is on hydrometeorological climate shocks: droughts and floods. Given its reliance on natural capital, these events are already the largest source of climate impacts on Uruguay's economy, as evidenced by the impact of the 2022/23 drought in the country, and there is concern that future climate change could worsen the impacts of these shocks. This analysis attempts to cover an existing knowledge gap by estimating the direct and indirect impacts of these channels on the Uruguayan economy, and how they could be affected by climate change. Our modeling approach can serve as a building block for future bottom-up assessments of climate damages, as well as complementing top-down approaches (see CEA-OMB (2023) for a review of different modeling approaches).

Drought is a significant risk to Uruguay's L&A production. Droughts can cause a shortage of water and pasture, leading to lower yields and higher production costs. For crops, droughts can lead to reduced planted areas, lower yields, lower crop quality, and higher prices for consumers. This is especially the case for crops that rely on the variable summer rains in Uruguay, such as soybeans and maize. In the case of livestock, droughts can lead to a shortage of feed and water, which can cause significant losses in weight, breeding rates, and early weaning, part of which materializes into lower production only in subsequent years. Additionally, droughts can cause farmers to sell their livestock at lower prices due to a shortage of feed and water, which can have long-term impacts on the industry's profitability. The dairy industry can also be impacted by droughts, as a shortage of feed leads to supplemental feeding costs.

Consecutive droughts exacerbate their aggregate impact. Soil moisture is crucial for crop growth, and consecutive droughts can lead to a reduction in soil moisture levels. This can cause further yield losses and can lead to a decline in soil fertility over time, making it more difficult to produce crops in the future. Consecutive droughts can also have significant impacts on livestock production, as it can lead to a decline in pasture quality, which can make it more difficult for livestock to recover from the effects of a one-off drought.

At the other extreme, floods are also a significant risk to Uruguay's economy, especially in the low-lying areas of the country. Floods can cause significant damage to crops, pasture, and infrastructure, leading to losses in production and increased costs. For example, flooding can lead to soil erosion, which can reduce the quality and productivity of the land. Additionally, floods can impact transport and logistics, making it more difficult and expensive to move goods to markets.

3.1. Future climate conditions for the country are uncertain, particularly for precipitation patterns

The potential future impact of climate change on hydrometeorological[5] events is highly uncertain, for several reasons. The most important source of uncertainty is establishing the trajectory of global emissions for the next decades, which depend on factors like the evolution of low-carbon technologies, the changes in global policies for decarbonization, social attitudes towards climate change, etc. We assess future climate scenarios using Representative Concentration Pathways (RCP), which describe different trajectories for emissions and concentrations of the full suite of greenhouse gases (GHG) and aerosols and chemically active gases, as well as land use/land cover. These RCP pathways are the standard tool to present alternative future scenarios, and we use this convention in the following sections.

The standard RCP pathways considered in World Bank climate-aware macroeconomic analysis are:

- RCP2.6 represents a pathway where greenhouse gas emissions are strongly reduced, resulting in a best estimate global average temperature rise of 1.6°C by 2100 compared to the pre- industrial period.
- RCP4.5 is an intermediate stabilization pathway corresponding to slowly reducing carbon emissions, with a best estimate global average temperature rise of 2.4°C by 2100.
- RCP8.5 is a pathway where greenhouse gas emissions continue to grow unmitigated, leading to a best estimate global average temperature rise of 4.3°C by 2100.

At the level of the physical atmospheric science, projections of climate variables such as temperature and precipitation for a given RCP pathway are also subject to uncertainty. As with any other modeling exercise, different modeling approaches will not yield exactly the same results. This is particularly the case for climate processes that occur at smaller scales, where large Earth models need to adopt simplifying assumptions. The Coupled Model Intercomparison Project (CMIP) maintains a continuous effort to update and compare the results of different models which is "useful for understanding which results are consistent across models, and which results are less agreed upon."[6]

The literature on climate projections tends to show stronger patterns and agreement for temperature trends than for precipitation. This is also true for Uruguay and adjacent climatic zones. As shown in Figure 4 and Figure 5, the multi-model averages of CMIP show large additional increases in temperatures for the country, predicting almost 4°C higher temperature by 2100 in the very extreme conditions of RCP 8.5 and

[5] Hazards that involve the transfer of water and energy between the land surface and the lower atmosphere. These are caused by extreme meteorological and climate events such as floods or droughts.
[6] https://wcrp-cmip.org/cmip-overview/

almost 2°C in RCP 4.5. On the other hand, the projections for average annual precipitation indicate slight increases on average, but there are no significant differences across RCPs and the dispersion of model forecasts is very large, indicating a low degree of agreement across models. A more formal analysis of the discrepancies among models is conducted by Gouveia et al. (2022), who construct estimates of the probability density functions to reflect the underlying uncertainties in different models for South America, finding that those for precipitation extremes are much wider and multimodal than for temperature extremes.

The dispersion of model results for precipitation creates the need to decide on the appropriate projection sets for simulations of future climate shocks. In their assessment of future drought risk, IDB (2019) documents the wide discrepancies of models regarding future precipitation and choses the model that provides the best fit to the observed conditions in Uruguay between 1981-2010. We follow this study approach in the next sections, using their calibrations to quantify loss incidence curves under alternative RCP conditions. However, we caution that recent research has highlighted the limitations of existing models to reproduce long-term increases in austral summer precipitation during the last century (Varuolo-Clark et al. (2021)) and their current geographical distribution (Diaz, Saurral and Vera, 2021). This suggests that using a single model based on historical fit, while appropriate for assessing the historical influence of climate shocks and having the benefit of transparency and being easy to convey to target audiences, may not fully capture the expected impact of climate change.[7]

Figure 4: Projected Mean Temperature in Uruguay

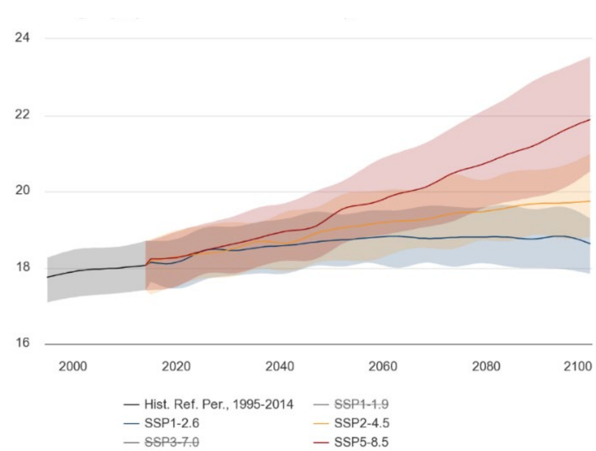
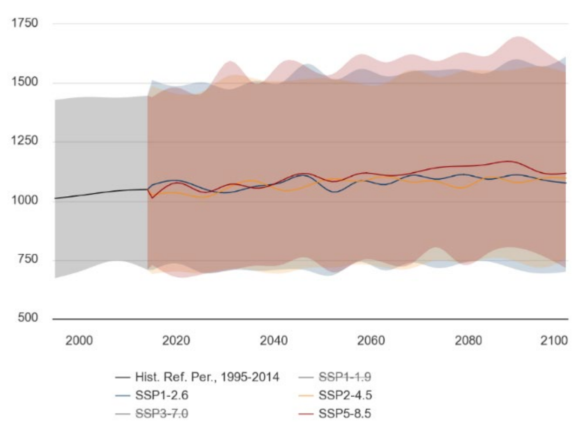


Figure 5: Projected Precipitation in Uruguay



Source: World Bank Climate Change Knowledge Portal.

[7] The preferable methodology would be to develop estimates of loss curves based on the predictions of several models for each concentration scenario, and then gauge model uncertainty providing a range of future outcomes which reflects the discrepancies across models. This option has been used in recent World Bank publications of Country Climate Change and Development Reports. Data limitations have not made it possible to pursue this route in this paper, but the need to develop a broader set of loss estimates reflecting different models is an important area that fiscal policy makers need to consider in future exercises.

4. Analytical approach: A macroeconomic model for Uruguay that accounts for climate damages

Climate (and its future change) has complex interactions with macro-financial variables, which can occur through a wide array of channels (Feyen et al., 2020), a topic that has received increasing attention in the literature. Authors have investigated the effects of temperature changes on growth (Burke et al, 2015, Khan et al. 2021, among others), the importance of local variability in weather (Ayiapi et al. 2022), the economic and technological consequences of decarbonization (Hallegate et al., 2023, among others), the implications of fossil fuel abandonment in oil exporters (Semienuk et al, 2022) or the impact of climate on sovereign ratings (Klusak et al., 2023), just to cite a few areas where intense research is ongoing.

Climate-related disasters have also been a topic of continuous research (see Skidmore, 2022 for a recent overview of this literature). Methodological approaches in this area have been very diverse. An important strand of the literature has focused on identifying the short- and medium-term effects of climatic disasters on GDP and other macroeconomic variables (see Cavallo et al. 2023 for a review centered in Latin America and the Caribbean) using empirical methods, particularly panel data techniques. A more recent trend has been the development of macroeconomic models with rich short-term dynamics and explicit representation of natural disasters and their impact (Gallic and Vernmandel, 2020, Rozemberg et al. Cantelmo et al, 2023). The approach we use in this paper is closer to these papers.

To assess the macroeconomic effect of hydrometeorological shocks, we build a model for Uruguay based on the workhorse macroeconomic projection model used by the World Bank, MFMod. This structural macroeconometric model provides a coherent framework to quantitatively account for the loss channels and indirect effects of climate shocks on the economy as a whole, based on historical trends and expected behaviors. The modeling choice was informed by the type of questions that we try to assess. Macrostructural models such as MFMod make a concerted effort to estimate the economic and behavioral determinants of economic variables, developed to be both consistent with economic theory in the long run, and observed dynamics of the economy in the short term. As a result, the speed of adjustment of each country-specific model to its economically determined long-term equilibrium is estimated to reflect the historical behavior of the economy. Macroeconometric models such as MFMod are thus particularly well fitted to reproduce the short-to-medium-term dynamics of an economy as a response to shocks, while also providing a fair level of granularity to the analysis. This contrasts with other modeling approaches, such as computed general equilibrium models, which can provide a good amount of sectoral detail but are not designed to assess the type of short-term dynamics that are relevant for this exercise.

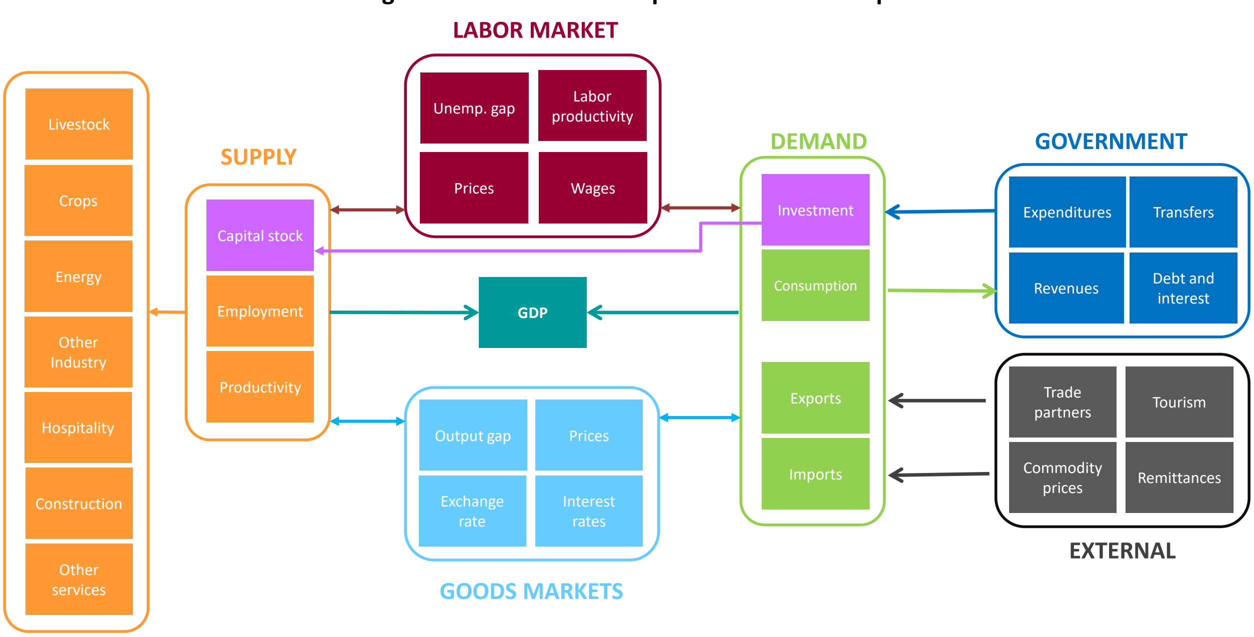
A stylized representation of the economic linkages in the MFMod fitted to the Uruguayan economy is shown in Figure 6. The modeling of GDP comprises three standard measurements. GDP from the (i) production side, (ii) expenditure side, and (iii) income side (see Burns et al. 2019 for more details). Climate shocks like droughts and flooding are modeled as impacting on the production side of the economy, which then flows through to incomes and expenditure. The standard MFMod models GDP from the production side of the economy as three sectors: agriculture, industry, and services. For the purposes of this analysis, the URY-MFMod disaggregates the production side of the economy further to allow for better analysis of the impact of climate shocks on different sectors. The agriculture sector is split into livestock (including dairy) and crops, services are split into hospitality (commerce, restaurants, and hotels), construction and other services, and industry is split into energy and all other industry.

Potential GDP, measured by the production function, is the supply potential of the economy and anchors the real side of the model. It determines how much output can be produced when all resources in the economy are fully employed (given existing distortions, technology and preferences). Potential output (Y_t^*) is a function of total factor productivity (TFP) (A_t), structural employment (N_t^*), the capital stock (K_{t-1}), and the wage share of income (α). These components are combined in a standard Cobb-Douglas production function.

$$Y_t^* = A_t N_t^{*\alpha} K_{t-1}^{1-\alpha}$$

Adjustment mechanisms in the model serve to adjust demand in line with supply over the long run. In the short run, output is driven by demand, or GDP from the expenditure side (household consumption, government consumption, and investment). Here there is consistency in the sense that shocks to final demand will affect production, but production is constrained based on its factor use and factor costs (wages and cost of capital). Factor use and factor costs together determine GDP from the income side. Labor demand, wages, and output are thus jointly determined. Labor and wage outcomes affect consumption decisions of households and these in turn affect overall prices. Prices impact the user cost of capital, which affects investment. Investment and consumption determine final demand, which then has an impact on industry output – thus closing the link.

Figure 6: URY-MFMod simplified economic map



For more information on the standard MFMod setup, see Burns *et al*. 2019.

The MFMod fitted to Uruguay is further expanded to allow for losses and damages due to climate shocks. The standard Cobb-Douglas specification is modified to account for damages from climate shocks, including: i) reductions in sectoral TFP due to droughts, and ii) the impact of flooding on capital stock.

Droughts can have a severe impact on agriculture, with insufficient rainfall leading to reduced output in the crops and livestock sectors. This is a reduction in output given the same inputs (capital and labor is unaffected), so droughts are modeled as a sector-specific productivity shock.

Floods can cause significant damage to infrastructure and other capital assets. This damage must then be repaired, diverting spending away from investment into new productive capital. Floods are therefore modeled as a shock to the capital stock of the economy, with flow-on implications for investment spending.

The next section discusses the modeling of each of these climate shocks in turn.

Livestock and agriculture yields

The modeling connects livestock and agricultural yields to climate shocks and then maps them to economic activity. To account for different productivity shocks in each sector, we construct a production function for each sector, which is modified to account for losses due to climate shocks. The agricultural damage or losses due to the drought ($d_{i,t}$) is incorporated into the model as reduced TFP, because the same amount of capital and labor produces a reduced amount of output compared to previous years.

$$Y_{i,t}^{*} = \left(1 + d_{i,t}\right) \cdot A_t \cdot {N_t^{*}}^{\alpha} \cdot K_{t-1}^{1-\alpha}$$

Output in the L&A sectors is then a function of their respective production functions. Damage or losses are allowed to have an autoregressive component, calibrated to the persistence of shocks on L&A output, as will be described later.

Capital damages from flooding

As described in in Burns, Jooste and Schwerhoff (2021), the production function is amended to account for the damaged stock of capital (DS_t). The economic impact of a unit of damaged capital is assumed to be equal to the average productivity of capital ($\frac{Y}{K}$) times the damaged capital. The level of damaged capital stock at time t is determined according to the following formula:

$$DS_t = DS_{t-1} + D_t - I_t^{REP}$$

where D_t is new damages in time t and I_t^{REP} is repairs carried out.

Capital not affected by natural disasters (K_t) grows with capital investment (I_t) less investment spending on repairs due to flooding:

$$K_t = (1-\delta)K_{t-1} + I_t - I_t^{REP}$$

In Uruguay, government investment makes up roughly 30 percent of total investment, and private investment accounts for the remainder. Given this, the assumption in Burns, Jooste and Schwerhoff (2021) that all reconstruction is undertaken by the government is relaxed. Capital repair costs are split 30-70 between the government and the private sector.

Because capital repairs can take time, and there is not always budget or resources immediately available, it is assumed that reconstruction investment (both public and private) cannot exceed 15 percent of total investment spending in that year. We assume that repairs occur instead of investment in new capital.

$$I_t^{REP} = \min\left[DS_t, 0.15 \cdot I_t\right]$$

To reflect the idea that the economic impact of damaged capital exceeds that of marginal capital, the standard potential output equation is modified to explicitly account for the higher productivity of destroyed capital (see Hallegatte & Vogt-Schilb (2016) for an in-depth treatment):

$$Y_t^* = A_t \cdot N_t^{*\alpha} \cdot K_{t-1}^{1-\alpha} - \frac{Y}{K} DS_t$$

5. Data inputs: Building from existing studies

Having set up the analytical framework, this section describes the data inputs that will be used to identify each damage channel and quantify the sectoral and aggregate impacts of climate shocks.

5.1 Agricultural yields

Data on direct losses to crop and livestock yields caused by changes in rainfall levels and seasonal timing are based on loss curves from a comprehensive disaster risk study (IDB, 2019). Figure 7 shows the direct losses expected from droughts, expressed as a function of their periodicity (i.e. how frequent a drought of a given magnitude is expected, in years), for different climate scenarios (as represented by different RCP pathways). Loss curves were adjusted to be consistent with MGAP's estimated losses in 2022/23 drought (MEF 2023) a one-in-a-hundred-year event according to Uruguay's meteorological agency (INUMET, 2023).

Droughts have historically had a significant direct impact on both livestock and agriculture. The order of magnitude of damages in the historical/baseline scenario for droughts with return periods of 50 years or less is similar for crops and livestock, i.e. increasing rapidly until around US$600 million. For larger droughts, losses increase in the case of livestock to over US$1.6 billion for return periods of 200 years, while they increase at the margin in the case of crops (Figure 7).

Climate change is expected to increase the magnitude of damages for crops. While damages for crops increase monotonically with more extreme (i.e., higher RCP) climate scenarios, livestock damages are expected to change little with respect to historical experience (Figure 7 and Figure 8). The differences can be explained by the definition of drought used in the IDB (2019) study. As is common in many studies of drought hazard, drought events are characterized using the three-month Reconnaissance Drought Index (RDI),[8] which is shown to replicate better the historical occurrence of "identified" drought events in Uruguay. This indicator tends to capture short duration agricultural droughts. A biological model of crop output and livestock pasture availability is then used to identify the loss of yield associated with drought conditions defined in this fashion. Water availability conditions that can lead to significant losses in production are different for different crops and for livestock. Short duration drought events in the summer have very negative implications for grain yields. Unlike crops, whose lifecycle covers only a few months, livestock can enter a period of compensatory growth if drought conditions reverse, which can partially make up for single acute drought losses. The climate model underlying IDB (2019) projects an increased occurrence of droughts during the summer months when rainfall is crucial for grain yields, but does not anticipate significant alterations in average precipitation patterns across various climate scenarios. Caution is, in any event, required to interpret these results, given the uncertainties in the projection of future precipitation patterns discussed in a previous section.

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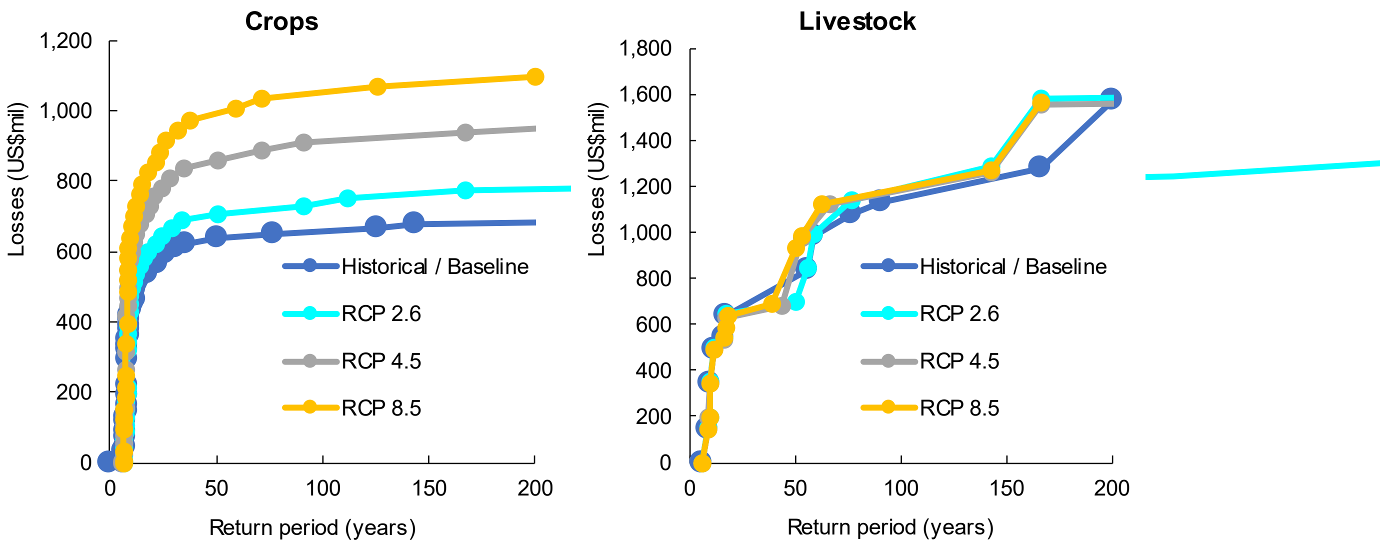
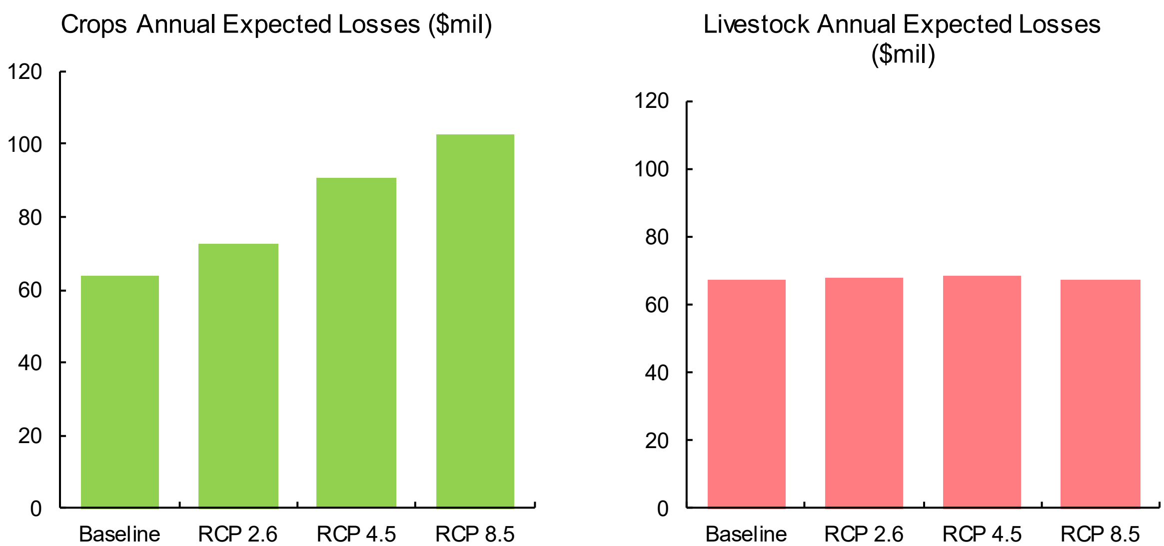
[8] Droughts are defined as events where the normalized 3 month SDI is below -1.

Figure 7: Drought return periods and losses for Uruguay under different warming scenarios (based on 2023 sector values)



Source: World Bank estimates based on IDB (2019), MEF (2023), and INUMET (2023).

Figure 8: Expected annual losses under different warming scenarios (based on 2023 sector values)

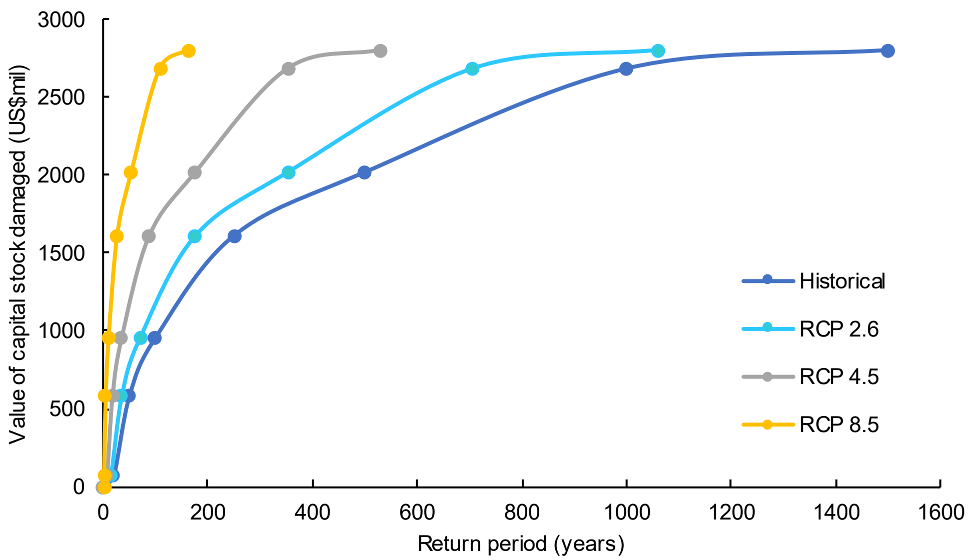


Source: World Bank estimates based on IADB (2019), MEF (2023), and INUMET (2023).

5.2 Flooding

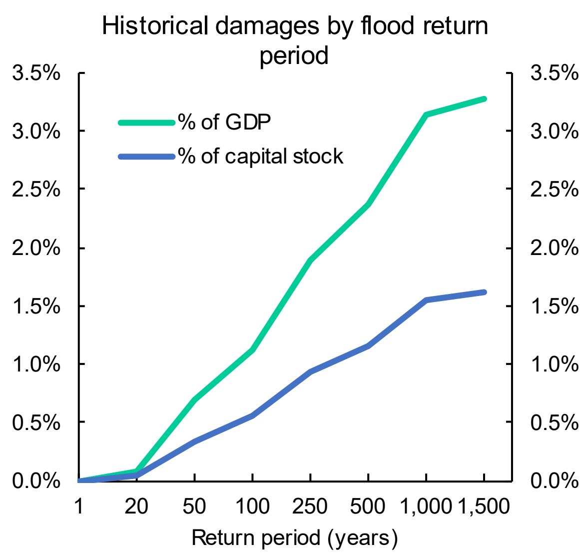
Data on damages from flooding and flooding frequency are taken from UNDRR 2015 (the GAR15 dataset). Capital stock in Uruguay that is exposed to flooding has a value of US$116 billion (2015 prices), or roughly twice the value of GDP. Uruguay has historically experienced moderate floods, with a 1 in 50-year flood destroying US$642 million worth of assets (2015 prices). This is the equivalent of 0.34 percent of capital stock exposed to flooding, or 0.68 percent of GDP. Every year, with no further climate change, there is a 2 percent chance that a 1 in 50-year flood will occur. As suggested in Myhre et al. 2019, it is assumed that the frequency or probability of floods of any given size doubles with every degree increase in temperature. This means that floods of a certain size (or expected damages to the capital stock) will have shorter return periods as temperatures rise (Figure 9). These short return periods and higher probabilities of flooding can be translated to expected damages from increased inland flooding due to climate change (Figure 10).

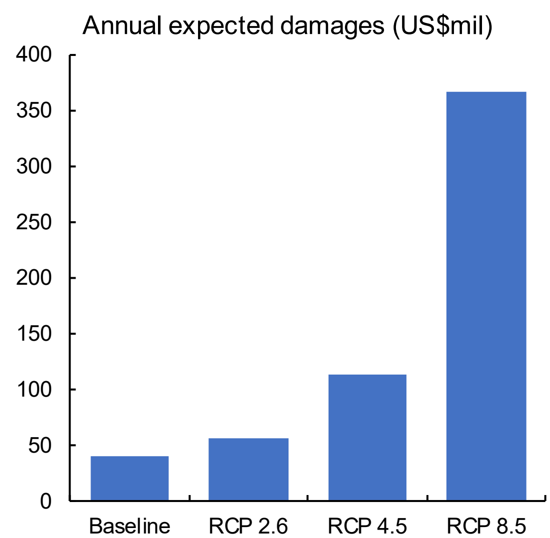
Figure 9: Flood return periods and damages for Uruguay under different warming scenarios



Source: UNDRR 2015 dataset and World Bank calculations.
Note: 2023 US$ millions.

Figure 10: Uruguay historical flood damages and expected flood damages under climate change





Source: UNDRR 2015 dataset and World Bank calculations.
Note: Based on economic values in 2023.

6. The macroeconomic impact of climate shocks in Uruguay

6.1 Droughts

Droughts can have a significant and long-lasting impact on the livestock and crops sectors, particularly in regions where agriculture is a primary source of income and food supply. The recovery time for each sector can vary depending on a range of factors, including the severity and duration of the drought, the availability of resources, and the resilience of the local ecosystem. In some cases, recovery can take several years or even decades, particularly in regions where the land has been severely degraded or where farmers have lost significant amounts of livestock. In other cases, recovery can be relatively quick, particularly if farmers have access to resources and technologies that can help them manage the effects of drought. However, it is important to note that even after the immediate effects of drought have been mitigated, the long-term effects can linger, affecting the productivity and profitability of the sector for years to come.

Direct and indirect second-round effects on other sectors along the value chain and through general equilibrium effects are also sizeable. The crops sector is a large contributor to intermediate inputs into production in other sectors of the economy (goods from one industry that are used in the production process of another industry). Of total crops outputs, 10 percent are intermediate inputs into the livestock sector (for e.g., feed crops) and around 25 percent are intermediate inputs into the industry sector which includes food manufacturing (Table 1). Similarly, of total livestock production, 77 percent of output is an intermediate input into the industry sector, mostly into food manufacturing, but also hides and leather products. L&A raw outputs are not large inputs into the services sectors – partly because hospitality (which includes restaurants and cafes) is a small portion of total services, but also because the hospitality sector is more likely to use *transformed* livestock and agriculture products from the manufacturing sector rather than the raw outputs. Through their intermediate inputs into manufacturing and raw commodity exports, agriculture and livestock represent a sizeable part of the Uruguayan economy. Given this, and the second-round importance of food manufacturing and its downstream industries and exports, the macroeconomic impact of droughts exceeds the direct impact of L&A over GDP.

Table 1: Selected IO shares for Crops and Livestock industries

	Share of outputs to other sectors (as intermediate inputs)				Share of outputs to final demand	
	Crops	**Livestock**	**Industry**	**Services**	**Household consumption**	**Exports**
Crops	22%	10%	25%	1%	13%	21%
Livestock	0%	5%	77%	0%	4%	9%
Industry	2%	2%	16%	19%	22%	35%

Source: BCU 2016

We first perform two quantitative exercises to assess the macroeconomic impact of droughts. First, we analyze the effects of a single drought event to illustrate the staggered direct impacts on L&A and the magnitude of the overall impact on relevant macroeconomic variables and their recovery dynamics. We also assess the distributional implications of such a shock. Second, we run 1,000 stochastic simulations out to year 2100, drawing from a distribution of droughts consistent with the loss curves presented on Figure 7. This illustrates probabilistic paths for an economy subject to climate shocks alone against a baseline of no climate shocks, and how that could change under different climate scenarios.

Impact of a single 2022/2023-sized drought[9]

For a single drought event, the impact on the livestock sector is less acute than in the agriculture sector, but more persistent. Crops have a shorter production cycle than livestock. They can typically be planted, grown, and harvested within a few months to a year, whereas livestock, particularly beef cattle, require several years to reach maturity. This means that the impact of drought on some crops may be felt more acutely in the short term, but the recovery period can also be shorter. Furthermore, crops can be replanted more easily than livestock can be replaced. If crops are lost due to drought, farmers can often replant the same or different crops in the same field in the next growing season. In contrast, if livestock are lost due to drought, farmers may need to invest significant time and resources into rebuilding their herds, which can take years.

The first exercise describes the impulse-response functions for selected macroeconomic variables of a one-in-a-hundred-year drought such as the 2022/23 drought. The cumulative impact of this drought on the L&A sector is calibrated to US$1,800 million, which is the estimated direct losses from the current drought in Uruguay. Using public data by MGAP, we assume that 42 percent of these damages are materialized in the crops sector, with the remainder coming from the livestock sector. These losses are spread over three years (with most of the impact occurring in the first year) to account for the persistent effects of the drought, particularly in the livestock sector. For the crops sector, 87 percent of the losses are realized in year one of the drought, and the remaining 13 percent are realized in the subsequent year. For livestock, 60 percent of the losses are realized in year 1, with 30 percent and 10 percent realized in years two and three respectively. These dynamics are driven by econometrically estimated "speed of adjustment" parameters that determine the recovery speed of each industry in the model following a drought shock.

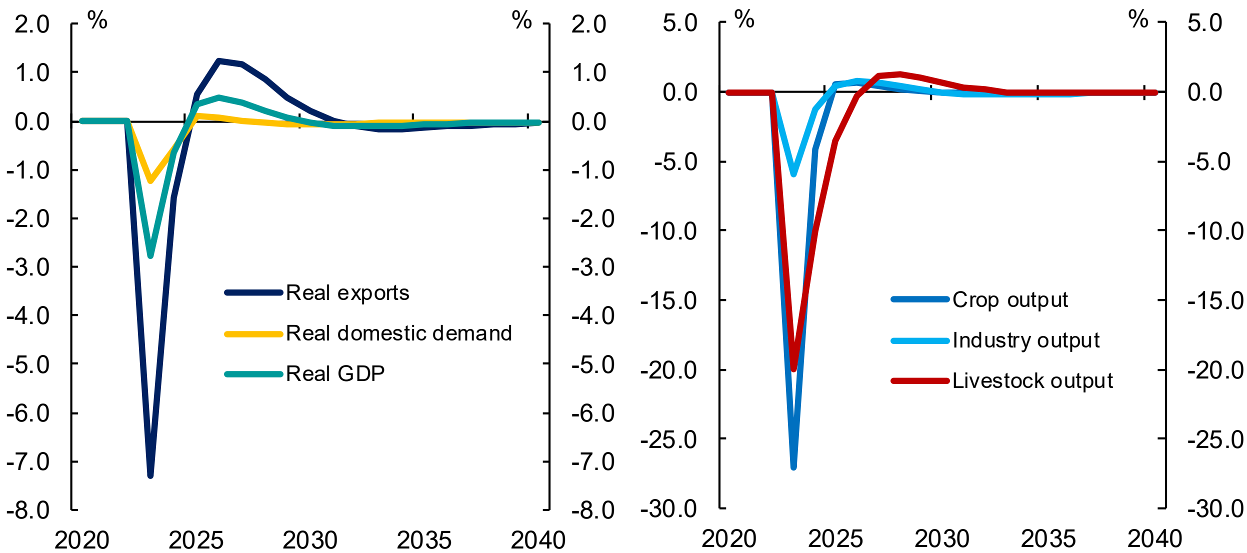
Overall, the accumulated direct impact on the livestock sector is larger than on the crops sector. Roughly 58 percent of the damages from this drought are expected to occur in the livestock sector, which contracts by 20 percent during the year of the drought (Figure 11b). In year two, the livestock sector remains 9.9 percent below baseline output, and in year three it is 3.5 percent below baseline. It is only by year four after the shock that the livestock sector has fully recovered from the drought. The impacts on the crops sector are a smaller proportion of total losses (42 percent of total damages to agriculture) but the impact is more concentrated in the year in which the drought occurs. Crop yields contract by 27 percent in the first year, and then rebound to 4.1 percent below the baseline in the second year after the drought. The industry sector, which includes the manufacturing of crop and livestock related products is also impacted, both by higher livestock and crop output prices, and by a reduction in the availability of these intermediate inputs into production. Industrial output shrinks 5.9 percent in the first year of the shock and is still 1.1 percent lower in the second year. By the third year after the shock, both crops and industrial output recover to baseline output volumes.

On impact, GDP is expected to contract 2.8 percent, while exports are expected to fall 7.3 percent. That implies a US$2.2 billion in loss of economic activity in the year the drought, and a US$440 million loss the following year, against a baseline of no drought. By the third year, output has recovered to slightly above its usual levels. The 7.3 fall in exports on impact is followed by a recovery in the following year, but still

[9] For ease of comparison, Annex A presents a summary table of results for the different exercises run in this paper.

1.6 percent lower than usual levels. Exports only recover to above the baseline level only three years after the drought, reflecting positive effects of the exchange rate depreciation on export demand. (Figure 11a).

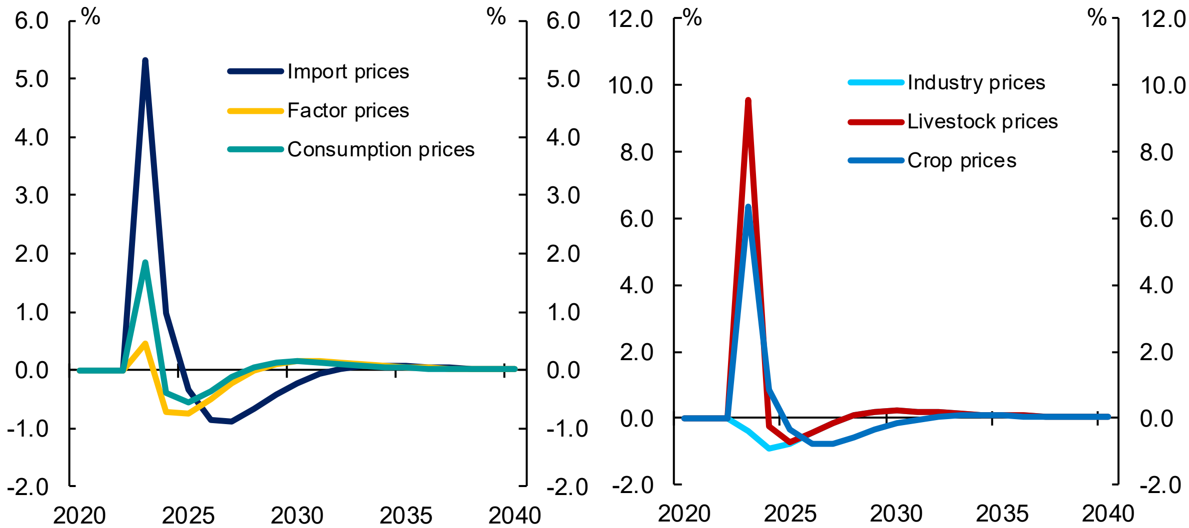
Figure 11: Drought scenario – Demand and sectoral output impacts



Source: World Bank analysis.
Note: Percent deviation from baseline

As agricultural production and exports decline, the exchange rate depreciates, fueling an increase in import prices (Figure 12). The nominal exchange rate depreciates 5.4 percent on impact, which translates into higher import prices. For livestock, the negative productivity shock leads to a 9.6 percent increase in prices. Agricultural prices are modeled separately for crops and non-traded agricultural products, which make up 80 and 20 percent of total crop production respectively. Non-traded agricultural prices increase by 8.6 percent, while crop prices, which follow world market prices, move in tandem with the exchange rate. Overall, agricultural prices increase by 6.3 percent. Since raw agricultural products and manufactured food products make up around 10 percent of household consumption in Uruguay, higher agricultural prices as a result of the drought combined with higher import prices leads to an increase in consumer prices of 1.7 percent. Prices then fall in the next year in response to the negative output gap, higher unemployment rate, and lower wages.

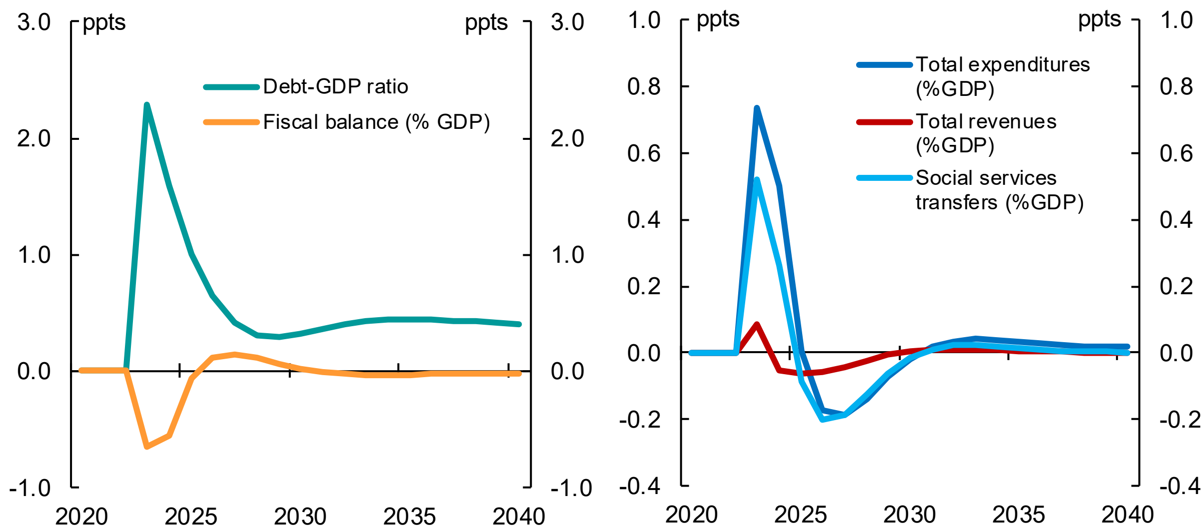
Figure 12: Drought scenario – Prices response



Source: World Bank analysis.
Note: Percent deviation from baseline. Exchange rate defined as Uruguayan Pesos per USD.

As output and exports contract, fiscal and external accounts deteriorate. Government revenues fall as a direct result of the deterioration in economic activity, partially offset by the price increase. Spending on social security payments increases by 5.6 percent (its share of GDP increases by 0.5 percentage points), which coupled with the assumption of fixed nominal spending in other expenditure categories results in a worsening of the fiscal balance by 0.7 percentage points of GDP. This leads to increased government borrowing, which raises the level of government debt (Figure 13). Combined with balance sheet effects due to the depreciation of the currency (Figure 14) and with a lower level of GDP in the year of the drought, this increases the debt-to-GDP ratio by 2.4 percentage points. As the economy recovers from the drought, a period of stronger economic growth and a return to normal levels of government revenue allows the debt-to-GDP ratio to stabilize at around 0.4 percentage points above its baseline levels. The debt-to-GDP ratio is permanently higher due to the increased value of USD denominated debt accrued during the period of the drought.

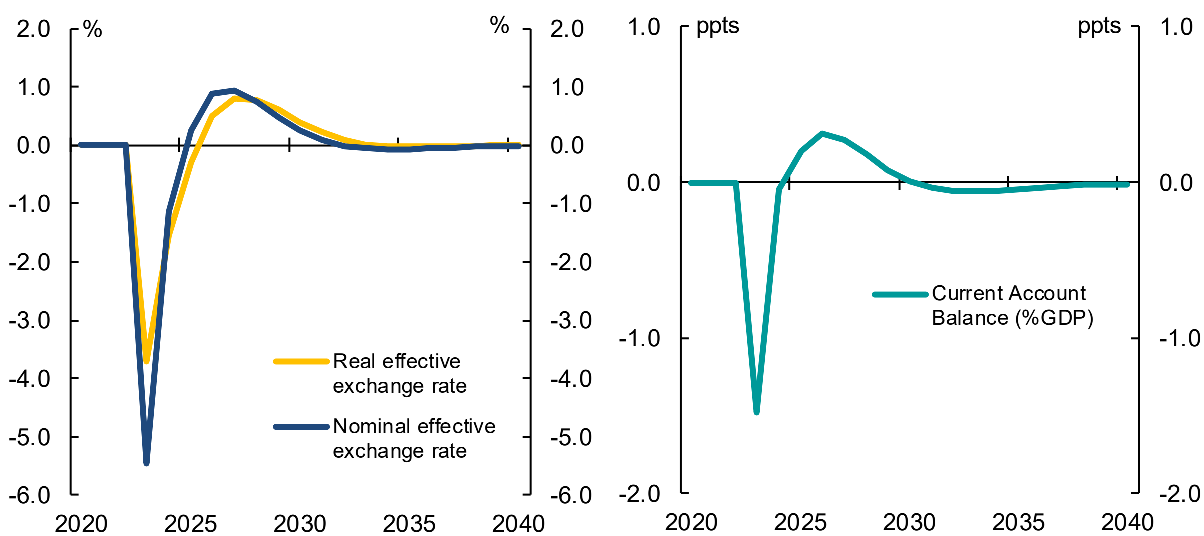
Figure 13: Drought scenario - Fiscal Accounts



Source: World Bank analysis.
Note: Percentage point deviation from baseline shown

External accounts deteriorate due to the fall in exports and the increase in (nominal) imports, as the exchange rate depreciation raises import prices by more than the reduction in import demand due to lower economic activity (Figure 14).

Figure 14: Drought scenario – Current Account



Source: World Bank analysis.
Note: Percent deviation from baseline shown for exchange rates, with a fall indicating a depreciation. Percentage point deviation from baseline shown for the Current Account Balance.

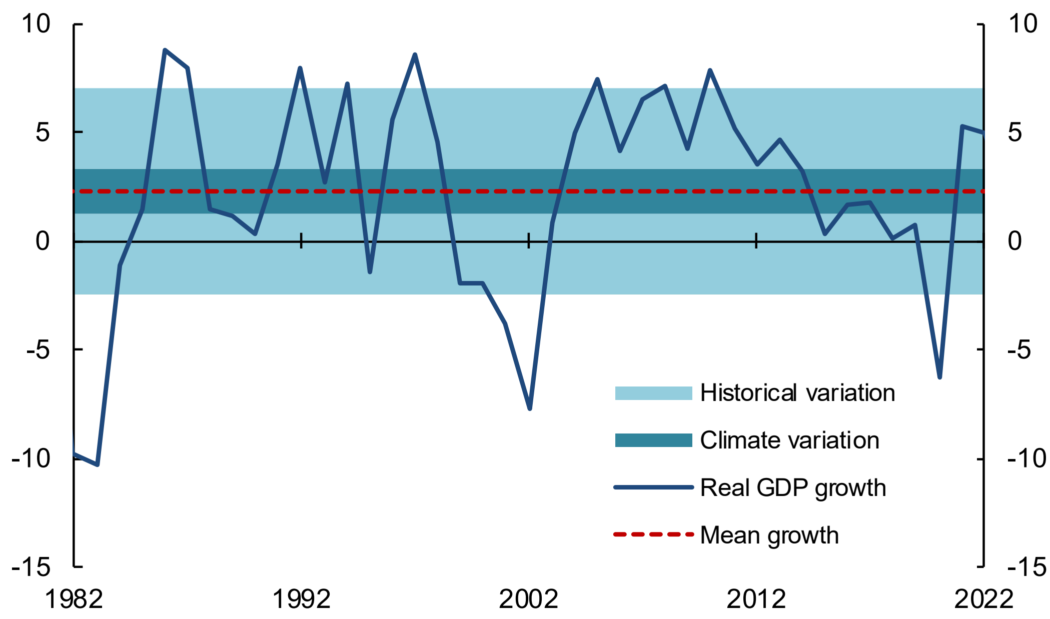
Poverty and vulnerability indicators increase with the drought, and remain above the baseline scenario after six years. Poverty measured by the international upper middle-income line of US$6.85 per day at purchasing power parity (PPP) increases 0.5 percentage points in the year of the shock. Poverty would still be 0.3 percentage points higher than in the baseline scenario in the projected horizon due to attrition. The new trend would be similar to the baseline, but at a higher level. Vulnerability, defined as not poor but living on less than US$14 per day PPP, follows a similar path, increasing on impact 0.5 percentage points and 0.3 percentage points higher in the projected horizon. The increase in poverty and vulnerability is to the expense of the middle class, which falls 0.8 percentage points and is still 0.5 percentage points below the baseline in the projected horizon. That is, without additional mitigation policies, a temporary shock can have protracted effects on the evolution of poverty and inequality.

An economy subject to stochastic drought shocks

The second exercise shocks the economy with stochastic droughts to understand their role on aggregate macro volatility and simulate their dynamic effects on selected macro variables. The baseline simulation uses the historical risk curves presented in Figure 7. That is, it responds to the following question: how would an otherwise stable Uruguayan economy behave if it was only subject to drought shocks of the same frequency and magnitude as in the past?

The volatility of a simulated Uruguayan economy only subject to drought shocks is 22 percent of observed GDP volatility in Uruguay (Figure 15).[10] Economic growth in Uruguay over the past 40 years has generally ranged from -10 to +9 per growth per year, with a mean real growth rate of 2.3 percent for the sample 1980 – 2019. The historical standard deviation of economic growth is quite large, at 4.7 percent. On the other hand, the growth rate of the simulated Uruguayan economy only subject to drought shocks fluctuates 95 percent of the time between -0.7 percent and 3.4 percent, with a standard deviation of 1 percent.

Figure 15: Uruguay real GDP growth and historical variance



Source: WBG databases and analysis

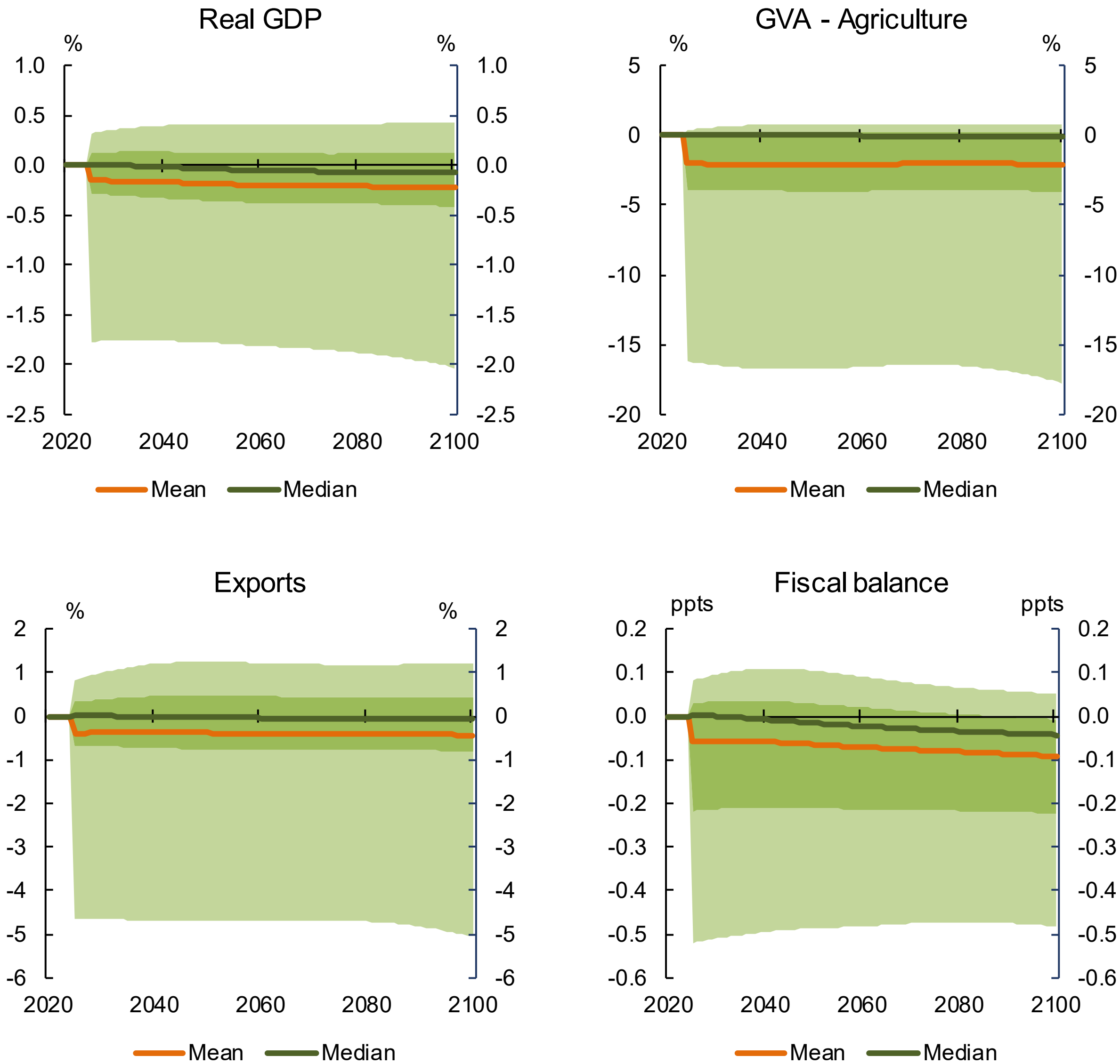
[10] The volatility of a simulated economy with climate shocks (droughts and floods) is also 22 percent of historical volatility.

Droughts occurring at historical rates lower annual GDP on average by 0.2 percent, but once every 40 years (or 2.5 percent of the time) GDP losses exceed 2 percent (Figure 16).[11] This is based on 1,000 stochastic simulations that incorporate the cumulative impacts of droughts. This lowers the overall productive capacity of the economy over time, and median real GDP from these simulations further reduced relative to the baseline as a result. Lower annual GDP is driven by L&A value-added falling on average by 2.1 percent, but falling more than 17 percent every 40 years. This translates into exports falling on average by 0.5 percent, and over 5 percent every 40 years. Lower output and export revenues impact fiscal accounts, which fall by 0.1 percentage points on average and by 0.5 percentage points of GDP every 40 years.

Losses are expected to worsen going forward as a result of climate change. Running the same analysis with risk curves for the RCP 4.5 climate scenario produces similar median results but increases the lower bounds on economic outcomes. Figure 17 shows that the lower bound of the 95 percent confidence interval for real GDP falls between 0.3 and 0.4 percentage points from the original. Given that in the baseline scenario the lower bound was -2.1 percent, that represents a 14 to 19 percent increase in potential climate damages to GDP in the RCP 4.5 scenario. Likewise, the impact of climate change on the agriculture industry has potential climate damages increasing from -17 percent by 4 percentage points, or by around 23 percent.

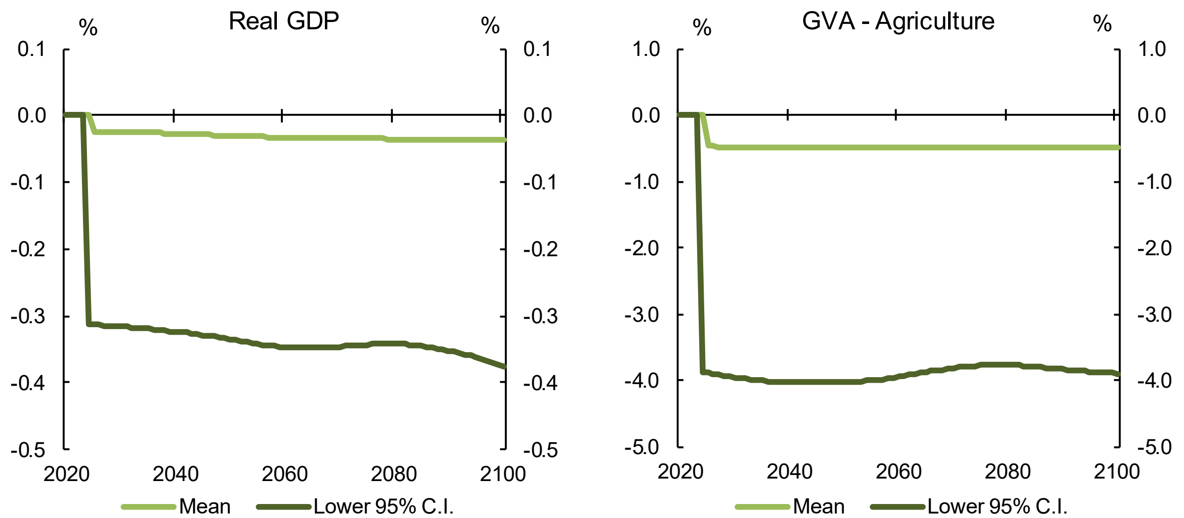
[11] Light-green shaded areas in Figure *16* show percentiles 2.5 and 97.5. That is, 2.5 percent of the time (or once every 40 years) observations lie above the upper-bound of the light-green shaded area, and 2.5 percent of the time observations lie below the lower-bound of the light-green shaded area.

Figure 16: Macroeconomic impacts from ongoing historical drought shocks



Note: Confidence intervals of 68 percent (dark green) and 95 percent (light green) are shown.

Figure 17: Difference in mean outcome between historical and RCP 4.5 drought shock simulations

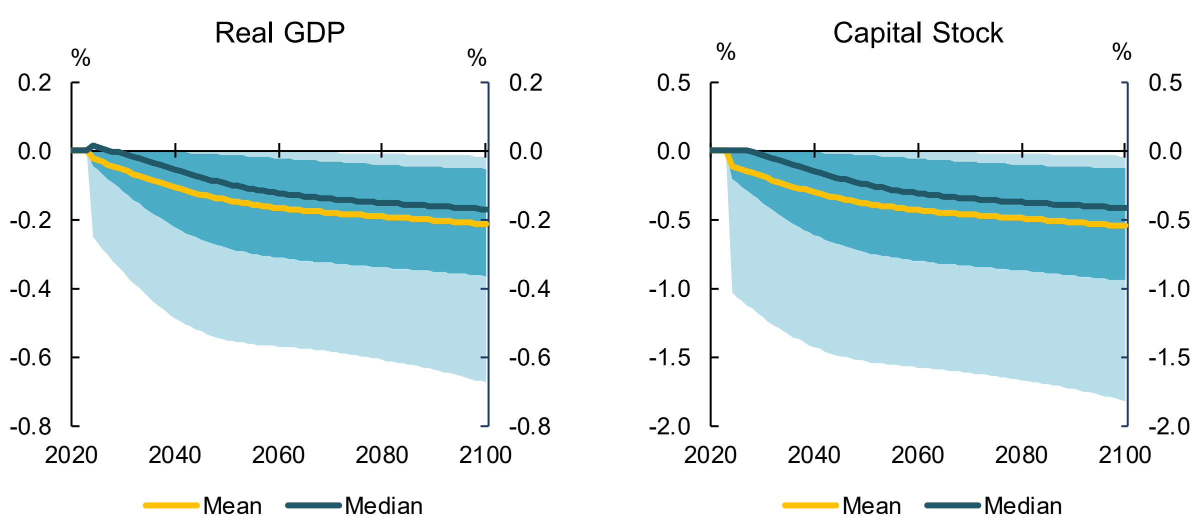


Note: Change in the mean outcome (light green) and the lower bound of the 95 percent confidence interval (dark green) are shown.

6.2 Floods

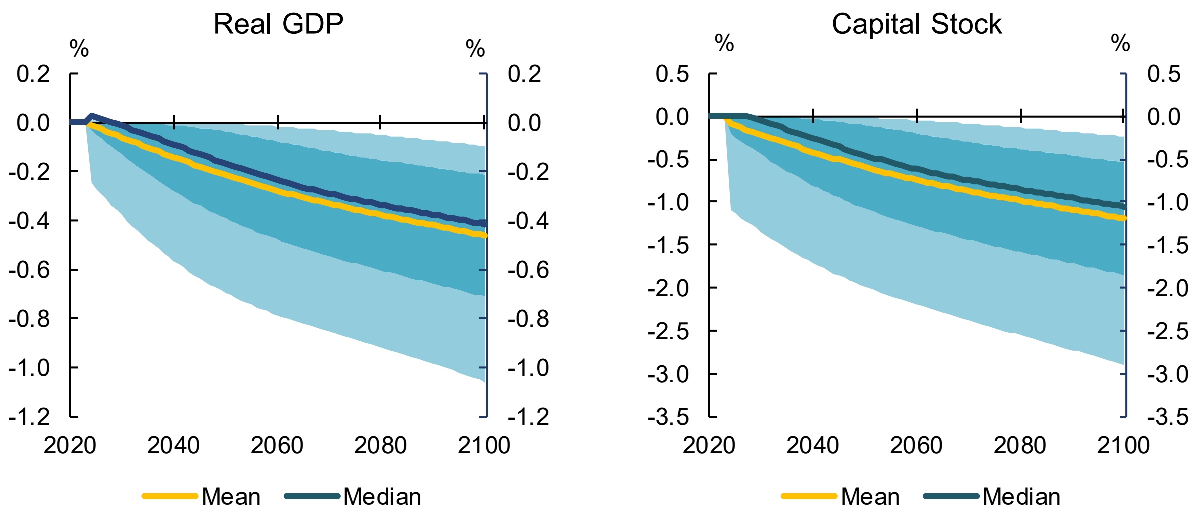
If flooding continues at historical rates, the cumulative impact on GDP would reach over -0.2 percent on average by 2100 (Figure 18). Capital stock would be depleted by 0.5 percent on average, with investment levels reduced in the economy due repeated flooding diverting funds to repairs. These impacts, while having roughly the same average impact as droughts on GDP by 2100, have smaller confidence intervals, with the lower bound outcome resulting in -0.6 percent lower GDP. Under climate change, flooding shocks become more frequent, with their frequency doubling for every degree Celsius of temperature increase. Under this scenario, the mean impact on GDP increases to over -0.4 percent by 2100, and capital stock is reduced over 1.2 percent with the same frequency by 2100. (Figure 19).

Figure 18: Historical / baseline impacts of flooding



Note: Results are presented as percent deviations from baseline. Confidence intervals of 68 percent (dark blue) and 95 percent (light blue) are shown.

Figure 19: Flooding - Macroeconomic impacts under the RCP 4.5 scenario



Note: Results are presented as percent deviations from baseline. Confidence intervals of 68 percent (dark blue) and 95 percent (light blue) are shown.

6.3 Compound climate and macroeconomic shocks[12]

Climate shocks do not occur in a vacuum; economies are continuously subject to a number of exogenous macroeconomic shocks of varying frequencies and intensities. Exogenous macroeconomic shocks are events that originate outside an economy but can have significant effects on the evolution of relevant aggregate variables. Many of such shocks, for good reasons, are a staple in macroeconomic projection sensitivities, risk analyses and stress tests. Four main types of exogenous macroeconomic shock are considered for this analysis:

Shocks to the US Interest Rate: Uruguay, like many other economies, may be affected by changes in the US interest rate. A higher US interest rate can lead to higher borrowing costs for the Uruguayan government. This can result in increased interest payments, potentially straining the country's fiscal position and limiting the availability of funds for other government expenditures.

Export Prices: Since Uruguay heavily relies on exporting agricultural commodities, a decline in global commodity prices can adversely affect its export revenue. This can lead to lower foreign exchange earnings, reduced export-led growth, and potential trade imbalances.

Import Prices: Changes in import prices can affect inflationary pressures within Uruguay and affect external accounts. If import prices rise due to exogenous shocks, it can lead to higher input costs for domestic producers, potentially resulting in increased consumer prices. This can impact domestic consumption and the overall cost of living. External accounts can deteriorate and put pressure on the exchange rate.

[12] We have presented the effects of stochastic drought shocks and the effects of stochastic flood shocks. Results for the combined effect of drought and flood shocks are omitted here for ease of exposition, but are listed as 'combined climate shocks' in Annex A.

Export Market Growth: Exogenous shocks that affect export market growth, such as economic downturns or geopolitical events in key trading partners, can significantly impact Uruguay's economy. If export markets experience a decline in economic growth, demand for Uruguayan exports may decrease. This can lead to lower export volumes, revenue, and potential job losses in export-oriented sectors.

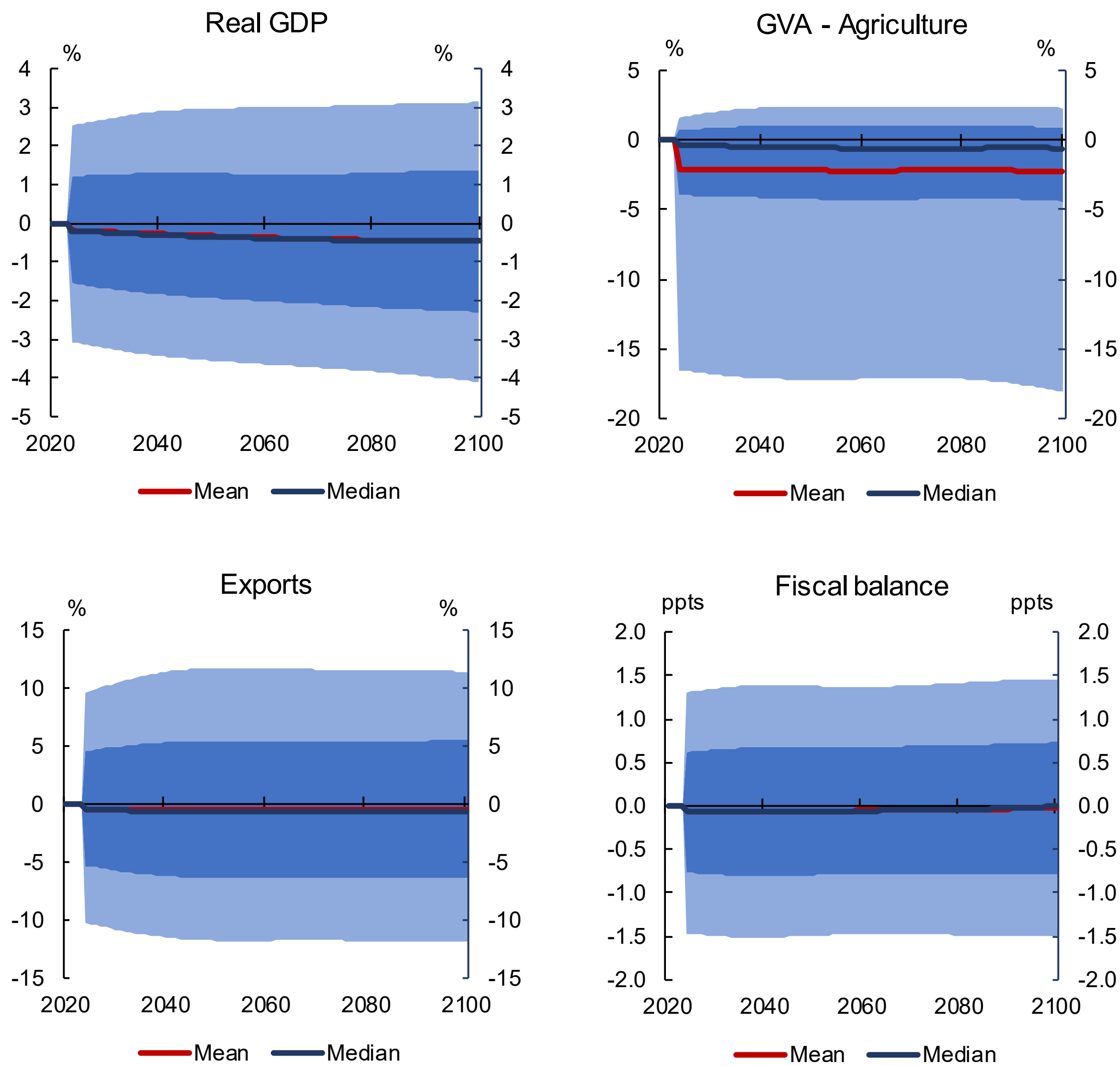
This exercise jointly simulates climate and macroeconomic shocks for a more comprehensive assessment of macroeconomic risks. While the previous exercises are useful to understand the orders of magnitude of the second-round effects of climate shocks, their persistence, and to better illustrate their transmission channels, this exercise complements them by taking into account the fact that: i) the negative impact of climate shocks can be buffered by offsetting positive macroeconomic shocks, such as low international interest rates, a spike in export prices, or strong external demand for Uruguayan products; and ii) the negative impact of climate shocks can be compound by negative macroeconomic shocks. The latter case is of most interest from a macroeconomic and fiscal risk management perspective. As with the climate shocks, 1,000 stochastic simulations are run using the historical distribution of these exogenous shocks to project potential pathways for the Uruguayan economy. These are combined with drought and flood shocks to illustrate how much additional volatility macroeconomic and climate shocks can generate in the economy when they occur concurrently.[13]

The economic impact of droughts and floods is exacerbated by the added economic volatility of exogenous macroeconomic shocks. This is reflected in the wider range of outcomes experienced by the simulated Uruguayan economy. For example, if a drought occurs jointly with a fall in agricultural commodity prices and an increase in US interest rates, this will have a compounded impact on economic activity, incomes, and the government's fiscal position. The median GDP outcome is still negative, with a larger downside risk to the agriculture sector than previously estimated (Figure 20). The combined impact of climate and macroeconomic shocks occurring at historical rates is estimated to lower annual GDP on average by 0.5 percent (compared to 0.4 percent when exogenous macroeconomic shocks are not incorporated), and downside risks roughly double, demonstrating the compounding effect of multiple shocks occurring at once. Lower annual GDP is driven by agricultural value-added falling on average by 2.3 percent.

External and fiscal accounts are also subject to larger swings as a result. The range of possible outcomes roughly double with respect to the climate shock scenarios. The fiscal balance can deteriorate around 0.8 percentage points of GDP in the face of a combination of negative shocks of the type that occur roughly once every six years. Negative combined shocks that occur once every forty years worsen fiscal accounts 1.5 percentage points of GDP. Compound negative shocks affect exports between 6 and 12 percent of GDP for the periodic shocks described above, respectively.

[13] The simulated shocks are obtained from a Vector Autoregression model with 1 lag on the deviations from the Hodrick-Prescott trend of international interest rates (in levels), export prices, import prices and external markets´ demand (all in logs). The VAR is estimated using annual data from 1995 to 2022. Simulated shocks are obtained assuming all variables are normally distributed.

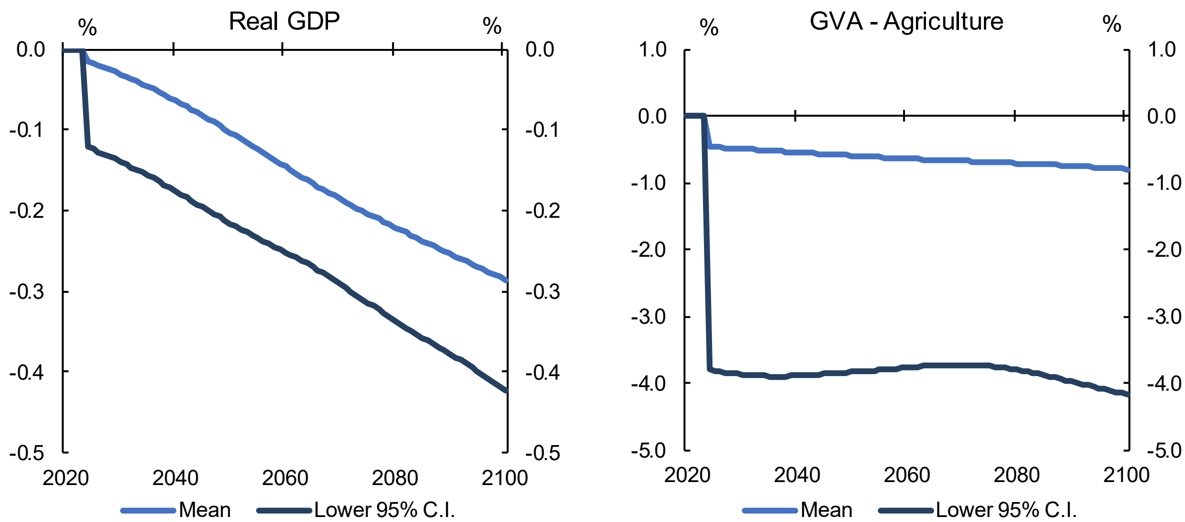
Figure 20: Impacts of combined historical macroeconomic and historical climate shocks



Note: Results are presented as percent deviations from baseline. Confidence intervals of 68 percent (dark blue) and 95 percent (light blue) are shown.

Climate change is expected to worsen aggregate outcomes further taking into account compound climate and macroeconomic shocks. Running the same analysis as above with risk curves for the RCP 4.5 climate scenario and historical macroeconomic shocks, the average losses in L&A increase, from -2.2 percent to -3.1 percent. At the same time, repeated floods damage the capital stock, and divert money from investment into new capital. As a result, real GDP is estimated to be on average around 0.3 percentage points lower than in the historical scenario by 2100 due to climate change and macroeconomic shock combined effects (Figure 21).

Figure 21: Difference between historical and RCP 4.5 climate shock simulations with macro shocks



Note: Change in the mean outcome (light blue) and the lower bound of the 95 percent confidence interval (dark blue) are shown.

7. Afterword

This work contributes to understanding the macro-critical effects of climate shocks in Uruguay. In doing so, it brings in elements that can be overlooked in standard macroeconomic assessments, which could be replicated in other emerging economies where climate shocks have relevant aggregate implications. It shows that climate shocks in Uruguay matter from a macroeconomic and fiscal perspective.

The magnitude of the effects are consistent with estimates of the direct impact of droughts in Uruguay, but larger than what is found in cross-country studies. While cross-country studies do find a link between water deficits and GDP growth (see for example Zaveri et al. (2023) or Kalkuhl and Wenz (2020)), their estimated impacts are milder. There are a few reasons behind these differences. First, the temporal definition of a drought. Cross-country studies typically identify droughts at an annual frequency: there is a drought if the average annual rainfall is below a certain threshold. This hides the fact that intra-annual patterns are of first-order importance to determine agricultural yields. In Uruguay, low summer precipitations ruin soybean and maize yields, no matter how much it rains over the winter or spring. This study, building on IDB (2019), uses a three-month drought index instead. Second, this study complements precipitation data with temperature data to account for evapotranspiration, which jointly correlates with agricultural yields. Third, this study uses a bottom-up approach following IDB (2019) and MEF (2023). That is, it builds from estimated impacts at the micro level, to then account for indirect impacts and general equilibrium effects. Finally, cross-country studies find average effects across countries that have different structural characteristics and, as such, for which the effect of droughts may vary significantly. This study is instead intended to capture Uruguay's specificities.

The analysis in this paper supports broad policy messages around Uruguay's development agenda. Climate shocks on average lower GDP, but most importantly add significant uncertainty to economic outcomes, compounded by other macroeconomic shocks, increasing the likelihood of bad years from a macro and fiscal perspective. This stresses the importance of institutional arrangements that help countries reduce uncertainty and cope with shocks. It also highlights the benefits of diversifying the country's economic structure and promoting adaptation investments that help build resilience to shocks.

Uruguay has made important strides in this regard in recent years. The structural fiscal rule instituted in 2020, complemented with the establishment of an autonomous Advisory Fiscal Committee, is a relevant step to strengthen the macroeconomic framework to help build buffers in good times while at the same time allowing for policy flexibility to respond to negative shocks. The modernization of the country's inflation targeting regime, more aligned to international best practices, also makes the macroeconomic policy framework both more flexible and robust. The issuance of a Sustainability-Linked Bond in 2022 tied to climate-related targets, and the approval of a Development Policy Loan with the World Bank in 2023 where the interest rate is also linked to the achievement of climate-related goals, are examples of innovative institutional arrangements with the potential both to improve the fiscal framework and promote climate action. Other measures, such as the regular publication of fiscal risk assessments that explicitly account for climate shocks, could help reinforce this agenda. The expected impact of climate change on climate shocks only makes these recommendations more relevant. And more urgent.

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Annex A. Summary of results

Droughts: single 2022/23 case, lowest point in scenario	
Real GDP	-2.8%
Real Exports	-7.3%
Livestock output	-20.0%
Crops output	-27.1%
Industry output	-5.9%
Fiscal Balance	-0.6ppts

Historical climate events

	Stochastic drought shocks at 2100		Stochastic flood shocks at 2100		Stochastic compound climate shocks at 2100		Stochastic macro + climate shocks at 2100	
	Mean outcome	1-in-40 year outcome	Mean outcome	1-in-40 year outcome	Mean outcome	1-in-40 year outcome	Mean outcome	1-in-40 year outcome
Real GDP	-0.2%	-2.0%	-0.2%	-0.7%	-0.4%	-2.3%	-0.5%	-4.1%
Real Exports	-0.4%	-5.1%	-0.2%	-0.8%	-0.7%	-5.3%	-0.4%	-11.9%
Livestock output	-1.9%	-16.4%	-0.3%	-1.0%	-2.2%	-16.7%	-1.9%	-16.5%
Crops output	-2.4%	-20.9%	-0.2%	-0.7%	-2.6%	-21.1%	-2.7%	-21.2%
Fiscal Balance	-0.1%	-0.5%	0.0%	-0.1%	-0.1%	-0.5%	0.0%	-1.5%

RCP 4.5 climate events

	Stochastic drought shocks		Stochastic flood shocks at		Stochastic compound		Stochastic macro + climate	
	Mean outcome	1-in-40 year outcome	Mean outcome	1-in-40 year outcome	Mean outcome	1-in-40 year outcome	Mean outcome	1-in-40 year outcome
Real GDP	-0.3%	-2.4%	-0.5%	-1.1%	-0.7%	-2.9%	-0.8%	-4.5%
Real Exports	-0.5%	-6.1%	-0.5%	-1.2%	-1.1%	-6.6%	-0.8%	-12.5%
Livestock output	-2.0%	-16.8%	-0.7%	-1.6%	-2.6%	-17.3%	-2.2%	-17.2%
Crops output	-3.4%	-28.7%	-0.5%	-1.1%	-3.9%	-29.0%	-4.0%	-29.1%
Fiscal Balance	-0.1%	-0.6%	-0.1%	-0.1%	-0.2%	-0.6%	-0.1%	-1.6%

RCP 8.5 climate events

	Stochastic drought shocks		Stochastic flood shocks at		Stochastic compound		Stochastic macro + climate	
	Mean outcome	1-in-40 year outcome	Mean outcome	1-in-40 year outcome	Mean outcome	1-in-40 year outcome	Mean outcome	1-in-40 year outcome
Real GDP	-0.3%	-2.6%	-1.2%	-2.1%	-1.5%	-4.0%	-1.5%	-5.4%
Real Exports	-0.6%	-6.8%	-1.4%	-2.4%	-2.0%	-8.1%	-1.7%	-13.6%
Livestock output	-1.9%	-17.1%	-1.8%	-3.1%	-3.7%	-18.4%	-3.3%	-18.2%
Crops output	-3.9%	-33.4%	-1.3%	-2.3%	-5.1%	-34.3%	-5.2%	-34.3%
Fiscal Balance	-0.1%	-0.6%	-0.1%	-0.2%	-0.2%	-0.8%	-0.1%	-1.7%

Technical Appendix

This technical appendix will describe the modeling of sectors in CC-URYMod. This is an expansion on both the standard MFMod approach, described in Burns et al (2019), and the standard climate change version of the model described in Burns, Jooste and Schwerhoff (2021).

As described in the main paper, there are seven sectors on the supply side of the model: crops, livestock (including dairy), electricity production, other industry, hospitality (commerce, restaurants, and hotels), construction, and other services. In the standard version of the model, each sector is derived from final demand and connected using IO tables.

In the standard climate change version of the model, intersectoral change is not adequately accounted for. For example, a drought shock would impact on production in the whole economy, but not specifically on the agriculture sectors, or those sectors which use agricultural products as inputs to production (such as other industry). It would also impact on aggregate factor prices, but not sectoral prices. These sector specific impacts are important to capture for Uruguay, and the modeling approach to do this is described below.

Sectoral output

Aggregate sectoral output (output at factor costs or Y_t^{FCST}) is determined by demand and is defined as market price GDP (Y_t^{MKTP}) less net indirect taxes (NIT_t):

$$Y_t^{FCST} = Y_t^{MKTP} - NIT_t$$

For *crops* and *livestock*, the long run is anchored using sectoral potential output ($Y_t^{i,*}$), reflecting that these industries are supply-driven:

$$Y_t^{i,*} = \left(1 - d_t^i\right) A_t N_t^{\sigma} K_{t-1}^{1-\sigma}$$

Potential output includes an industry-specific damage function (d_t^i) to allow for climate shocks to productivity in these sectors.

Actual output for these sectors is modeled using an error correction model (“ECM”) and will converge to potential in the long run. In the short run, changes in relative prices will impact on output decisions as well.

$$\Delta \ln\left(Y_t^i\right) = \alpha_i + \theta_i\left[\ln\left(Y_{t-1}^i\right) - \ln\left(Y_{t-1}^{i,*}\right)\right] + \lambda_i \Delta \ln\left(Y_{t-1}^i\right) + (1-\lambda_i)\Delta \ln\left(Y_t^{i,*}\right) + \sum_j \beta_{ij} \ln\left(\frac{P_{j,t}}{P_t^{FCST}}\right) + \varepsilon_{i,t}^Y$$

For *total industry*, the long run is anchored using sector demand ($Y_t^{i,IO}$), derived using IO coefficients. This reflects that these sectors are demand driven:

$$\Delta \ln\left(Y_t^i\right) = \alpha_i + \theta_i\left[\ln\left(Y_{t-1}^i\right) - \ln\left(Y_{t-1}^{i,IO}\right)\right] + \lambda_i \Delta \ln\left(Y_{t-1}^i\right) + (1-\lambda_i)\Delta \ln\left(Y_t^{i,IO}\right) + \sum_j \beta_{ij} \ln\left(\frac{P_{j,t}}{P_t^{FCST}}\right) + \varepsilon_{i,t}^Y$$

Using the trans-log cost function (see Haider, Jooste and McIsaac, 2023 for the derivation) the industry output equations are estimated as a function of their long-run equilibriums, relative sectoral prices ($\frac{P_{j,t}}{P_t^{FCST}}$), and an auto-regressive component (where λ_i gives the degree of autoregression). For Uruguay, data on sectoral prices was only available for crops, livestock, total industry, and total services, so these are the sectors we model using the trans-log cost function.

The own and cross-price elasticities are jointly estimated, and additionally the speed of adjustment (θ_i) and auto-regressive coefficients are estimated for each industry.

The *total services* sector is then the residual, and ensures that output is equal to demand:

$$Y_t^{SRVTOT} = Y_t^{FCST} - Y_t^{LVS} - Y_t^{CRP} - Y_t^{INDTOT}$$

From aggregate industry and aggregate services, sub-sectoral GVA is estimated using a simple weighted average of the lagged share and the demand derived share ($Y_t^{i,IO}$). For example:

$$\frac{Y_t^{ELE}}{Y_t^{INDTOT}} = \beta_1 + \beta_2 \frac{Y_{t-1}^{ELE}}{Y_{t-1}^{INDTOT}} + (1 - \beta_2) \frac{Y_t^{ELE,IO}}{Y_t^{INDTOT}} + \varepsilon_{i,t}^{ELE}$$

Finally, other industry and hospitality are the residual shares, such that:

$$Y_t^{IND} = Y_t^{INDTOT} - Y_t^{ELE}$$

$$Y_t^{HSP} = Y_t^{SRVTOT} - Y_t^{CNS} - Y_t^{SRV}$$

With this system, sectoral shares will shift in response to price and income effects, as well as climate and demand shocks.

Aggregate output will still follow the economy wide production function:

$$Y_t^* = (1 - d_t) A_t N_t^{\sigma} K_{t-1}^{1-\sigma}$$

Where the economy-wide damage function is effectively the weighted sum of each sectoral damage functions:

$$d_t = \sum_i \omega_{i,t} \cdot d_{i,t}$$

Sectoral prices

For this analysis, output price of Livestock, Non-traded crops, Total Industry and Total Services ($P_{i,t}$) is mapped to a sectoral equilibrium price ($P_{i,t}^*$) which reflects aggregate factor prices (W_t and R_t), aggregate productivity (A_t), and sector specific productivity shocks (d_t^i). Together, these reflect the marginal costs of the firm.

$$P_{i,t}^* = \frac{1}{(1 - d_t^i) A_t} \left(\frac{R_t}{1 - \alpha}\right)^{1-\alpha} \left(\frac{W_t}{\alpha}\right)^{\alpha}$$

The sectoral output price follows the functional form of the factor cost equation in the standard version of MFMod. Each sector price deflator is the weighted average of its lag, the sectoral equilibrium price and inflation expectations (π_t^*). In the short run, prices in all sectors will also respond to the size of the output gap (Y_t^{GAP}). This output gap response is not included in the livestock and crops industries.

$$\Delta \ln\left(P_{i,t}\right) = \theta \cdot \pi_t^* + \lambda \cdot \Delta \ln\left(P_{i,t}^*\right) + (1 - \theta - \lambda) \cdot \Delta \ln\left(P_{i,t-1}\right) + \beta \cdot Y_t^{GAP} + \varepsilon_{i,t}^P$$

These prices equations are estimated as a system so that coefficients are jointly estimated across sectors.

Crops are split into traded and non-traded to capture the different price dynamics.

Non-traded crop prices (P_t^{NT}) will depend on domestic factors, and so are included in the prices system described above.

Traded crop prices will follow global market prices. We construct a global crop price in US dollars (P_t^{WP}) by taking the weighted average of wheat, rice and soy prices using the share of each in Uruguay's crop exports. Domestic traded crop prices (P_t^T) are equal to this world price adjusted for the exchange rate.

$$P_t^T = P_t^{WP} \cdot exr_t$$

Total crop prices (P^{CRP}) are then the weighted average of traded and non-traded crop prices, using an assumption that the traded share (α^T) is 80 percent.

$$P_t^{CRP} = \alpha^T \cdot P_t^T + (1 - \alpha^T) \cdot P_t^{NT}$$

All other sub-sectoral prices are modeled using an ECM functional form so that they move in line with sectoral prices. For example:

$$\Delta \ln(P_t^{CNS}) = \theta\left[\ln\left(P_{t-1}^{CNS}\right) - \ln\left(P_{t-1}^{SRVTOT}\right)\ \right] + \Delta \ln(P_t^{SRVTOT}) + \varepsilon_{CNS,t}^P$$

Finally, factor costs are the weighted sum of sectoral prices:

$$P_t^{FCST} = \sum_i \omega_{i,t} \cdot P_{i,t}$$

Aggregate factor prices will still follow the economy wide equilibrium price:

$$P_t = \frac{1}{(1 - d_t)A_t}\left(\frac{R_t}{1 - \alpha}\right)^{1-\alpha}\left(\frac{W_t}{\alpha}\right)^{\alpha}$$

Where once again the economy-wide damage function is effectively the weighted sum of each sectoral damage functions:

$$d_t = \sum_i \omega_{i,t} \cdot d_{i,t}$$

Consumer prices

Agricultural output prices feed directly into consumer prices, reflecting their importance in the household consumption basket. Domestic food products make up 8.4 percent of household consumption, and domestic animal and crop raw outputs make up 2.2 percent.

Given this, it is assumed that 10 percent of variation in consumer prices is linked directly to agricultural prices.

Exports

Exports are of particular interest given the importance of agricultural exports to Uruguay's economy. The standard export demand equation is amended to directly incorporate changes in agricultural exports.

Equilibrium exports (X_t^*) are adjusted so that the non-agricultural component of exports (for example, tourism, business services, manufacturing) is a function of export market demand (X_t^{MKT}), but crop and livestock goods exports are a function of the output of those industries rather than demand:

$$X_t^* = (1 - \alpha_t^{AGR} - \alpha_t^{LVS}) \cdot X_t^{MKT} + \alpha_t^{AGR} \cdot Y_t^{AGR} + \alpha_t^{LVS} \cdot Y_t^{LVS}$$

Where α_t^{AGR} and α_t^{LVS} represent that crop and livestock shares of exports.

Export volumes are estimated as error correcting to their equilibrium level, with price elasticity accounted for in the short and long run:

$$\Delta \ln(X_t) = \theta \left[\ln(X_{t-1}) - \ln(X_{t-1}^*) - \beta_1 \cdot \ln\left(\frac{P_{t-1}^X}{P_{t-1}^{CON}}\right) \right] + \Delta \ln(X_t^*) - \beta_2 \cdot \Delta \ln\left(\frac{P_t^X}{P_t^{CON}}\right) + \varepsilon_t^X$$

Exchange rate

It is useful for modeling of the exchange rate to reflect economic fundamentals.[14] In the case of Uruguay, exports make up a large proportion of the economy and so changes in export volumes are pertinent to exchange rate behavior. The change in the export share of GDP ($\frac{X_t}{Y_t}$) is incorporated into the standard MFMod exchange rate equation:

$$\ln(exr_t) = \beta_1 + \ln(exr_{t-1}) + \ln\left(\frac{i_t^{US}}{i_t}\right) + \beta_2 \cdot d\left(\frac{X_t}{Y_t}\right) + \varepsilon_t^{exr}$$

Where exr_t is the exchange rate (Uruguayan pesos per USD), i_t^{US} is the implicit US interest rate on government debt, and i_t is the domestic monetary policy rate.

There is a negative and statistically significant estimate for β_2 indicating that as exports fall as a share of GDP (as they would during a drought) the Uruguayan exchange rate depreciates (an increase in the exchange rate in terms of Uruguayan pesos per USD is a depreciation).

Fiscal settings

For the climate shock simulations, it is assumed that most government spending is exogenous, so that the government looks through the shock, and does not adjust its budgeted spending.

The exception to this is social security transfers, where an equation is estimated that effectively holds the *real* social security payment per unemployed persons constant at the average rate from 2011 – 2019.

$$G_t^{SS} = \beta_1 \cdot \left(\frac{UNR_t}{100} \cdot LF_t \cdot P_t^{CON}\right) + \varepsilon_t^{GSS}$$

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[14] See for example: MacDonald, R and Clark, P (1998). "Exchange Rates and Economic Fundamentals: A Methodological Comparison of BEERs and FEERs." IMF Working Paper No. 1998/067. IMF, Washington DC.

According to the model this is URY$880,000 or approximately US$21,500 using the 2022 exchange rate.

As in the standard version of MFMod, fiscal revenues grow with nominal tax bases.

Total government debt (D_t^{TOT}) is split into domestic (D_t^{DOM}) and USD denominated debt (D_t^{USD}), so that an exchange rate depreciation will lead to rising debt relative to GDP.

$$D_t^{TOT} = D_t^{DOM} + D_t^{USD} \cdot exr_t$$

New debt each year is the difference between government revenues (Rev_t) and government expenditures (including interest payments) (Exp_t) and any debt revaluation that takes place ($Reval_t$).

$$D_t^{TOT,new} = Rev_t - Exp_t + Reval_t$$

It is assumed that half of new debt is denominated in USD:

$$D_t^{USD} = D_{t-1}^{USD} + 0.5 \cdot \frac{D_t^{TOT,new}}{exr_t}$$

Interest on foreign debt is modeled as a wedge on the interest rate of US government debt, while interest on domestic debt is modeled as a wedge on the domestic monetary policy rate.

$$i_t^{external} = \lambda + i_t^{US}$$

$$i_t^{domestic} = \gamma + i_t$$