Weather Shocks and Optimal Monetary Policy in a Climate-Vulnerable Economy*

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Abstract

This paper examines optimal monetary policy in response to weather shocks in a two-sector New Keynesian model calibrated for Peru, a climate-prone economy where a rural agricultural sector coexists with a modern manufacturing sector. While adverse weather shocks disproportionately impact the agricultural sector, monetary policy primarily influences the modern sector. Following an adverse weather event that triggers a recession and inflationary pressures, targeting the production price index (PPI) inflation in the manufacturing sector rather than the consumption price index (CPI) inflation appears to be optimal for the Central Bank, as it reproduces the dynamics of the Ramsey planner.

JEL classification: E32, E52, Q54.
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1 Introduction

How should a monetary authority conduct stabilization policies in response to weather shocks? What is the optimal policy response to the increased severity of extreme weather events, such as prolonged heat waves, hurricanes, or floods? The answer to these questions is not obvious as there are several factors to consider. One is that adverse weather events can have more disruptive effects on agriculture than on other sectors, leading to a reduction in production and inflationary pressure. As a result, the monetary policy strategy of leaning against the wind and maintaining price stability might not necessarily be optimal for all sectors (one size does not fit all!). Moreover, if the structure of the economy is highly segmented, such that labor is sector-specific and some individuals have limited access to financial markets, the scope of monetary policy is narrow. For instance, after an adverse weather shock the fraction of the population that is more vulnerable may not fully benefit from accommodative monetary policy that tries to revive the economy. Therefore, the design of the optimal policy in the face of weather shocks is particularly challenging and requires careful consideration of the economic structure, the severity of weather events, and the potential distributional impacts.

To address the climate-related challenges faced by central banks, this paper investigates optimal monetary policy in an economy facing weather shocks. The economy consists of two sectors: a rural agricultural sector where households farm and do not have access to financial markets, and a modern manufacturing sector where households have access to financial markets and can smooth consumption over time. Adverse weather shocks can damage farmland, which can be repaired by sustaining extra costs in production goods (fertilizers, pesticides, chemicals, seeds etc...) purchased from the manufacturing sector. In this respect, the economy presents a certain degree of dualism. The public sector is represented by a monetary authority that controls the short-term nominal interest rate and exerts its influence primarily on the manufacturing sector and only to a limited extent on the agriculture sector.

In the last decade, with the rising awareness of climate change issues, the economic literature has devoted an increasingly attention to the so-called 'physical risk' for the economy. Notably, physical risks refer to the potential for direct or indirect harm to physical assets, infrastructure, and ecosystems caused by climate-related events. In this respect, an important distinction should be made between chronic risks which are associated with longer-term shifts in climate patterns (e.g., sea level rise and ocean acidification), and acute risks which are associated with extreme events (e.g., hurricanes, prolonged heatwaves, droughts).[1] On the detrimental effect of warmer temperatures on economic activity, see e.g. Dell et al. (2012), Dell et al. (2014) and Deryugina and Hsiang (2014). For a quantification of the impact of extreme weather conditions and natural disasters see Yang (2008) and Hsiang (2010), among others.

In this strand of literature, particular attention has been devoted to the response of agricultural production to weather fluctuations and climate change. Indeed, due to its direct exposure to weather conditions, agricultural yields are highly sensitive to fluctuations in temperatures

[1] See, e.g., NFGS (2023b).

and precipitations. The literature documents significant negative impacts of climate change on agricultural production, with negative spillovers to the rest of the economy. The negative effects are found to be stronger for temperate and tropical regions, and for low-income countries. See Schlenker et al. (2007), Challinor et al. (2014), Acevedo et al. (2020) and Gallic and Vermandel (2020). One further complicating factor for the analysis of the economic impact of climate change on agriculture is the non-linearity of the effects. Indeed, while a moderate increase in temperatures may be somewhat beneficial for crop production, extreme temperatures and precipitations may be seriously detrimental to crop yields, as shown by Schlenker and Roberts (2009).

Recently, the literature has also focused on price dynamics, particularly the crop prices response to extreme weather events, and on the implications for food prices and inflation dynamics in general. Several studies find strong evidence of significant crop prices increases as a result of weather shocks, especially for cultures dedicated to local markets. See e.g., Fox et al. (2011), Mirzabaev and Tsegai (2012), Brown and Kshirsagar (2015) and Baffes et al. (2019). Looking at a more aggregate level, other papers have found a negative effect of weather variation on consumer prices stability. Heinen et al. (2019) investigate the effect of extreme weather shocks on prices and find that rare hurricane and flood events in the Caribbeans induce significant welfare losses due to price increases. Using sub-categories of consumer price indices, Gautier et al. (2023) find that the rise in prices is driven by a surge in food price inflation, while prices might decline for other products. In the same vein, Parker (2018) find that natural disasters, such as storms, generate food price inflation in the short run. The paper also finds heterogeneous effects of natural disasters on inflation dynamics depending on the level of development, with stronger responses for developing countries. In their analysis for the euro area countries, Ciccarelli et al. (2023) find that increases in monthly mean temperatures, via their impact on food, energy and services prices, have inflationary effects in summer and autumn, especially in warmer countries. Focusing on emerging and advanced countries, Faccia et al. (2021) confirms that hot summer temperatures increase food prices, especially in emerging market economies. More broadly, Cashin et al. (2017) investigate the role of the El Niño-Southern Oscillation (ENSO), a periodic climatic phenomenon that has worldwide atmospheric implications. [2] The paper identifies short-run inflationary pressures after an ENSO event in many countries, while the impact on economic activity is more heterogeneous.

Given the well-documented evidence of the potential threat that climate change and weather shocks pose to price stability, it is not surprising that climate change considerations are becoming increasingly important for central banks in the conduct of monetary policy (e.g., Carney 2015, Rudebusch et al. 2019, Lagarde 2021, NFGS 2023a). With the impacts of climate change increasingly materializing around the world, it is crucial to understand the effects of weather shocks on output and inflation, as well as the role that monetary policy can play in response to these events.

In this regard, a growing body of economic literature is focusing on the role of monetary policy

[2]For an overview of the essential features of the ENSO, see Neelin (2010).

in addressing climate-related risks. Most of these studies emphasize the impact of transition risks on price stability and identify potential room for stabilization policies from central banks, while others explore the potential role of conventional or unconventional monetary policies in greening the economy (e.g., Annicchiarico et al. 2024, Diluiso et al. 2021, Ferrari and Landi 2023, Giovanardi et al. 2023).

Less is known, however, about the optimal response of central banks to mitigate weather shocks and physical risks more broadly, and about the implications of the asymmetric effects of these shocks on the economy. While several papers underline the importance of physical risks for price and financial stability (Batten et al. 2016, Sanchez et al. 2022), few explicitly incorporate the implementation of monetary responses. An attempt in this direction is given in Economides and Xepapadeas (2018), where the authors model weather shocks as negative productivity shocks to analyze how the conduct of monetary policy is affected.

This paper aims to fill this literature gap by investigating the optimal monetary policy a central bank can implement to mitigate the inflationary pressures induced by an adverse weather shock. Given the results obtained in the literature on climate change, we model the special features of low-income and emerging countries, where the impact of weather shocks on the agricultural sector is expected to be more severe than in high-income countries and where a larger share of the population is directly exposed to their consequences. In particular, in conducting our analysis, we calibrate the model to the Peruvian economy. This choice is fully motivated in the next section.

Our results clearly show that, in response to an adverse weather event that hurts agriculture, precipitates the economy into a recession and gives rise to inflationary pressures, targeting the production price index (PPI) inflation for manufacturing rather than the consumption price index (CPI) inflation emerges as an optimal strategy for the Central Bank, as it effectively replicates the dynamics of the Ramsey planner.

The remainder of the paper is organized as follows. Section 2 presents some evidence of the inflationary consequences of adverse weather events for Peru. Section 3 presents the two-sector New Keynesian model we use as a laboratory for our normative analysis. Section 4 describes the calibration. Section 5 studies the optimal monetary policy in response to weather shocks, while Section 6 presents concluding remarks.

2 Weather Shocks in an Emerging Economy: The Case of Peru

In this paper, we investigate the optimal monetary response to the effect of weather shocks on inflation dynamics. Given the above-mentioned literature results, we chose to develop a theoretical framework based on the features of an emerging economy severely exposed to climate change and adverse weather events, and with a sizeable agricultural sector. This model relies on the characteristics of the Peruvian economy.

2.1 Features of Peru

Peru is indeed a country with interesting features for our analysis. Located on the Pacific coast in South America, Peru is an upper-middle-income country. Its agricultural sector is still strategic, representing 7.2% of the GDP in 2021 and occupying 27.9% of the employed population, according to the World Bank (compared to 7.0% and 27.0% in 2015, respectively).

According to the last agricultural survey of the Peruvian National Statistical Institute (INEI)[3], the agricultural sector of the country presents some important characteristics that we will include later on in the model. First, we observe that the production units are largely heterogeneous, with large producers cultivating crops intended for international markets while there is a large number of small-scale farmers, representing 81.8% of the farming units and using a more traditional approach. Following the report, 78.1% of them were cultivating a land with surface of up to five hectares in 2015. Although most of the small-scale farmers own at least a part of their land, many of them do not necessarily use credit (87.5% didn't ask for any type of credit in the 12 past months in 2015) nor are insured (99%, although 17.8% of them can save). Another important feature is that farmers use agrochemical products for their production (64.8% of them). It is also worth noting that while most of their production (74.9%) is intended for sale, self-consumption is not negligible and represents 6.8% of the production.

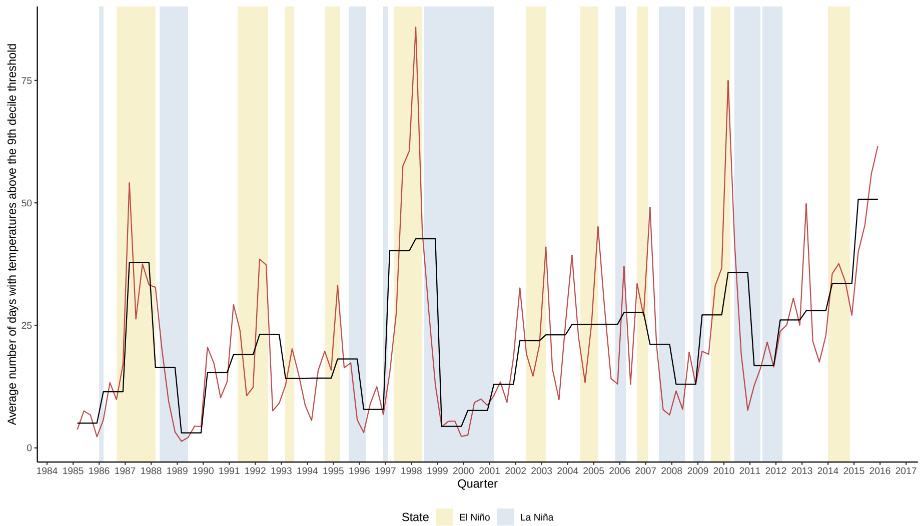
In the model, we consider only the small-scale producers for two main reasons. First, we investigate the macroeconomic policy response to inflation due to weather shocks on a national scope. We thus exclude fluctuations resulting from external trade, which are also less exposed to price variations due to local weather conditions. Given that the large-scale producers tend to produce for these markets, we exclude them from our analysis. The second reason comes from the employment dynamics. With most of the labor force involved in agriculture being small-scale producers, incomes and purchasing power variations will concern only these types of producers, while the large-scale producers would remain more preserved from weather shocks. The model will thus allow for self-consumption of agricultural production, use of agrochemical products in the production function, and neglect the access to credit.

Another important feature for the selection of Peru as example in this paper is its exposure to the ENSO fluctuations, that influence the country's temperatures and precipitations. Indeed, due to its location, the country faces directly the variation in temperatures associated with the ENSO, with the hot phase - El Niño - being associated with warmer and dryer conditions while the cold phase - La Niña - induces cooler temperatures and more precipitations. As we can see from Figure 1 and Figure 2 below, with El Niño events, the number of maximal temperature anomalies at the national level (i.e. number of days where the maximal temperatures are above the historical 9^{th} decile) rises, while during La Niña events, precipitation anomalies increase. The alternations of El Niño and La Niña phases are periodical and not due to climate change. Yet, it is expected that rainfall variability due to El Niño–Southern Oscillation will be amplified

[3] The last version of the survey entitled "Encuesta Nacional Agropecuaria, Principales Resultados – Pequeñas y Medianas Unidades Agropecuarias, 2014 – 2019 y 2021 - 2022s" is available here (in Spanish).

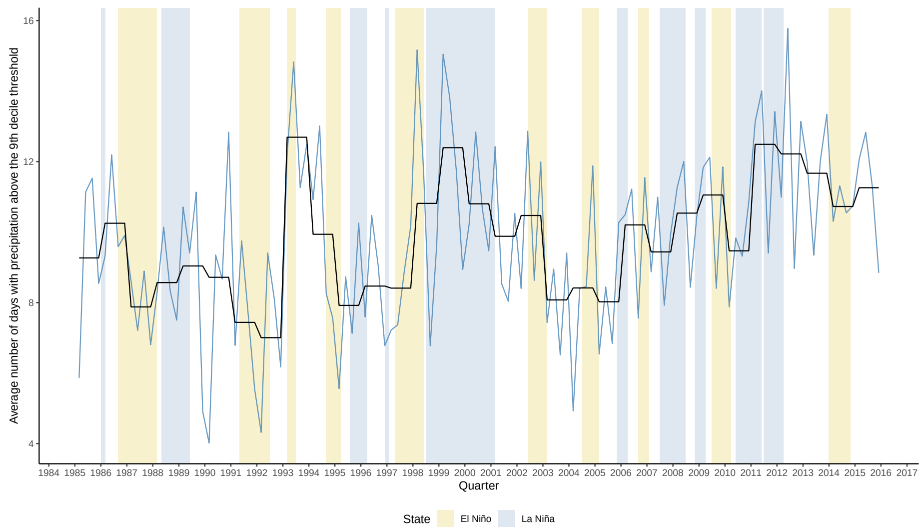
under global warming, according to the Intergovernmental Panel on Climate Change (2021)[4].

Figure 1: Quarterly Number of Days with Hot Temperature Anomalies



<u>Notes:</u> The figure presents the evolution of the quarterly number of days where the mean temperature exceeds the 9^{th} decile of temperature distribution computed using the daily temperatures of the five past years (red line). The black line represents the evolution of the annual average of the monthly anomalies. The yellow and blue areas correspond respectively to El Niño and La Niña phases.

Figure 2: Quarterly Number of Days with Precipitation Anomalies



<u>Notes:</u> The figure presents the evolution of the quarterly number of days where the sum of precipitation exceeds the 9^{th} decile of precipitation distribution computed using the daily precipitations of the five past years (green line). The black line represents the evolution of the annual average of the monthly anomalies. The yellow and blue areas correspond respectively to El Niño and La Niña phases.

Besides its effects on ENSO fluctuation, climate change may also affect Peru with the rise

[4]The report of the IPCC underlines that different scenarios project an amplification of rainfall variability by the second half of the 21st century. See point B.1.3 in the IPCC summary report, Masson-Delmotte et al. (2021).

of average temperatures. As highlighted by the last Country Climate and Development Report for Peru[5], the country is exposed to many sources of natural hazard. The agricultural sector is particularly exposed, and production is expected to decrease for almost all crops in all scenarios of climate change.

Focusing on Peru, economic literature has also found negative effects of weather shocks on agricultural production. On a macroeconomic level, Crofils et al. (2024) find that a representative weather shock entails agricultural output by 0.5%, leading to a loss of GDP of 0.15% below the trend. Aragón et al. (2021) explore at a microeconomic level the response of agricultural productivity to climate change using Peruvian household data and finds that higher temperatures harm productivity. In response, farmers may implement adaptation strategies, by increasing the planted surfaces or increasing crop mix. Sietz et al. (2012) highlight the vulnerability of smallholder Peruvian households to weather extremes, which tend to threaten food security. Sources of vulnerability include risks of harvest failure and lack of alternative incomes, features that we include in the model.

2.2 Empirical Analysis

In this subsection, we carry out an empirical analysis using a VAR approach to estimate the response of the Peruvian economy to a weather shock. The results obtained are used later in the theoretical framework to calibrate the model.

This analysis relies on macroeconomic quarterly data from the Central Bank of Peru and Temperature and Precipitation data from PISCOt V1.1 and CHRIPS v2.0 databases as in Crofils et al. (2024). The exact source of data and their transformation procedures can be found in Appendix A.

Here, we estimate a restricted VAR model with 2 lags:

$$Y_t = \alpha + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \epsilon_t, \tag{1}$$

where Y_t is the vector of endogenous variables at time t, α is a vector of constant terms, ϵ_t is the vector of errors and β_1 and β_2 our parameters of interest.

We include in the vector of endogenous variables the following components:

$$Y_t = \begin{bmatrix} Temp_t \\ GDPa_t \\ GDP_t \\ C_t \\ \Pi_t \end{bmatrix},$$

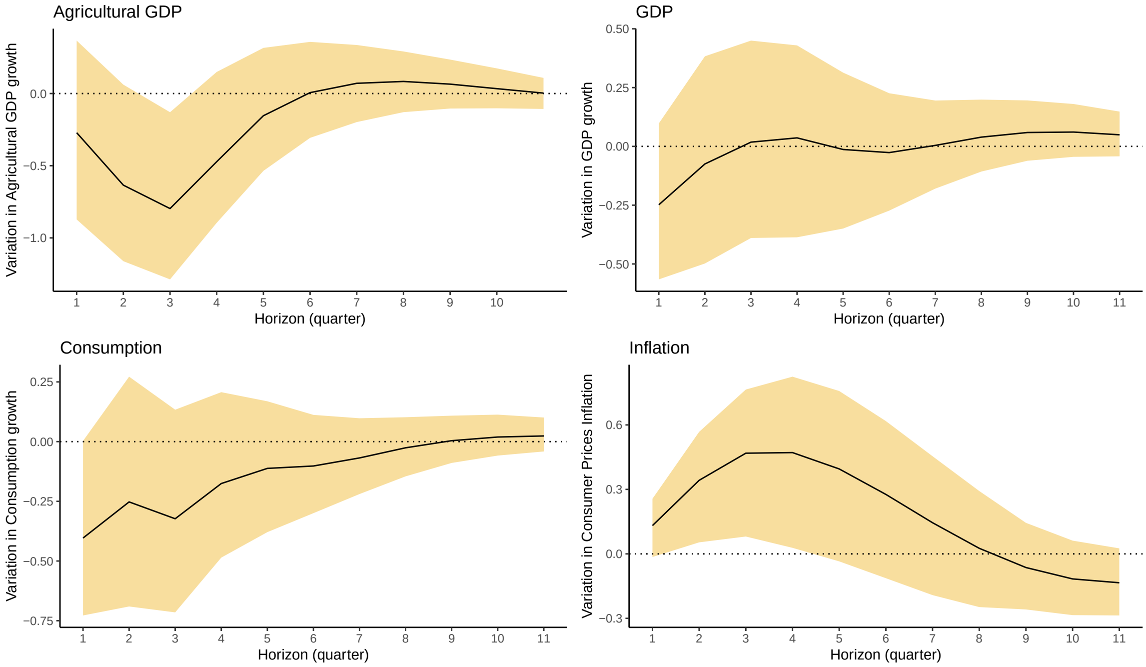
where $Temp_t$ is a quarterly measure of temperature anomalies, computed at a regional level following the methodology of Natoli (2023)[6]. $GDPa_t$, GDP_t, C_t and Π_t are respectively the

[5] See the World Bank Group's report CCDR (2022), available here.
[6] See Appendix A for more details on the construction of the variable.

growth rate of the value added of the agricultural sector to the GDP, of the GDP, the consumption and the inflation rate. All the variables are deseasonalized and subtracted from their trend component using an HP filter. The variables are ranked by degrees of exogeneity assumptions. Importantly, we use here a restricted VAR model, by allowing a lag effect on temperature anomalies coming only from its past values. Indeed, given that we focus only on weather anomalies - and not averages - in a specific country, one can assume that it is unlikely that the economic activity of Peru may trigger or affect temperature shocks (see Blanc and Schlenker 2017).

Figure 3 below presents the response of the Peruvian economy to a positive shock on temperature anomalies, using the coefficients obtained estimating Equation 1. In Appendix, Figure A-1 presents the results for a positive precipitation shock.

Figure 3: VAR model response to a Temperature shock



Notes: The figure presents the impulse response function of the selected macroeconomic variables following a temperature shock of one standard variation. The horizon is in quarter and the yellow area represents the bootstrapped error bands for a 90% confidence interval obtained with 10,000 runs.

We obtain an overall detrimental effect of temperature shocks on economic outcomes. An increase of one standard deviation in the temperature anomalies leads to a gradual reduction of the Agricultural sector's value-added by 0.8% at most after three periods. This in turn leads to a short-term contraction of GDP growth by 0.25% and a decrease in consumption, although the latter appears less significant. Finally, the shock leads to inflationary pressures with a lagged effect, with inflation going up to 0.5% three quarters after the shock. These results are in line with the estimates of Gallic and Vermandel (2020) for New Zealand or Crofils et al. (2024) for Peru in terms of magnitude and direction.

In what follows we will present a model economy to try to rationalize these findings, and then use the framework as a laboratory to characterize the optimal monetary policy response to adverse weather events hitting the agricultural sector.

3 The Model Economy

The model economy consists of two broad sectors: the agricultural sector and the non-agricultural sector. Each sector produces a specific good that is exchanged with the other. In the agricultural sector, consumers subsist by working as farmers and exchanging their produce for non-agricultural goods, which they use for consumption and to improve land quality. The non-agricultural sector consists of households that derive utility from consumption and leisure. On the production side, monopolistic competitive firms produce differentiated goods and face price adjustment costs *à la* Rotemberg (1983). This assumption is needed to introduce a role for monetary policy in affecting real allocation in a cashless economy. On top of these producers, there are final-good producers who simply combine the differentiated goods into a bundle that is then sold in a perfectly competitive market. Finally, labor is not mobile between sectors. In the spirit of Lewis (1954), the structure of the economy is meant to capture a certain degree of dualism, where a traditional agricultural sector coexists with a modern non-agricultural sector, primarily identified with manufacturing. The monetary authority, that controls the short-term interest rate, is assumed to be benevolent in the Ramsey sense; that is, it aims to achieve the decentralized equilibrium that maximizes an aggregated welfare function and has the ability to commit to its promises, preventing it from reneging on its commitments.

3.1 Agricultural Sector

The agricultural sector is populated by a mass s_F of households that derive their subsistence from the land they own, consuming a portion of their production while selling the surplus to the rest of the households. The proceeds from selling excess produce are used to purchase manufactured goods and cover the land costs necessary to restore land and rebuild livestock. These agents do not have access to financial markets, and the only way they can smooth out consumption over time is through their spending on the quality of land. We refer to these agents as farmers, and use the superscript F to indicate the economic variables that refer to them.

Farmers earn their living from agricultural production according to the following technology:

$$Y_t^A = B_t^A \left(\Omega(\varepsilon_t^w) L_{t-1}^F\right)^{\alpha_A} (H_t^F)^{1-\alpha_A}, \tag{2}$$

where Y_t^A is the quantity produced, $\alpha_A \in (0,1)$, B_t^A is a measure of the total factor productivity of the agricultural sector, L_{t-1}^F is the amount of land used by a farmer to produce and H_t^F denotes the time spent farming; while $\Omega(\varepsilon_t^w)$ is a function representing the fraction of land that can be lost following an adverse weather shock ε_t^w. As in Gallic and Vermandel (2017), it is assumed that the land evolves according to the following law of motion:

$$L_t^F = (1-\delta_L)\Omega(\varepsilon_t^w) L_{t-1}^F + V_t^F, \tag{3}$$

where $\delta_L \in (0,1)$ is the natural decay rate of land and V_t^F represents the quantity of non-agricultural goods needed to restore land and keep its level of productivity. To capture the fact that agricultural production depends on weather conditions and account for the potential damage caused by weather shocks, following Gallic and Vermandel (2020) and in the spirit of the Integrated Assessment Models (IAMs), we introduce the damage function that determines land productivity in the following way:

$$\Omega(\varepsilon_t^w) = (\varepsilon_t^w)^{-\theta^W}, \tag{4}$$

where $\theta^W > 0$ represents the elasticity of land productivity with respect to the weather shocks, ε_t^w, evolving exogenously according to the process

$$\log \varepsilon_t^w = \rho^w \log \varepsilon_{t-1}^w + \eta_t^w, \tag{5}$$

where $\rho^w \in [0,1)$ is the persistence of the weather shock, while η_t^w is assumed to be identically and independently distributed with mean zero and standard deviation equal σ^w. Depending on the size of the persistence, a positive realization of η_t^w can potentially give rise to a prolonged episode of extreme weather conditions that damage crops and livestock.

Each household derives utility from consumption and disutility from labor, so that its lifetime utility function is of the form:

$$\mathcal{U}_0^F = \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\log(C_t^F) - \chi_F \frac{(H_t^F)^{1+\eta_F}}{1+\eta_F} \right) \right], \tag{6}$$

where $\mathbb{E}_0$ denotes the rational expectation operator, $\beta \in (0,1)$ is the subjective discount factor, C_t^F is a consumption basket composed by agricultural goods, $C_{A,t}^F$ and manufacturing good consumption, $C_{M,t}^F$, while $\eta^F > 0$ is the inverse of the Frisch elasticity of labor supply, and χ^F is a scale parameter pinning down the steady state of hours worked. We assume that the representative farmer allocates their consumption between the two goods according to a CES function:

$$C_t^F = \left[\varphi^{\frac{1}{\mu}} {C_{A,t}^F}^{\frac{\mu-1}{\mu}} + (1-\varphi)^{\frac{1}{\mu}} {C_{M,t}^F}^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}}, \tag{7}$$

where $\mu > 0$ is the elasticity of substitution, while $\varphi \in (0,1)$ denotes the share of the agricultural good in the total consumption basket. The cost minimization conditions imply that, at the optimum, the quantity demanded for each good is $C_{A,t}^F = \varphi C_t^F \left(P_t^A / P_t \right)$ and $C_{M,t}^F = (1-\varphi) C_t^F \left(P_t^M / P_t \right)$, where P_t is the consumption price index:

$$P_t = \left[\varphi (P_t^A)^{1-\mu} + (1-\varphi)(P_t^M)^{1-\mu} \right]^{\frac{1}{1-\mu}}. \tag{8}$$

Since in this sector households earn their living only from agricultural production, the flow budget constraint faced by the typical farmer is

$$P_t^A(Y_t^A - C_{A,t}^F) = P_t^M C_{M,t}^F + P_t^M \tau_V \frac{\left(V_t^F\right)^{\phi_V}}{\phi_V}, \tag{9}$$

where P_t^A and P_t^M denote the nominal price of the agricultural and manufacturing goods, respectively, while $\phi_V > 1$ and $\tau_V > 0$ are parameters that determine land restoration costs.

The typical farmer in period t chooses $C_{M,t}, H_t^F, V_t^F, L_t^F$ so to maximize the expected lifetime utility (6), given prices, the flow budget constraint (9), the available technology (2), the land time evolution process (3), the damage function (4), and the realization of the weather shocks (7). See Appendix B for further details. Note that these agents do not have access to financial markets, therefore the only way they have to smooth out their consumption over time is through decisions regarding the amount of resources to be spent on land.

3.2 Manufacturing Sector

In the manufacturing sector, there are three agents: (i) a continuum of monopolistically competitive firms of mass $1-s_F$ each of which produces a single horizontally differentiated intermediate good, (ii) perfectly competitive firms that combine intermediate goods to produce the final manufacturing firm, and (iii) households that consume, offer labor services, and rent out capital to firms of the manufacturing sector.

3.2.1 Final Good Producers

We assume the existence of a mass $1 - s_F$ of identical and perfectly competitive final-good producers whose individual production is denoted as Y_t^M. These producers combine differentiated intermediate manufacturing goods according to a CES technology:

$$Y_t^M = \left(\frac{1}{1-s_F}\int_0^{1-s_F} Y_{j,t}^{M\,(\theta-1)/\theta} dj\right)^{\frac{\theta}{\theta-1}}, \tag{10}$$

where $Y_{j,t}^M$ denotes the quantity of the generic intermediate good j, while $\theta > 1$ is the elasticity of substitution between differentiated intermediate goods. In the optimum, the typical producer minimizes total costs, so that the demand function for the generic intermediate good j is $Y_{j,t}^M = \left(P_{j,t}^M / P_t^M\right)^{-\theta} Y_t^M$, where P_t^M is the 'ideal' price index:

$$P_t^M = \left[\frac{1}{1-s_F}\int_0^{1-s_F} \left(P_{j,t}^M\right)^{1-\theta} dj\right]^{\frac{1}{1-\theta}}, \tag{11}$$

that, given the assumption of perfect competition, determines the price at which manufacturing production is sold.

3.2.2 Intermediate Goods Producers

The manufacturing sector consists of a continuum of monopolistically competitive producers indexed by $j \in (0, 1-s_F)$. Each producer hires labor inputs, $H^{\bar{F}}_{j,t}$, and capital $K^{\bar{F}}_{j,t-1}$ in perfectly competitive factor markets to produce the manufacturing good $Y^M_{j,t}$ using the following constant return to scale technology:

$$Y^M_{j,t} = B^M_t (K^{\bar{F}}_{j,t-1})^{\alpha_M} (H^{\bar{F}}_{j,t})^{1-\alpha_M} \tag{12}$$

where $\alpha_M \in (0,1)$ and B^M_t measure the level of total factor productivity. Each producer has monopolistic power in the production of its own specific good and when setting its price faces quadratic adjustment costs as in Rotemberg (1983), measured in terms of the final good, equal to $(\chi^P/2)\left(P^M_{j,t}/P^M_{j,t1} - 1\right)^2 P^M_t Y^M_t$, where $\chi^P > 0$ captures the degree of price rigidity. Note that for the factor inputs, we are using the superscript $\bar{F}$ to denote the variables referring to non-farmers.

Given the available technology (12) and the demand function $Y^M_{j,t} = \left(P^M_{j,t}/P^M_t\right)^{-\theta} Y^M_t$, the problem of a typical j firm is then to choose $H^{\bar{F}}_{j,t}, K^{\bar{F}}_{j,t-1}, P^M_{j,t}$ to maximize the expected discounted sum of profits

$$\mathbb{E}_0 \sum_{t=0}^{\infty} Q^{\bar{F}}_{t,0} \left[P^M_{j,t} Y^M_{j,t} - W_t H^{\bar{F}}_{j,t} - R^k_t K^{\bar{F}}_{j,t-1} - \frac{\chi^P}{2} \left(\frac{P^M_{j,t}}{P^M_{j,t-1}} - 1 \right)^2 P^M_t Y^M_t \right], \tag{13}$$

where $Q^{\bar{F}}_{t,0}$ is the nominal discount factor that agents use in period t to value nominal profits, and is equal to the discount factor of non-farmers households, while W_t and $R_t k$ denote the nominal wage and the rental rate of capital. See the appendix for further details.

3.2.3 Households

There is a mass $1-s_F$ of households that work only in the manufacturing sector. As for farmers, the typical non-farmer derives utility from consuming a consumption basket, $C^{\bar{F}}_t$, and disutility from labor, $H^{\bar{F}}_t$, and faces a lifetime utility function of the form:

$$\mathcal{U}^{\bar{F}}_0 = \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\log(C^{\bar{F}}_t) - \chi_{\bar{F}} \frac{(H^{\bar{F}}_t)^{1+\eta_{\bar{F}}}}{1+\eta_{\bar{F}}} \right) \right], \tag{14}$$

where $\eta^{\bar{F}} > 0$ is the inverse of the Frisch elasticity of labor supply and $\chi^{\bar{F}} 0$ is the scale parameter pinning down the steady state of hours worked. Likewise farmers, the non-farmers' consumption basket $C^{\bar{F}}_t$, is a composite good made of quantities $C^{\bar{F}}_{A,t}$ of agricultural goods and $C^{\bar{F}}_{M,t}$ of manufacturing goods according to a CES function:

$$C^{\bar{F}}_t = \left[\varphi^{\frac{1}{\mu}} C^{\bar{F}\,\frac{\mu-1}{\mu}}_{A,t} + (1-\varphi)^{\frac{1}{\mu}} C^{\bar{F}\,\frac{\mu-1}{\mu}}_{M,t} \right]^{\frac{\mu}{\mu-1}}, \tag{15}$$

therefore, the cost minimization conditions determine the quantity demanded for each good is $C^{\bar{F}}_{A,t} = \varphi C^{\bar{F}}_t \left(P^A_t/P_t\right)$ and $C^{\bar{F}}_{M,t} = (1-\varphi)C^{\bar{F}}_t \left(P^M_t/P_t\right)$, where P_t is given by (8).

Non-farmers are the sole owners and workers of the firms in the manufacturing sector, and own physical capital that they rent out to producers. The flow budget constraint of the typical non-farmer household then reads as

$$P_t C^{\bar{F}}_t + P^M_t I^{\bar{F}}_t + B^{\bar{F}}_t = W_t H^{\bar{F}}_t + R^k_t K^{\bar{F}}_{t-1} + R_{t-1} B^{\bar{F}}_{t-1} + D^{\bar{F}}_t, \tag{16}$$

where $I^{\bar{F}}_t$ is investment spending, B^H_t denotes the quantity of one-period risk-free nominal bonds, $B^{\bar{F}}_{t-1}$ denotes the amount of bond carried from period $t-1$, R_{t-1} is the nominal (gross) interest rate, W_t is nominal wage, R^k_t is the nominal rate of return on physical asset $K^{\bar{F}}_{t-1}$ and $D^{\bar{F}}_t$ are dividends from ownership of firms. During each period, a fraction δ_K of capital depreciates, requiring households to invest to compensate for this decline. This gives rise to the following law of motion for capital:

$$K^{\bar{F}}_t = (1-\delta_K)K^{\bar{F}}_{t-1} + I^{\bar{F}}_t. \tag{17}$$

The typical household in this sector chooses $C^{\bar{F}}_t, H^{\bar{F}}_t, I^{\bar{F}}_t, K^{\bar{F}}_t, B^{\bar{F}}_t$ so to maximize the lifetime utility (14), subject to the budget constraint (16) and the accumulation equation of capital (17). See Appendix B.

3.3 Aggregation, Equilibrium Conditions, and Monetary Policy

After aggregating all agents of the economy and imposing market clearing conditions on factor and goods markets, the standard equilibrium conditions of the model economy can be derived. See Appendix B, where a formal definition of decentralized competitive equilibrium is provided.

Since the economy is populated by a mass s_F of farmers and $1-s_F$ of non-farmers, the market clearing condition for agricultural goods requires aggregate supply to be equal to aggregate consumption, that is

$$s^F Y^A_t = s^F C^F_{A,t} + \left(1-s^F\right) C^{\bar{F}}_{A,t}. \tag{18}$$

For the manufacturing good, the market clearing condition is instead equal to

$$\left(1-s^F\right) Y^M_t \left[1 - \frac{\chi^P}{2}\left(\frac{P^M_{j,t}}{P^M_{j,t-1}} - 1\right)^2\right] = s^F \left(C^F_{M,t} + \tau_V \frac{\left(V^F_t\right)^{\phi_V}}{\phi_V}\right) + \left(1-s^F\right)(C^{\bar{F}}_{M,t} + I^{\bar{F}}_t), \tag{19}$$

where we account for the price adjustment costs sustained to re-set prices and the fact that the final good is also used for investment purposes and to increase the quality of land. By combining (18) with (9) the market clearing condition can be expressed in terms of exchange between the two sectors:

$$\left(1-s^F\right) P^A_t C^{\bar{F}}_{A,t} = s^F P^M_t \left(C^F_{M,t} + \tau_V \frac{\left(V^F_t\right)^{\phi_V}}{\phi_V,}\right) \tag{20}$$

which simply implies that the total expenditure on agricultural goods by non-farmers must equal the total expenditure on manufactured goods by farmers. The price ratio P^A/P^M represents the terms of trade for the agricultural sector.

For future reference, it is beneficial to define the following aggregate variables. Aggregate investments and capital are given by

$$I_t = (1 - s_F) I_t^{\bar{F}}, \tag{21}$$

$$K_t = (1 - s_F) K_t^{\bar{F}}. \tag{22}$$

Aggregate consumption is

$$C_t = s_F C_t^F + (1 - s_F) C_t^{\bar{F}}, \tag{23}$$

while aggregate real production in the economy is defined as:

$$P_t Y_t = s_F P_t^A Y_t^A + (1 - s_F) P_t^M Y_t^M. \tag{24}$$

Regarding the conduct of monetary policy in response to weather shocks, we consider alternative scenarios. In Section 5, we start by assuming that the central bank follows a simple interest rate rule of the Taylor type. Then, we derive the optimal monetary policy. However, before turning to the study of the optimal monetary policy response to weather shocks, we need to discuss some characteristics of the model economy that make conducting monetary policy more challenging.

3.4 Sources of Inefficiencies and Dualism

The model economy employed as a laboratory for our analysis of optimal monetary policy presents some sources of inefficiency that are common to New Keynesian models, along with some specific characteristics to be ascribed to the dual structure of the economy.

A first source of inefficiency arises from the assumption of costly price adjustments. This pricing assumption leads to a wedge between aggregate demand and aggregate output, as resources are needed to adjust prices. This wedge vanishes in the absence of inflation. For this reason, it would be optimal to stabilize prices and have a zero-inflation policy.

Another source of inefficiency stems from the presence of monopolistically competitive firms in the manufacturing sector. These firms set prices above marginal costs, leading to positive price markups and an inefficiently low level of economic activity. This is a well-established static distortion from standard monopoly analysis. As a result of costly price adjustments, markups are time-varying. In response to shocks, price markups induce inefficient output fluctuations in manufacturing, which call for monetary policy interventions.

In addition to the above distortions that derive from the New Keynesian structure of the manufacturing sector, the economy is, in some respects, dual in the sense that it is divided into a rural, agricultural sector in which households work their own land, and have no access to financial markets and a modern manufacturing sector in which households earn labor income, own firms, and have unconstrained access to financial markets. As a result, the consumption levels of the two categories of households are different, with farmers exhibiting lower consumption levels compared to non-farmers. Under these circumstances, consumption disparities amplify the misallocative consequences of imperfect competition, particularly in terms of land quality.

To illustrate this phenomenon, it is sufficient to look at the efficient condition for land accumulation, which can be derived by analyzing the model economy under the first-best allocation. For the sake of simplicity, consider the efficient condition in the steady-state condition:

$$\beta \frac{\alpha_A \chi_F (H^F)^{1+\eta_F}}{(1-\alpha_A) L^F} = [1-\beta(1-\delta_L)] \frac{\tau_V \left(V^F\right)^{\phi_V - 1} \chi_{\bar{F}} (H^{\bar{F}})^{\eta_{\bar{F}}+\alpha_M}}{(1-\alpha_M) B^M (K^{\bar{F}})^{\alpha_M}} \tag{25}$$

where the term on the left shows the present discounted value of the marginal benefit derived from an additional unit of usable land, while the term on the right represents the marginal cost of restoring an extra unit of cultivable land, net of the next-period marginal costs saved on land carried out from the previous period. In decentralized equilibrium, the corresponding equilibrium condition is instead the following:

$$\beta \frac{\alpha_A \chi_F (H^F)^{1+\eta_F}}{(1-\alpha_A) L^F} = [1-\beta(1-\delta_L)] \frac{\tau_V \left(V^F\right)^{\phi_V - 1} \chi_{\bar{F}} (H^{\bar{F}})^{\eta_{\bar{F}}+\alpha_M}}{(1-\alpha_M) B^M (K^{\bar{F}})^{\alpha_M}} \mathcal{M}^p \mathcal{H}, \tag{26}$$

(26) is different from (25) for the term $\mathcal{M}^p > 1$, which is the level of the (gross) price markup in a steady state with zero inflation, and $\mathcal{H} \equiv C^{\bar{F}}/C^F > 1$, which is an index of heterogeneity between farmer and non-farmer households consumption level.[7] Since both terms are larger than one, in the decentralized equilibrium, the marginal benefit of land is above its efficient level. This implies that the investment in land is too low. Two factors then contribute to an inefficient level of land accumulation in this dual economy: positive markups and consumption disparities between rural and urban households.

In what follows, we will show that since factor inputs are also sector-specific, adverse weather shocks are likely to severely hurt the rural sector, worsening inequalities between farmers and non-farmer households while increasing inflation. In Section 5, we will show that all these features introduce further trade-offs for the Ramsey planner, especially when inequality issues are not set aside.

A further remark is needed here on the scope of monetary policy in this dual economy. It should be noted that monetary policy has a direct influence only on consumption and investment decisions among individuals in the manufacturing sector. Meanwhile, the consumption patterns of farmers are influenced by the value of agricultural production, the available cultivable land (and therefore by weather events), and the terms of trade, which determine farmers' purchasing power. The influence of monetary policy on this sector is therefore indirect. This limits the

[7] In Appendix B we show that price markup $\mathcal{M}^p$ is equal to P^M/MC, where MC denotes the nominal marginal cost of increasing output in manufacturing.

stabilizing role of monetary policy and its ability to stabilize CPI inflation in the face of an adverse weather event that primarily damages agriculture.

4 Calibration

This section describes the calibration strategy. Time is measured in quarters, and the model is calibrated for Peru. Table 1 below summarizes the value of the parameters. We set some of the benchmark parameters in line with the existing literature while capturing some features of the Peruvian economy.[8]

We set the value of the discount factor β to 0.993, a value close to the standards of the literature, and a steady-state with no inflation (i.e. $\bar{\Pi} = 1$), leading to the steady-state value for the interest rate $\bar{R} = 1.007$. We set the mass of farmers in the economy $s_F = 0.28$ to match the level of employment in the agricultural sector in Peru, according to the World Bank. We normalize the steady-state relative price of the manufacturing good P^M/P to 1, so that, the (gross) inflation rate of the manufacturing good is also equal to one ($\Pi^M = 1$) Given that we express the model in relative terms with respect to the price of the final good, we obtain with equation 8 that $P^A/P = 1$.

On the agricultural sector side, we set the initial total endowment of productive land to $\bar{L} = 1$. Following IMF estimates, we set the share of agricultural goods in the consumption basket to 27%, a standard value for emerging countries: $\varphi = 0.27$[9]. To calibrate the parameters of the agricultural sector, we rely on the estimates and calibration of Gallic and Vermandel (2020). We also fix the natural decay of land to $\delta_L = 0.05$ based on their corresponding estimate. Finally, we use their estimates of the elasticity of land productivity to weather shock to calibrate the damage function. They obtain a value of 20.59 for the parameter θ_W, which we set to $\theta_W = 20$ to match our empirical responses of weather shocks on macroeconomic variables, as presented in Section 2. In the same spirit of representing the agricultural sector, we calibrate the elasticity of productive land to agricultural production to $\alpha_A = 0.15$. Concerning the land cost function, the curvature of the function is fixed to $\phi_V = 1.76$ to match the estimates of Gallic and Vermandel (2017) for this parameter, while τ_V is a parameter set to pin down the model at the steady-state. The authors also estimated the degree of substitutability between agricultural and manufacturing goods. Here, we diverge from the value they obtain because we focus on a developing economy setup, where one can expect that the agricultural and non-agricultural goods are complementary rather than substitutes. In that sense, we rely on the estimations of Ginn and Pourroy (2022) which also integrates a CES function for food and non-food consumption dynamics in their model for India, an emerging economy. While their estimate leads to a value of 0.71, we opt for a slightly higher degree of substitutability in the case of Peru, by calibrating μ to 0.8.

Concerning the manufacturing sector, we set the elasticity of capital intensity to output to $\alpha_M = 0.30$, a common value in the literature. The elasticity of substitution between the

[8]Note that this calibration is preliminary and will be revised in future versions of the manuscript.
[9]See Amaglobeli et al. (2023).

Table 1: Calibrated Parameters of the Model

Parameter	Name	Value
β	Discount factor	0.993
$\bar{\pi}$	CPI Inflation target	1
Households		
s_F	Mass of farmers households	0.28
μ	Elasticity of substitution between goods	0.3
φ	Share of agricultural goods in the consumption basket	0.27
η^F	Curvature of the disutility over labor for farmer households	1
$\eta_{\bar{F}}$	Curvature of the disutility over labor for farmers non-farmer households	1
Agricultural Sector		
α_A	Elasticity of agricultural output to land	0.15
$\bar{L}$	Endowment in agricultural land	1
δ_L	Natural decay of land productivity	0.05
ϕ_V	Curvature of the land cost function	1.76
θ_W	Elasticity of land productivity with respect to the weather shocks	20
Manufacturing Sector		
α_M	Elasticity of manufacturing output to capital	0.30
δ_K	Capital depreciation rate	0.025
θ	Price elasticity	6
χ_P	Degree of price rigidity	54
Weather Shock		
ρ_W	Persistence of the weather shock	0.38
σ^w	Standard deviation of the weather shock	0.01

intermediate goods is fixed to $\theta = 6$, as in Annicchiarico and Di Dio (2015), while the degree of price rigidity is set to $\chi_P = 54$, close to the estimates of Diluiso et al. (2021). Finally, we set the capital depreciation rate to $\delta_K = 0.025$.

The values of curvature of labor disutility for both types of households η_F and $\eta_{\bar{F}}$ is set to 1. We also calibrate the steady state values of the hours worked for the two households to $H^F = H^{\bar{F}} = 1/3$, implying that the households spend one-third of their time working in the agricultural and manufacturing sector, respectively.

Several scale parameters are then computed as residuals to pin down the steady state. This is the case for the weights of labor disutility in the welfare function of households, χ_F and $\chi_{\bar{F}}$. This is also the case of the steady-state values of the total factor productivity, B^A and B^M.

Finally, we calibrate the distribution of the weather shock process. We rely on the estimate of Gallic and Vermandel (2020) to set the persistence of the AR process to $\rho_W = 0.38$. This also enables us to match the empirical results. In the exercises presented below, we assume a standard deviation of $\sigma^w = 1\%$ for the shock for illustrative purposes.

5 Weather Shocks and Monetary Policy

In this section, we study the optimal monetary policy for an economy experiencing adverse weather events. We first describe the dynamic behavior of the economy in the decentralized competitive equilibrium where monetary policy is conducted via an interest rate rule, and then we proceed to characterize the optimal monetary policy.[10].

5.1 Decentralized Competitive Equilibrium

We analyze the dynamic response of the economy to a weather shock in the decentralized competitive equilibrium, assuming that monetary policy is conducted according to a standard Taylor rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\iota_r} \left[\left(\frac{\Pi_t}{\Pi}\right)^{\iota_\pi} \left(\frac{Y_t}{Y}\right)^{\iota_y}\right]^{1-\iota_r}, \tag{27}$$

where non-indexed variables refer to steady-state levels, $\iota_r \in [0, 1)$ is the smoothing parameter, and $\iota_\pi > 0$ and $\iota_y > 0$ measure the responsiveness of the nominal interest rate to changes in inflation and aggregate output. For our initial exercise, we set $\iota_\pi = 1.5$ and $\iota_y = 0.125$ and $\iota_r = 0$. Note that according to equation (27), monetary policy targets CPI inflation.

Figure 4 illustrates the response of key macroeconomic variables to an adverse weather shock. The response of the economy is as expected and consistent with the results discussed in Section 2. The shock negatively impacts cultivable land, leading to a sharp decline in agricultural production and, consequently, in the consumption levels of farmers. To restore land productivity, farmers are forced to further reduce their consumption to purchase production goods from the manufacturing sector.

In the manufacturing sector, the shock propagates through different channels. First, the increase in the price of agricultural goods negatively affects the consumption of non-farmers. Since the two goods are imperfect complements, there is also a fall in demand for the manufacturing goods, which is not compensated by the higher demand for production goods of farmers. Monetary policy, which responds more intensively to the rise in CPI inflation than to the output contraction, is restrictive. This results in a further decrease in consumption among individuals in the manufacturing sector, worsening the recessionary effects of the weather shock for this sector. As a result, we observe that the negative weather shock immediately triggers an increase in the price markup that further exacerbates the inefficiency inherent to the decentralized market equilibrium[11].

The opposite dynamics of prices in the two sectors translate into an improvement in terms of trade in favor of farmers. This implies that they can sell their produce at a relatively higher price, requiring them to exchange a smaller quantity of agricultural output Y_A for each unit of fertilizer V. The terms-of-trade improvement mitigates the detrimental consequences of the

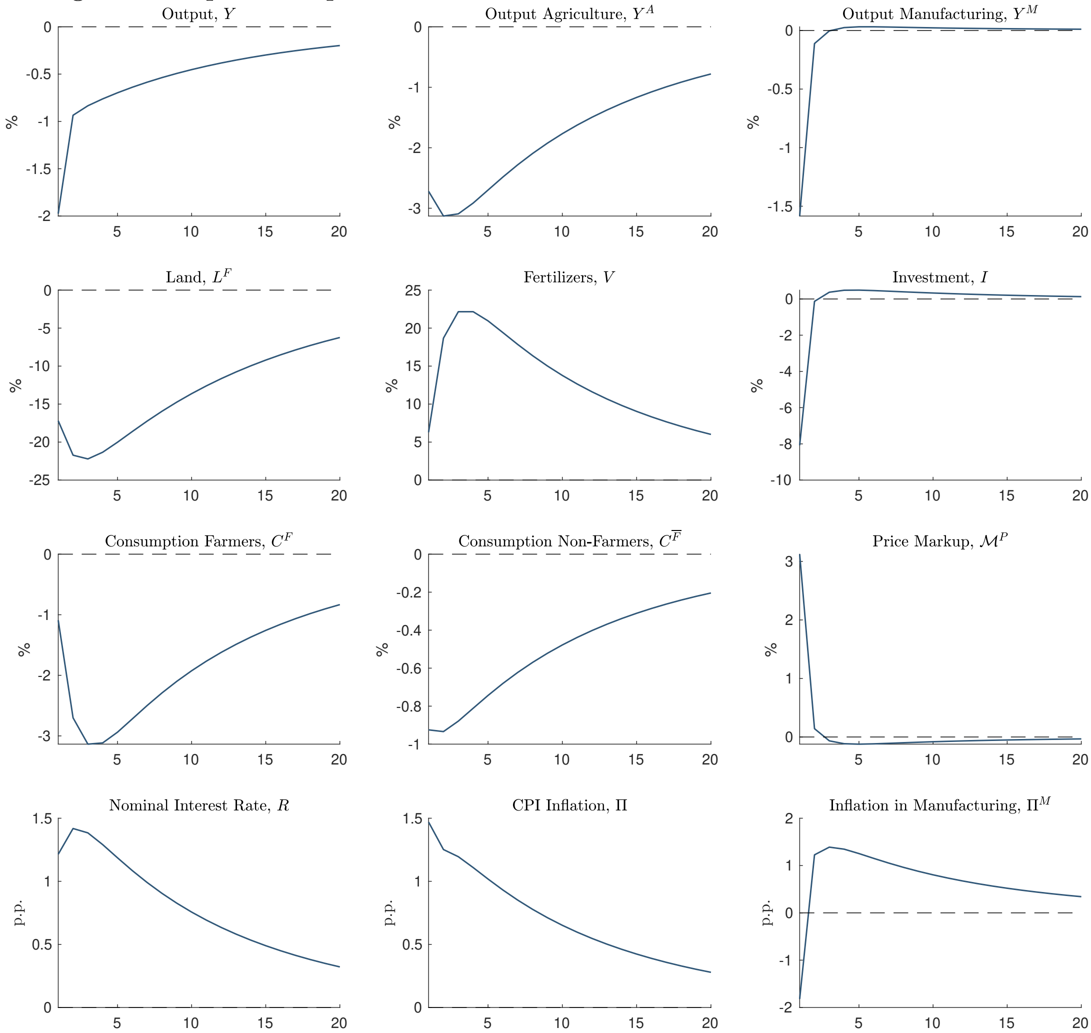
[10] The model is solved using the Dynare package, suing a third-order approximation perturbation method. See Adjemian et al. (2022)

[11] Nominal marginal costs decline because of the lower production, but since changing prices is costly in this sector, the price markup temporarily increases.

weather shock for farmers. However, despite this effect, consumption disparities increase as a result of the shock.

In the next section, we will see how a benevolent Ramsey planner, controlling monetary policy, finds it optimal to allow CPI inflation to increase while allowing only a moderate increase in inflation in the manufacturing sector.

Figure 4: Impulse Responses to an Adverse Weather Shock - Interest Rate Rule



Notes: The figure presents the impulse responses to a one standard deviation weather shock under the decentralized competitive equilibrium. All variables are reported as percentage deviations from their stochastic steady-state level, with the exception of the nominal interest rate and of the inflation rates, which are reported as annualized percentage point deviations.

5.2 Optimal Monetary Policy

We are now ready to derive the optimal monetary policy response to weather shocks hurting the agriculture sector. In particular, we consider the problem of a monetary authority, which we will call the "Ramsey planner", that controls the short-run nominal interest rate R_t to maximize the expected utility of all households, given the constraints represented by the general equilibrium conditions of the decentralized economy outlined in Appendix B. In particular, we will focus on the following objective function:

$$\mathcal{U}_t = \mathbb{E}_t \left[\mathcal{U}_t^F + \left(1 - s^F\right) \mathcal{U}_t^{\bar{F}} \right], \tag{28}$$

where $\mathcal{U}_t^F$ and $\mathcal{U}_t^{\bar{F}}$ are the lifetime utility functions of farmers and non-farmer households defined in (6) and (14), while the discount factor of the planner is then that of agents, β. Equation (28) is then the (utilitarian) social welfare function of the economy.

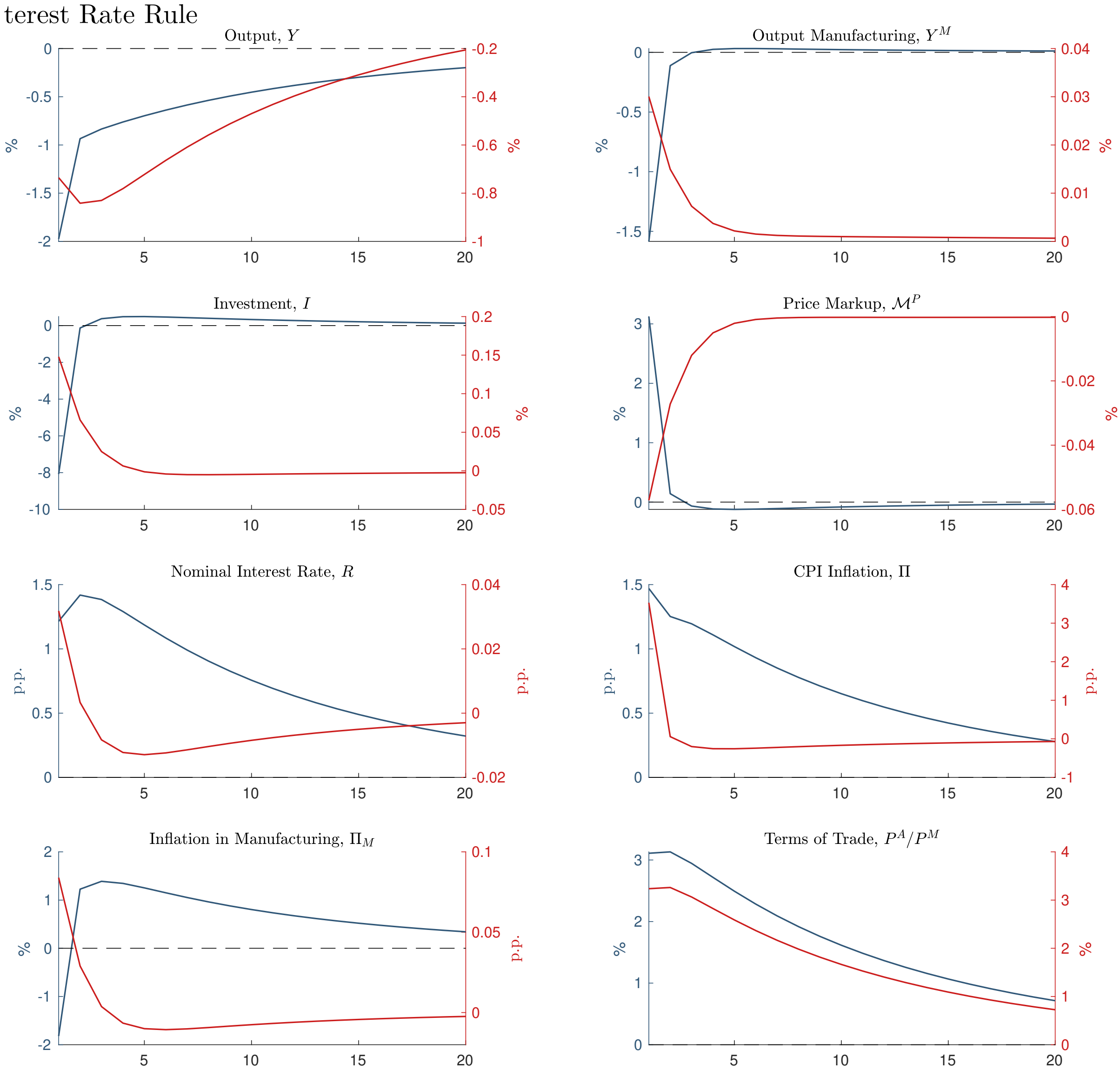
Following standard practice in the literature, we assume that the Ramsey planner is able to bind itself to the contingent policy rule it announces in period t (i.e., there is an ex-ante commitment to a feedback policy enabling dynamic adaptation of the policy in response to evolving economic conditions).[12] The Ramsey planner then maximizes (28), subject to the constraints represented by the equilibrium conditions of the market economy. Once the first-order conditions are derived, it is possible to analyze the optimal monetary policy in the long run by examining the Ramsey optimal steady-state inflation rate. This involves computing the modified golden rule steady-state inflation rate, which is the steady-state inflation rate that results from imposing steady-state conditions ex-post on the first-order conditions of the Ramsey plan. We find that the steady-state inflation rate associated with the Ramsey optimal policy is zero.[13]. In doing so, the planner selects the inflation rate that eliminates the price adjustment costs.

Figure C-1 presents the response of the economy to an adverse weather shock when monetary policy is optimally set. We observe that the Ramsey planner finds it optimal to depart from price stability, allowing for a higher increase in CPI inflation while stabilizing inflation in the manufacturing sector. The planner, in fact, tolerates only moderate inflation in the manufacturing sector (PPI inflation for manufacturing), contrary to the response in the decentralized competitive equilibrium. Overall, it should be noted that under the optimal monetary policy regime, the dynamics of the main macroeconomic variables in agriculture remain almost unchanged when compared to their behavior under the decentralized competitive equilibrium. This is because, as mentioned earlier, monetary policy lacks the capacity to directly influence the agriculture sector. Figure 5 focuses instead on the variables for which the Ramsey planner and the decentralized competitive equilibrium differ in their response to weather shocks.

[12] This is known as the 'timeless perspective' approach to optimal policy, so that the initial period problem becomes irrelevant once the initial period has long since passed. See Woodford (2003).

[13] This result is consistent with those obtained in a streamlined New Keynesian model with Rotemberg pricing, as in Schmitt-Grohé and Uribe (2008) The inflation rate so computed is the so-called *modified golden rule steady-state* inflation, which differs from the *golden rule steady-state* inflation, which is instead the inflation rate that maximizes welfare at the deterministic steady state

Figure 5: Impulse Responses to an Adverse Weather Shock - Optimal Monetary Policy v. Interest Rate Rule



Notes: The figure presents the impulse responses to a one standard deviation weather shock under the Ramsey equilibrium (right-hand side scale, red lines) and decentralized competitive equilibrium (left-hand side scale, blue lines). All variables are reported as percentage deviations from their stochastic steady-state level, with the exception of the nominal interest rate and of the inflation rates, which are reported as annualized percentage point deviations.

In contrast to the decentralized competitive equilibrium, the dynamics of the variables related to the manufacturing sector exhibit a quite different response. Indeed, instead of raising its nominal interest rate to act upon CPI inflation, the Ramsey planner sets the monetary policy to handle PPI inflation for manufacturing. This is done by fixing a lower nominal interest rate in the economy. This affects the response of investment, which remains stable instead of decreasing as in the decentralized competitive equilibrium. With stable investment, capital is renewed and leads to more stability in the manufacturing output. In addition, given that PPI inflation for manufacturing is controlled, price markups are also partially penalized, contributing to the production of the sector.

Thus, while the dynamic in the agricultural sector remains unchanged, the Ramsey planner response to a weather shock consists of reducing the manufacturing inflation variation, compared to the decentralized competitive equilibrium. As a result, the terms of trade are improved in favor of the farmers' households. Indeed, the policy induces an increase in the rise of relative agricultural prices, while the manufacturing prices are relatively lower than in the decentralized response. The combined effects lead to an increase in the terms of trade, which intensifies the mechanism highlighted in the previous section: farmers' households benefit from the increase in agricultural prices for their revenues, and spend less for the purchase of manufacturing goods, both in terms of private consumption and of production goods. Their consumption is therefore relatively higher than under an non-optimal monetary policy, while the non-farmers' households suffer from higher relative agricultural prices, resulting in a slight decrease in the consumption disparity.

It is interesting to note that the Ramsey planner solution is to focus on PPI inflation for manufacturing instead of CPI inflation. In Appendix C, we conduct an exercise similar to that in Section 5, but replacing the Taylor rule of the Central Bank. Instead of targeting CPI inflation, the Central Bank reacts only to PPI inflation for manufacturing. Figure C-3 presents the differences in the responses of decentralized competitive equilibrium with CPI and PPI inflation targeting. Our goal is to compare the effectiveness of the policies and their welfare implications.

To assess the impact of different monetary policy regimes on welfare in the presence of weather shocks, Table 2 presents welfare levels for both farmers and non-farmers under the three policy scenarios. The first metric refers to the conditional welfare, that is the expected welfare conditional on the initial state of the economy being the deterministic steady state[14]. The second metric is welfare measured at the stochastic steady, which is the equilibrium at which agents would choose to stay in absence of shocks, although they account for future volatility[15]. To facilitate the comparison, we also measure the welfare cost of a particular monetary policy specification relative to the Ramsey policy, defined as the increase in consumption required to make a representative consumer in either sector indifferent between living in an economy with the specific policy and an economy where the monetary authority adheres to the Ramsey policy. We observe that the welfare costs of not adopting the optimal monetary policy are always higher for non-farmers than for farmers. However, under a monetary policy that targets PPI inflation for manufacturing, the welfare costs become negligible for both categories of agents. These results stem from the fact that monetary policy primarily affects the manufacturing sector, with only an indirect impact on the rural sector. As a result, by targeting PPI inflation for manufacturing, the Central Bank can effectively mimic the optimal Ramsey policy.

[14] This is the metric commonly used along with unconditional welfare when comparing different policy regimes. See, e.g., Schmitt-Grohé and Uribe (2007)

[15] On the concept of stochastic steady state, see Juillard and Kamenik (2005). Sometimes this is also referred to as risky steady-state. See Coeurdacier et al. (2011).

Table 2: Welfare

	Ramsey	Rule targeting Π		Rule targeting Π^M	
Conditional welfare		level	cost	level	cost
Welfare F	-48.4761	-48.7398	0.1847	-48.5396	0.0445
Welfare $\bar{F}$	-15.5223	-15.8541	0.2325	-15.5996	0.0541
Stochastic steady state					
Welfare F	-48.3416	-48.5789	0.1662	-48.3906	0.0343
Welfare $\bar{F}$	-15.4866	-15.7854	0.2094	-15.5499	0.0444

Notes: Welfare costs are measured with respect to the Ramsey policy and are expressed in percentage. A positive figure indicates that welfare is higher under the Ramsey policy than under the alternative policy rules.

6 Conclusions

In this paper, we have investigated the optimal monetary policy in response to adverse weather shocks in a two-sector New Keynesian model calibrated for a climate-prone economy, where an agricultural rural sector coexists with a modern manufacturing sector. Given the limited scope of monetary policy in affecting macroeconomic outcomes in agriculture, it is optimal for the Central Bank to respond to the inflationary pressure triggered by a crop-damaging weather shock by stabilizing PPI inflation for the manufacturing sector, rather than the CPI inflation. Targeting PPI inflation can help to stabilize the economy and avoid inflationary pressures, effectively mirroring the Ramsey optimal policy.

Our results are particularly relevant for low- and middle-income countries, where the impact of weather shocks on the agricultural sector is expected to be more severe than in high-income countries. In this regard, our findings highlight once again the importance of considering the specific structure of the economy when designing monetary policy.

Our study has several limitations that will be addressed in future versions of this paper. First, we now abstract from considering the role of fiscal policy to address weather shocks. The optimal monetary policy design is expected to depend on the availability of a fiscal tool that can be employed alongside monetary policy to stabilize the economy. Second, we have not accounted for potential shifts in the variability of weather shocks, and for the repercussions that increased uncertainty can have for inflation dynamics and optimal monetary policy.

Appendix A

This appendix presents the data and the empirical strategy used in Section 2 to analyze the effects of weather shocks on Peruvian economic outcomes. The data used are similar to the ones of Crofils et al. (2024) for the Peruvian context.

Data

We rely on multiple sets of data. First, the economic data are taken from the Central Bank of Peru[16]. We use four key series for our analysis:

- an index for the Gross Domestic Product (in base 100 with respect to 2007, with reference *PN02516AQ*)

- an index for the Agricultural Gross Domestic Product (in base 100 with respect to 2007, with reference *PN02508AQ*)

- the amount of spending in Private Consumption (in million of New Soles of 2007, with reference *PN02529AQ*)

- the Consumer Price Index (relative to the prices in Lima in base 100 with respect to December 2021, with reference *PN38705PM*)

All the time series are extracted on a quarterly basis. Private consumption is then computed as an index in base 100 with respect to 2007. The time series are then deseasonalised using the R package `Seas`[17], expressed in growth rate, and filtered from their trend component using a Hodrick–Prescott filter[18].

The weather variables come from two sources of gridded daily data. The temperature data are obtained from the PISCOt V1.1 database, from January 1981 to December 2016. Precipitation data are taken from the CHRIPS v2.0 database, from 1981 to present. Both datasets are freely available online[19]. We rely on the same aggregation strategy as Crofils et al. (2024), where the authors used the Copernicus dataset to aggregate the data on a regional daily basis by weighting each grid cell with its share of agricultural land.

Finally, the variations in the El Niño-Southern Oscillation (ENSO), exposed in Figures 1 and 2, are obtained from the U.S. National Oceanic and Atmospheric Administration (NOAA, tables available here). Following the definition given by the source, an El Niño event occurs when the index exceeds a 0.5 threshold for 5 consecutive periods. Symmetrically, a La Niña event happens when the index is lower than the -0.5 threshold for 5 consecutive periods.

[16] *Banco Central de Reserva del Perú.* Data can be downloaded here.
[17] See Toews et al. (2007).
[18] See the package `mFilter` here.
[19] See Huerta et al. (2018) and Funk et al. (2015) for the temperatures and precipitations datasets respectively.

Weather Shock Variable

In this analysis, we use on a different method to measure the weather shock than the one of Crofils et al. (2024). Instead, we construct our variable on a quarterly basis as in Natoli (2023). In this paper, the index is built upon region-specific temperature thresholds, corresponding to the 1^{st} and 9^{th} deciles of the temperature and precipitation distributions for each quarter. More specifically, the author computes for each quarter the deciles of temperatures using the observations of the five past years, so the thresholds may evolve with time and therefore temperatures below the lower or above the higher thresholds can be considered as surprises. We adopt a similar method, computing these thresholds for both the averaged daily temperatures and daily precipitation sums.

Having computed these thresholds series, we can count for each quarter the number of days where temperatures and precipitation are outside the interval formed by the thresholds:

$$regional\_surprise^T_{i,t} = \sum_{d=1}^{n_t} [I(T_{i,t} < l^T_{i,t}) + I(T_{i,t} > u^T_{i,t})] - n_t \times 0.2 \times 0.2$$

$$regional\_surprise^P_{i,t} = \sum_{d=1}^{n_t} [I(P_{i,t} < l^P_{i,t}) + I(P_{i,t} > u^P_{i,t})] - n_t \times 0.2 \times 0.2$$

where $i = [1, .., I]$ design the regions, $T_{i,t}$ and $P_{i,t}$ are the temperatures and precipitations for region i at time t. $l^T_{i,t}$ and $l^P_{i,t}$ refer to the quarterly lower thresholds of temperatures and precipitations (i.e. the first deciles of the corresponding distributions using the observations of the five previous years in region i). Similarly, $u^T_{i,t}$ and $u^P_{i,t}$ correspond to the upper thresholds (the ninth deciles of the distributions). Finally, n_t is the number of days within each quarter. Thus, $n_t \times 0.2 \times 0.2$ correspond to the theoretical number of days with temperatures or precipitations outside the thresholds' interval, so that $regional\_surprise^T_{i,t}$ and $regional\_surprise^P_{i,t}$ correspond indeed to surprises concerning the number of days within a quarter with abnormal temperatures or precipitations. These equations correspond to Equation (4) of the paper of Natoli (2023).

Finally, we aggregate those shocks at a national level. Natoli (2023) uses the following formula to aggregate the surprises

$$national\_shock_{t,y} = \sum_{i=1}^{I} (regional\_surprise_{i,t} \times w_{i,y-1})$$

which is equivalent to Equation (5) of the paper, where $w_{i,y-1}$ are regional-level weights proxying their vulnerability to temperatures at an annual frequency. Our approach is very similar, but we use here as weight the average of the regional annual contribution to Gross Value of Agricultural Production between 2007 and 2015, extracted from the National Statistical Institute of Peru[20]. This allows us to better account for the regional importance of weather shocks, depending on

[20] See INEI, *Sistema de Información Regional para la Tomada de Decisiones*. Data available here.

the agricultural production.

Thus, we create two weather shock variables:

$$national\_shock^{T}_{t,y} = \sum_{i=1}^{I} (regional\_surprise^{T}_{i,t} \times w_i)$$

$$national\_shock^{P}_{t,y} = \sum_{i=1}^{I} (regional\_surprise^{P}_{i,t} \times w_i)$$

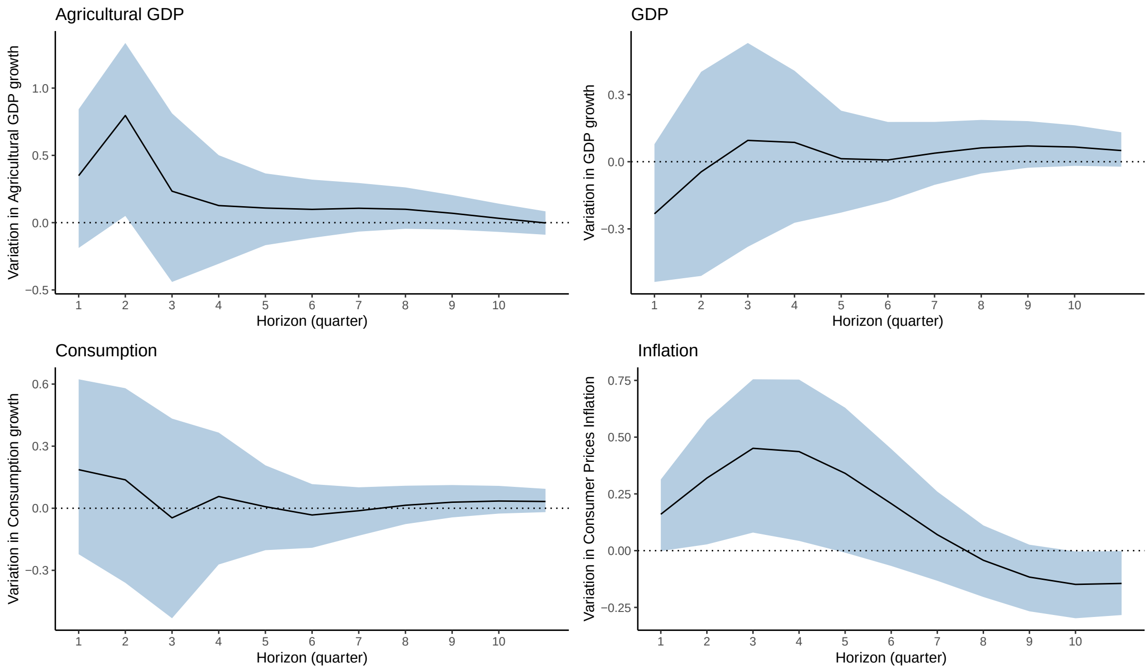
with w_i the time-invariant regional contribution to the national annual agricultural production.

VAR

In addition to the response of the economy following a temperature shock exhibited in Section 2, we present below the response to a precipitation shock. The VAR model is the same as the one presented above.

Contrary to temperature shocks, precipitation shocks can induce an increase in agricultural production variation. This result can be explained by more heterogeneity in the effect of precipitations, because wetter conditions can be beneficial to crop production up to a certain point. The effect of the GDP however can be negative, although not significant in this estimation. We note that the effect on inflation is still positive, leading to inflationary pressures to which the central bank may act.

Figure A-1: VAR model response to a Precipitation shock



Notes: The figure presents the impulse response function of the selected macroeconomic variables following a precipitation shock of one standard variation. The horizon is in quarter and the blue area represents the bootstrapped error bands for a 90% confidence interval obtained with 10,000 runs.

Appendix B

This appendix reports the first-order conditions describing the optimal solution to the agents' problem operating in both sectors and provides a formal definition for the decentralized competitive equilibrium of the economy.

Agricultural Sector

The typical farmer in period t chooses $C_{M,t}, H_t^F, V_t^F, L_t^F$ so to maximize the expected lifetime utility (6), given prices, the flow budget constraint (9), the available technology (2), the land time evolution process (3). At the optimum, the following first-order conditions must hold:

$$\frac{1}{C_t^F} = P_t \lambda_t^F, \tag{B-1}$$

$$\chi_F (H_t^F)^{\eta_F} = \lambda_t^F P_t^A (1 - \alpha_A) Y_t^A \frac{1}{H_t^F}, \tag{B-2}$$

$$\lambda_t^L = \lambda_t^F P_t^M \tau_V \left(V_t^F \right)^{\phi_V - 1}, \tag{B-3}$$

$$\alpha_A \beta \mathbb{E}_t \lambda_{t+1}^F P_{t+1}^A Y_{t+1}^A \frac{1}{L_t^F} - \lambda_t^L + \beta \mathbb{E}_t \lambda_{t+1}^L (1 - \delta_L) \Omega(\varepsilon_{t+1}^w) = 0, \tag{B-4}$$

where λ_t^F and λ_t^L represent the Lagrange multipliers associated with the flow budget constraint (9) and to the land accumulation equation (3), respectively. By combining the above conditions, one can easily obtain the two conditions determining the optimal labor supply and optimal decision regarding land accumulation:

$$\chi_F (H_t^F)^{\eta_F} = \frac{1}{C_t^F} p_t^A (1 - \alpha_A) Y_t^A \frac{1}{H_t^F}, \tag{B-5}$$

$$p_t^M \tau_V \left(V_t^F \right)^{\phi_V - 1} =: \beta \mathbb{E}_t \frac{C_t^F}{C_{t+1}^F} \left[\alpha_A p_{t+1}^A Y_{t+1}^A \frac{1}{L_t^F} + (1 - \delta_L) p_{t+1}^M \tau_V \left(V_{t+1}^F \right)^{\phi_V - 1} \Omega(\varepsilon_{t+1}^w) \right], \tag{B-6}$$

where $p_t^A = P_t^A / P_t$ and $p_t^M = P_t^M / P_t$.

Manufacturing Sector

Intermediate Goods Producers Given the available technology (12) and the demand function $Y_{j,t}^M = \left(P_{j,t}^M / P_t^M \right)^{-\theta} Y_t^M$, the problem of a typical j firm is then to choose $H_{j,t}^{\bar{F}}, K_{j,t-1}^{\bar{F}}, P_{j,t}^M$ to maximize the expected discounted sum of profits.

At the optimum, the first-order conditions with respect to the two factor inputs are,

$$\Phi_{j,t}(1-\alpha_M)B_t^M(K_{j,t-1}^{\bar{F}})^{\alpha_M}(H_{j,t}^{\bar{F}})^{-\alpha_M} = W_t, \tag{B-7}$$

$$\Phi_{j,t}\alpha_M B_t^M(K_{j,t-1}^{\bar{F}})^{\alpha_M-1}(H_{j,t}^{\bar{F}})^{1-\alpha_M} = R_t^k, \tag{B-8}$$

where $\Phi_{j,t}$ denotes the nominal marginal cost of production. Since all firms have access to the same technology and face the same demand functional form, profit maximization implies that all firms choose the same price, that is $P_{j,t}^{\bar{F}} = P_t^{\bar{F}}$ for all $j \in (0, 1-s_F)$, produce the same output $Y_t^{\bar{F}}$, with the same factor inputs. The optimal price setting delivers the following New Keynesian Phillips Curve:

$$Y_t^M - \theta Y_t^M - \chi^P\left(\Pi_t^M - 1\right)Y_t^M\Pi_t^M + \chi^P\mathbb{E}_t Q_{t,t+1}\left(\Pi_{t+1}^M - 1\right)Y_{t+1}^M\left(\Pi_{t+1}^M\right)^2 + \frac{\Phi_t^r\theta Y_t^M}{p_t^M} = 0, \tag{B-9}$$

where $\Phi_t^R = \Phi_t/P_t$.

Households The typical household in this sector chooses $C_t^{\bar{F}}, H_t^{\bar{F}}, I_t^{\bar{F}}, K_t^{\bar{F}}$ so to maximize the lifetime utility (14), subject to the budget constraint (16) and the accumulation equation of capital (17). At the optimum, the following first-order conditions must hold:

$$\frac{1}{C_t^{\bar{F}}} = P_t\lambda_t^{\bar{F}}, \tag{B-10}$$

$$\chi_{\bar{F}}(H_t^{\bar{F}})^{\eta_{\bar{F}}} = \lambda_t^{\bar{F}}W_t, \tag{B-11}$$

$$\lambda_t^q = \lambda_t^{\bar{F}}P_t^M, \tag{B-12}$$

$$\lambda_t^{\bar{F}}P_t^M + \beta(1-\delta_K)\mathbb{E}_t\lambda_{t+1}^{\bar{F}}P_{t+1}^M + \mathbb{E}_t\beta\lambda_{t+1}^{\bar{F}}R_{t+1}^k = 0, \tag{B-13}$$

$$\frac{1}{R_t} = \beta\mathbb{E}_t\left(\frac{\lambda_{t+1}^{\bar{F}}}{\lambda_t^{\bar{F}}}\right), \tag{B-14}$$

where λ_t^F and λ_t^q represent the Lagrange multipliers associated to the flow budget constraint (16) and to the land accumulation equation (17), respectively. Given the definition of $\lambda_t^{\bar{F}}$, the nominal discount factor in (B-9) is then $Q_{t,t+1} = \beta\left(\frac{\lambda_{t+1}^{\bar{F}}}{\lambda_t^{\bar{F}}}\right)$.

By combining the above conditions, one can easily obtain the optimal condition determining the optimal labor supply and the Euler equations on physical capital and risk-free bonds:

$$\chi_{\bar{F}}(H_t^{\bar{F}})^{\eta_{\bar{F}}} = \frac{1}{C_t^{\bar{F}}}w_t, \tag{B-15}$$

$$\frac{1}{R_t} = \beta \mathbb{E}_t \left(\frac{C_t^{\bar{F}}}{\Pi_{t+1} C_{t+1}^{\bar{F}}} \right), \tag{B-16}$$

$$p_t^M = \beta(1-\delta_K)\mathbb{E}_t \frac{C_t^{\bar{F}}}{C_{t+1}^{\bar{F}}} p_{t+1}^M + \beta \mathbb{E}_t \frac{C_t^{\bar{F}}}{C_{t+1}^{\bar{F}}} r_{t+1}^k, \tag{B-17}$$

where $\Pi_t = P_t/P_{t-1}$.

Decentralized Competitive Equilibrium

We are now ready to provide a formal definition for the decentralized competitive equilibrium of the economy. To this end, we define factor inputs in real terms as $w_t = W_t/P_t$ $r_t^k = R_t^k/P_t$.

Definition 1 *For a given nominal interest rate* $\{R_t\}_{t=0}^{\infty}$ *and for a given set of the exogenous process on weather* $\{\varepsilon_t^w\}_{t=0}^{\infty}$*, a competitive equilibrium for the distorted competitive economy is described by a sequence of allocations and process* $\{C_{A,t}^F$, $C_{M,t}^F$, C_t^F, Y_t^A, $C_{A,t}^{\bar{F}}$, $C_{M,t}^{\bar{F}}$, $C_t^{\bar{F}}$, Y_t^M, p_t^A, p_t^M, Π_t, Π_t^M, Φ_t^R, w_t, r_t^k, $I_t^{\bar{F}}$, $K_t^{\bar{F}}$, $H_t^{\bar{F}}$, H_t^F, V_t^F, $L_t^F\}_{t=0}^{\infty}$*, that for a given initial level of land and capital* $\{L_{-1}, K_{-1}\}$ *satisfy the equilibrium conditions:*

1. $1 = \left[\varphi(p_t^A)^{1-\mu} + (1-\varphi)(p_t^M)^{1-\mu}\right]^{\frac{1}{1-\mu}}$
2. $C_{A,t}^F = \varphi C_t^F \left(p_t^A\right)^{-\mu}$
3. $C_{M,t}^F = (1-\varphi)\, C_t^F \left(p_t^M\right)^{-\mu}$
4. $p_t^A Y_t^A = C_t^F + p_t^M \tau_V \frac{(V_t^F)^{\phi_V}}{\phi_V}$
5. $Y_t^A = B_t^A(\Omega(\varepsilon_t^w) L_{t-1}^F)^{\alpha_A} (H_t^F)^{1-\alpha_A}$
6. $\chi_F (H_t^F)^{\eta_F} = \frac{1}{C_t^F} p_t^A \,(1-\alpha_A)\, Y_t^A \frac{1}{H_t^F}$
7. $p_t^M \tau_V \left(V_t^F\right)^{\phi_V - 1} = \beta \mathbb{E}_t \frac{C_t^F}{C_{t+1}^F} \left[\alpha_A p_{t+1}^A Y_{t+1}^A \frac{1}{L_t^F} + (1-\delta_L) p_{t+1}^M \tau_V \left(V_{t+1}^F\right)^{\phi_V - 1} \Omega(\varepsilon_{t+1}^w)\right]$
8. $L_t^F = (1-\delta_L)\Omega(\varepsilon_t^w) L_{t-1}^F + V_t^F$
9. $C_{A,t}^{\bar{F}} = \varphi C_t^{\bar{F}} \left(p_t^A\right)^{-\mu}$
10. $C_{M,t}^{\bar{F}} = (1-\varphi)\, C_t^{\bar{F}} \left(p_t^M\right)^{-\mu}$
11. $p_t^M Y_t^M = C_t^{\bar{F}} + p_t^M I_t^{\bar{F}} + \frac{\chi^P}{2}\left(\Pi_t^M - 1\right)^2 p_t^M Y_t^M$
12. $p_t^M = \beta(1-\delta_K)\mathbb{E}_t \frac{C_t^{\bar{F}}}{C_{t+1}^{\bar{F}}} p_{t+1}^M + \beta \mathbb{E}_t \frac{C_t^{\bar{F}}}{C_{t+1}^{\bar{F}}} r_{t+1}^k$
13. $\frac{1}{R_t} = \beta \mathbb{E}_t \left(\frac{C_t^{\bar{F}}}{\Pi_{t+1} C_{t+1}^{\bar{F}}}\right)$

14. $\chi_{\bar{F}}(H_t^{\bar{F}})^{\eta_{\bar{F}}} = \frac{1}{C_t^{\bar{F}}} w_t$

15. $K_t^{\bar{F}} = (1-\delta_K)K_{t-1}^{\bar{F}} + I_t^{\bar{F}}$

16. $Y_t^M = B_t^M (K_{t-1}^{\bar{F}})^{\alpha_M} (H_t^{\bar{F}})^{1-\alpha_M}$

17. $\Phi_t^R (1-\alpha_M) \frac{Y_t^M}{H_t^{\bar{F}}} = w_t$

18. $\Phi_t^R \alpha_M \frac{Y_t^M}{K_{t-1}^{\bar{F}}} = r_t^k$

19. $\Pi_t = \Pi_t^M \frac{p_{t-1}^M}{p_t^M}$

20. $Y_t^M - \theta Y_t^M - \chi^P \left(\Pi_t^M - 1\right) Y_t^M \Pi_t^M + \frac{\Phi_t^R}{p_t^M} \theta Y_t^M + \chi^P \beta \mathbb{E}_t \left(\frac{C_t^{\bar{F}}}{\Pi_{t+1} C_{t+1}^{\bar{F}}}\right) \left(\Pi_{t+1}^M - 1\right) Y_{t+1}^M \left(\Pi_{t+1}^M\right)^2 = 0$

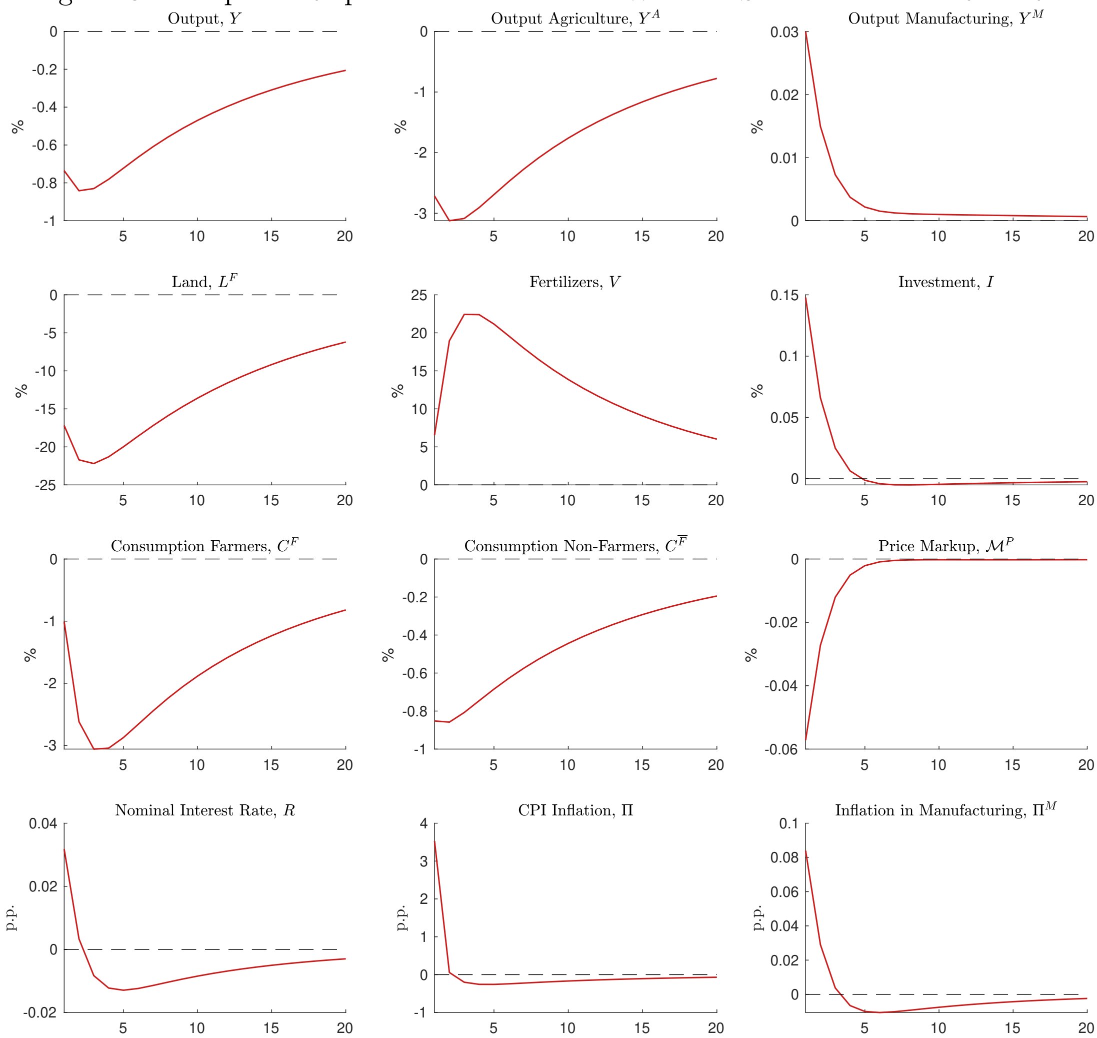
21. $\left(1 - s^F\right) p_t^A C_{A,t}^{\bar{F}} = s^F p_t^M \left(C_{M,t}^F + \tau_V \frac{(V_t^F)^{\phi_V}}{\phi_V}\right)$

Appendix C

Weather Shock under Ramsey Planner

In this appendix, we report some additional results. Figure C-1 shows the response of the economy to a negative weather shock under the optimal monetary policy. In this case, Figure C-1 is analogous to Figure 4 because they both show the response of the economy to a negative weather shock, but they show the response under different policy regimes.

Figure C-1: Impulse Responses to an Adverse Weather Shock - Interest Rate Rule



Notes: The figure presents the impulse responses to a one standard deviation weather shock under the Ramsey equilibrium. All variables are reported as percentage deviations from their stochastic steady-state level, with the exception of the nominal interest rate and of the inflation rates, which are reported as annualized percentage point deviations.

Targeting PPI Inflation in the Manufacturing sector

In this appendix, we also analyze the dynamic response of the economy to an adverse weather shock in the decentralized competitive equilibrium, assuming that monetary policy is now conducted according to a Taylor rule targeting PPI inflation for manufacturing:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\iota_r} \left[\left(\frac{\Pi_t^M}{\Pi^M}\right)^{\iota_{\pi^M}} \left(\frac{Y_t}{Y}\right)^{\iota_y}\right]^{1-\iota_r}, \tag{C-1}$$

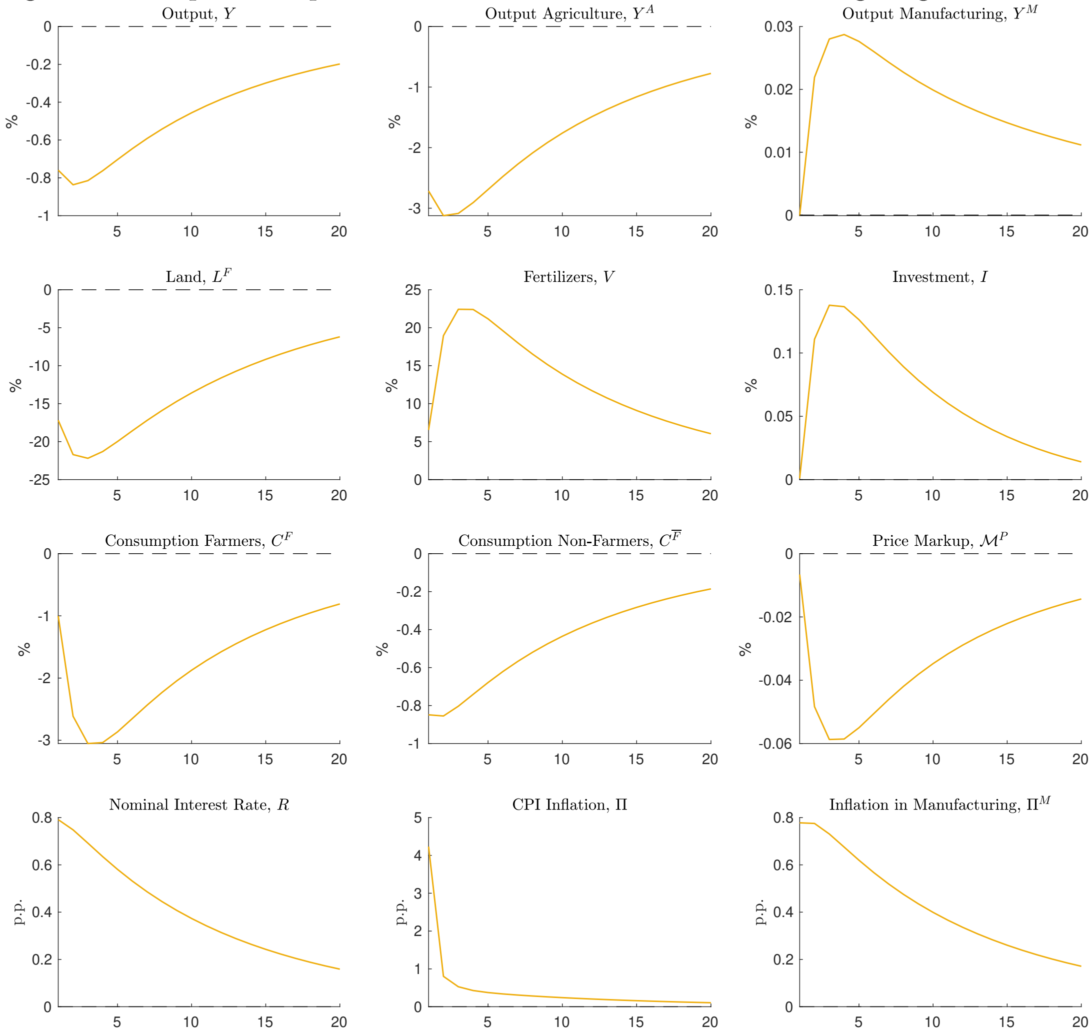
where non-indexed variables refer to steady-state levels, $\iota_r \in [0, 1)$, and $\iota_\pi > 0$ and $\iota_y > 0$. Consistently with what done in the main text, we set $\iota_{\pi^M} = 1.5$ and $\iota_y = 0.125$ and $\iota_r = 0$.

Figure C-2 below shows the results. As for the Ramsey planner case, we observe here that the dynamics of the variables related to the agricultural sector remain the same: a weather shock induces a fall in land productivity, leading to a decrease in agricultural output and a rise in the demand for fertilizers to compensate the productivity losses.

However, the responses in the manufacturing sector differ and are in fact closer to the dynamics of the Ramsey planner equilibrium. Focusing on the stability of PPI inflation for manufacturing leads smaller increase in nominal interest rate. Accordingly, investment reacts less and we observe a decrease in price markups in this sector. The combined effects conduce to a faster recovery of the manufacturing production. In terms of prices, CPI inflation reacts more strongly in the first periods but converges more rapidly to its steady state value. The terms of trade are more affected in this case, because relative agricultural prices increase more than in the CPI inflation targeting case, while the reverse happens for the relative manufacturing prices.

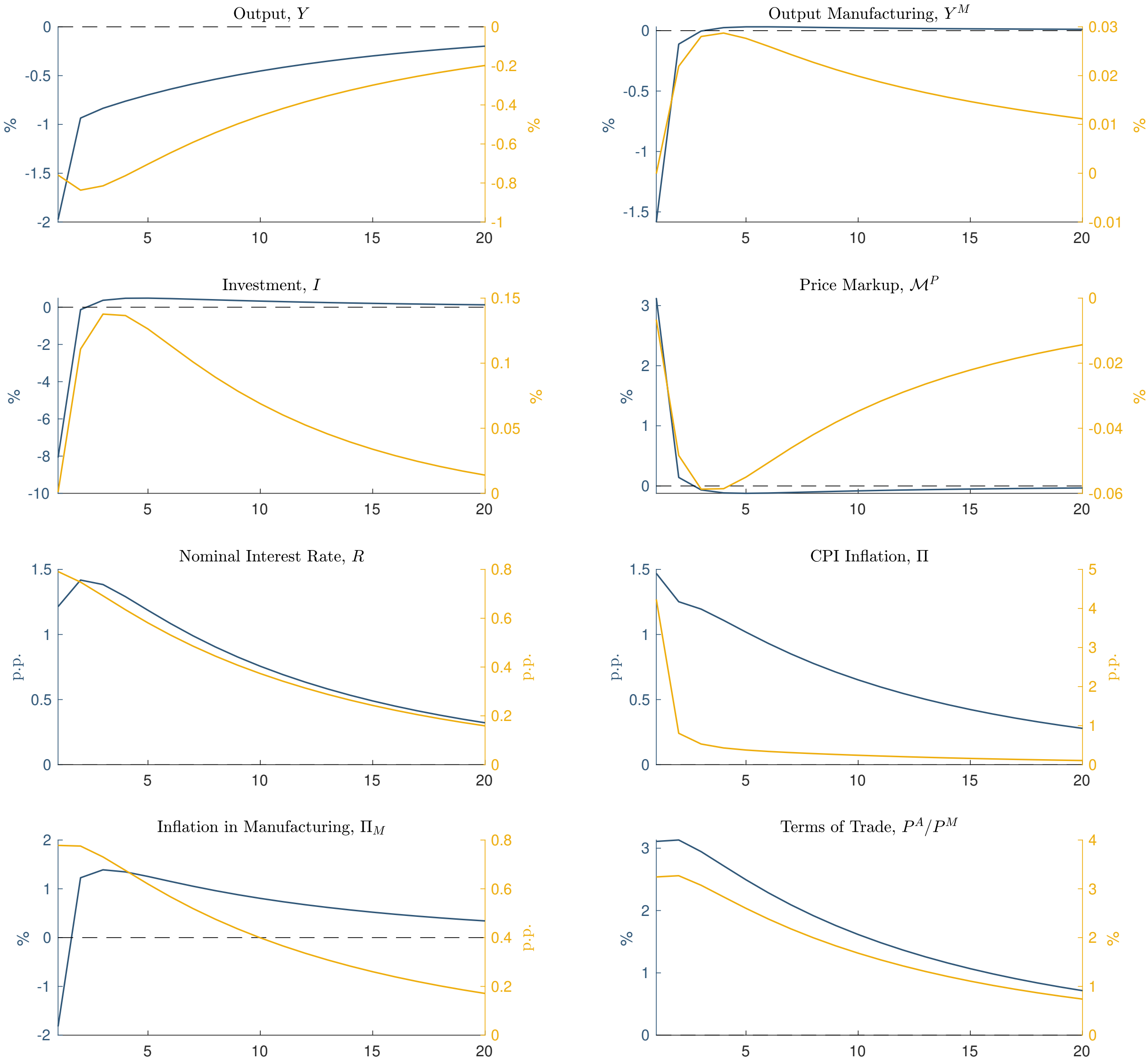
Contrary to Ginn and Pourroy (2020), we find that targeting core inflation (i.e., targeting the inflation of the manufacturing good price in the Taylor rule) is welfare improving. This result is driven by the dual structure of our model. Given that the Central Bank cannot directly affect the agricultural sector and thus the farmers' consumption, its best response is then to maintain as low as possible the variation in manufacturing prices. This response has two effects. First, it allows the farmers to buy production goods at a relatively lower price, which can be used instead for consumption purposes. Second, by maintaining manufacturing inflation, the agricultural prices are relatively higher than in the situation of headline targeting, leading to an increase in the value of the agricultural production and thus of the farmers' incomes. The combined effects conduce to an increase in the farmers' purchasing power, which is lower when the Central Bank targets the overall price inflation.

Figure C-2: Impulse Responses to an Adverse Weather Shock - Targeting PPI Inflation



Notes: The figure presents the impulse responses to a one standard deviation weather shock under the decentralized competitive equilibrium targeting PPI inflation in the manufacturing sector. All variables are reported as percentage deviations from their stochastic steady-state level, with the exception of the nominal interest rate and of the inflation rates, which are reported as annualized percentage point deviations.

Figure C-3: Impulse Responses to an Adverse Weather Shock - CPI v. PPI Inflation Targeting



Notes: The figure presents the impulse responses to a one standard deviation weather shock under the decentralized competitive equilibrium targeting CPI inflation (left-hand side scale, blue lines) and PPI inflation for manufacturing (right-hand side scale, yellow). All variables are reported as percentage deviations from their stochastic steady-state level, with the exception of the nominal interest rate and of the inflation rates, which are reported as annualized percentage point deviations.

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