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THE CETEX DISCUSSION PAPER SERIES: LAND AND OCEAN

Macroeconomic impacts of changes in land use in an agricultural-commodity exporting country: the case of Argentina, 2003–23

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Summary

Climate change and environmental degradation pose significant risks to commodity-dependent developing economies, yet their macroeconomic and financial implications remain underexplored. We use an environmental stock-flow consistent model to examine how land-use changes driven by agricultural expansion and intensification impact balance-of-payments dynamics, wage and price inflation, and financial stability in agricultural commodity-exporting countries.

Exchange rate devaluations and increases in commodity prices boost agricultural output and export revenues, but also lead to increased carbon dioxide emissions and ecosystem degradation, ultimately reducing land productivity. These price changes translate into wage and price dynamics and impact economic activity and constrain investment, raising a policy dilemma: promoting short-term expansion of agricultural exports results in long-term environmental damage and loss of productive capacity.

The analysis demonstrates that physical climate risks, such as extreme weather events, directly impact central bank reserve accumulation by disrupting agricultural exports. The impact is not restricted to the trade balance, since portfolio decisions by non-resident investors take into consideration expected dynamics in foreign exchange accumulation. Using Argentina as a case study, the research confirms that climate shocks represent a material risk to monetary policy implementation in commodity-dependent emerging market economies.

Addressing these challenges from a monetary policy perspective requires a multidimensional framework, with regulatory policies (such as green credit subsidies and loan loss provisions) complementing other, more structural market developments (such as insurance and future markets) to stimulate green investment, avoid inflationary pressures and maintain banking stability.

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The CETEx Discussion Paper Series: Land and Ocean is designed to provide a broader and deeper understanding of environmental risks by introducing economic and financial policymakers to ecosystem degradation issues such as deforestation, pollution and biodiversity loss on land and in the oceans. The series aims to support financial and economic policymakers as they contend with and make considerations for these environmental degradation issues, in addition to climate change. The papers have been written and peer-reviewed by leading experts from academia, think tanks and central banks and are based on cutting-edge research.

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1. Introduction

Over the past decade, numerous research efforts have focused on understanding the macroeconomic impacts of climate change (IPCC, 2018; BCBS, 2021). Some of these impacts are the direct consequences of acute physical risks such as short-lived but more frequent natural disasters (floods, droughts, hurricanes and others) or chronic physical risks such as rising temperatures, rising sea levels and changing rainfall patterns that occur gradually over time. The financial aspects of these impacts have been researched thoroughly (NGFS, 2019; 2022), particularly for emerging and developing countries (IMF, 2017), but the international dimensions of the effects of physical climate risks have been underexplored.

Agriculture is a critical component of the economy when considering climate-related physical risks, particularly in commodity-exporting countries where the sector underpins exports, employment and gross domestic product (GDP). Disruptions to the production of agricultural crops — and consequently, exports — can have significant impacts on key monetary policy variables in emerging markets and developing economies (EMDEs), such as exchange rates, reserve accumulation, credit supply and inflationary pressures. Recent evidence confirms these linkages: physical climate risks can also reduce international capital flows to EMDEs (Lemma et al., 2025), while both transition and physical risks increase sovereign borrowing costs, though the effects vary (Beirne et al., 2021; Boehm, 2022; Dammette et al., 2024; Anyfantaki et al., 2025).

Beyond climate change, nature degradation (IPBES, 2019) — including deforestation, water scarcity and soil degradation — poses direct risks to macroeconomic performance and financial stability. The Network for Greening the Financial System has developed a framework for analysing these risks, including the potential impact on trade and capital flows (NGFS, 2024), and work by the International Monetary Fund (IMF) echoes these concerns (Gardes-Landolfini et al., 2024).

Among nature-related risks, deforestation is particularly relevant for agriculture-dependent economies. Evidence shows that deforestation is primarily driven by agricultural expansion, particularly in countries with comparative advantages in agriculture (Almeida et al., 2024; Farrokhi et al., 2025), creating a reinforcing cycle: countries reliant on agricultural exports for foreign exchange revenues face pressure to expand production, which degrades the ecosystems that sustain agricultural productivity (Dasgupta, 2021). Population growth, even in other countries, further intensifies these pressures on food systems, land use and deforestation (Farrokhi et al., 2025).

> “Countries reliant on agricultural exports for foreign exchange revenues face pressure to expand production, which degrades the ecosystems that sustain agricultural productivity.“

Using an environmental stock-flow consistent model, this paper maps the different transmission channels through which climate and nature risks affect monetary policy implementation in EMDEs, particularly in those reliant on agricultural exports. The model specifically analyses the potential impacts of soil degradation and reduced agricultural productivity on inflation, interest rates and financial stability in an open-economy setting. The effects on the exchange rate are of paramount importance, since they drive wage and price setting, and incentives for expanding the agricultural frontier (i.e. the boundary of agricultural development). The analysis examines the contradictory impacts of international borrowing shocks, which lead to depletion of foreign exchange reserves, and eventual devaluations. Devaluations change profitability expectations of agricultural production, and lead to increased output and the expansion of the agricultural frontier.

In addition, the analysis evaluates policy responses to these potential impacts, in terms of stimulating green loans and penalising brown loans. While some of these dynamics have previously been analysed in a closed-economy setting (Dafermos et al., 2024), and EMDEs' vulnerability to a low-carbon transition has been studied using similar theoretical approaches (Moreno et al., 2024; Nalin et al., 2024), this paper extends the literature by integrating nature-related losses — particularly their impact on agricultural productivity and output — within an open-economy monetary policy framework. This builds on recent work examining nature–agricultural linkages in EMDEs (Yilmaz et al., 2025).

The paper also conducts an econometric study to evaluate the impacts of extreme climate change events on reserve accumulation in Argentina, a major agricultural-exporting economy, for the period 2003–23. The analysis focuses on droughts, severe rainfall and temperature extremes, examining how these physical climate risks impact agricultural yields of the four main export crops in Argentina (soya, corn, wheat and sunflower). In turn, lower yields lead to fewer exports. The impact can transmit to exchange rates and/or losses of foreign reserves, key variables in the implementation of monetary policy in EMDEs. In the case of Argentina, results confirm that these extreme events significantly affected reserve accumulation through their impact on exports. It is worth remembering that Argentina implemented strict exchange controls during this period, and external vulnerabilities to climate change had a bearing on foreign exchange availability. While Argentina is an extreme case, results validate the importance of both short-lived and chronic physical climate risks for the conduct of monetary policy in commodity-dependent EMDEs.

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2. Building the environmental stock-flow consistent model

2.1. Model characteristics

Building on previous research (Godley and Lavoie, 2010; Dafermos et al., 2024), the model consists of an economy with two sectors: a land-dependent sector comprising firms participating in the agricultural sector (denoted 'agricultural' in the model), and other industrial sectors (whose firms are denoted 'industrial' in the model). The agricultural sector, focused on the cultivation of crops, produces for both domestic consumption and for export, while the industrial sector produces only for the domestic market. Both the agricultural and industrial sectors use 'brown' or 'conventional' (i.e. high greenhouse gas emitting) and 'green' (i.e. low greenhouse gas emitting) capital stock, financed by brown and green loans, respectively, from domestic and international banks. Table 1 presents the balance sheet of the different sectors of this fictional economy. Plus signs represent assets, and minus signs represent a liability or net worth. Conventional capital, domestic credit to firms and external credit to the agricultural sector are denoted *Kca*, *Cca* and *Fca*, respectively. Green capital, domestic credit and external credit are denoted *Kva*, *Cva* and *Fva*, respectively. Analogous denominations hold for the industrial sector, with the suffix *f*. In addition, the model assumes that the government issues bonds (*Bp*) to banks (*Bb*) and households (*Bh*) and accumulates foreign exchange reserves (*Rp*).[1]

[1] In this model, the Treasury and the central bank reserves are combined into the public sector.

Table 1. Balance sheet for the model economy

	Households	Agricultural sector	Industrial sector	Banks	Government	External sector	Total
Deposits	*+Dh*			*-D*			*0*
Government bonds	*+Bh*			*+Bb*	*-Bp*		*0*
Conventional domestic credit		*-Cca*	*-Ccf*	*+Cc*			*0*
Green domestic credit		*-Cva*	*-Cvf*	*+Cv*			
Conventional external credit		*-Fca*	*-Fcf*			*+Fc*	
Green external credit		*-Fva*	*-Fvf*			*+Fv*	
Conventional capital		*+Kca*	*+Kcf*				*+Kc*
Green capital		*+Kva*	*+Kvf*				*+Kv*
International reserves					*+Rp*	*-Rf*	
Net wealth	*-Vh*	*-Va*	*-Vf*	*-Vb*	*-Vp*	*-Ve*	*-K*

Table 2 shows the transaction flow matrix of this economy, capturing all the transactions of goods, income and flows of financial assets and liabilities in the model and the relationships between the various economic actors. Keeping with the notation of Godley and Lavoie (2010), a plus sign represents a source of funds (of sales, of wages and distributed profits, of tax revenues, of interest revenues of households, banks and the external sector, of increments in liabilities like bonds and different types of domestic and external credit) and a minus sign represents a use (consumption by households, conventional and green investment by both sectors, interest payments, retained profits, different types of lending by banks and the external sector, and asset accumulation of bonds, deposits and international reserves). In the columns of firms and banks, we distinguish between 'current' (C) and 'capital' (K) transactions. The latter have patrimonial impact, such as investment purchases, retained profits and increments in borrowing.

The following assumptions were made for the model economy:

1. Only the agricultural sector exports, but both the agricultural and industrial sectors import.
2. Firms (of both sectors) distribute part of their profits to households.
3. Banks transfer all their profits to households.
4. Through its expenditure the government transfers to households, purchases from firms, and pays interest on its bonds that are held by banks and households.

Financial balances are matched by changes in assets (deposits, bonds, loans, capital stock, foreign exchange reserves). External debt (green and conventional loans) is entirely borrowed by the non-financial corporations, i.e. the agricultural and industrial sectors.

Physical stocks are another important component of the model, defining the different types of land and the accumulation of carbon emissions in the atmosphere. In the model, there are four types of land: (1) agricultural land (used for agricultural production); (2) urban land (where industries are located); (3) degraded land (i.e. former agricultural land that has lost its fertility), and (4) natural land. Natural land and (to a lesser extent) agricultural land are assumed to produce ecosystem services, while urban and degraded land do not.

"Physical stocks are another important component of the model, defining the different types of land and the accumulation of carbon emissions in the atmosphere."

Table 2. Transaction flow matrix of the model economy

		Households	Agricultural sector		Industrial sector		Banks		Government	External sector	Total
			C	K	C	K	C	K			
GDP	Consumption	-C	+Ca		+Cf						0
	Government expenditure	+Gh	+Ga		+Gf				-G		0
	Conventional investment		+Ica	-Ica	+Icf	-Icf					0
	Green investment		+Iva	-Iva	+Ivf	-Ivf					0
	Exports		+Xa							-X	0
	Imports		-Ma		-Mf					+M	0
Income	Taxes	-Th	-Ta		-Tf				+T		0
	Wages	+W	-Wa		-Wf						0
	Profits	+PD	-Pa	+PRa	-Pf	+PRf	-PB				0
Interests	Deposits	$+Dh*i_d$					$-D*i_d$				0
	Government bonds	$+Bh*i_b$					$+Bb*i_b$		$-B*i_b$		0
	Conventional credit		$-Lca*i_{lc}$		$-Lcf*i_{lc}$		$+LSc*i_{lc}$				0
	Green credit		$-Lva*i_{lv}$		$-Lvf*i_{lv}$		$+LSv*i_{lv}$				0
	Conventional external credit		$-Fca*i_{fc}*\sigma$		$-Fcf*i_{fc}*\sigma$					$+Fc*i_{fc}*\sigma$	0
	Green external credit		$-Fva*i_{fv}*\sigma$		$-Fvf*i_{fv}*\sigma$					$+Fv*i_{fv}*\sigma$	0
Financial balance		Rh	Ra		Rf		Rb		Rp	Re	0
ΔDeposits		-d(Dh)						+d(D)			0
ΔGovernment bonds		-d(Bh)						-d(Bb)	+d(Bp)		0
ΔConventional domestic credit				+d(Lca)		+d(Lcf)		-d(LSc)			0
ΔGreen domestic credit				+d(Lva)		+d(Lvf)		-d(LSv)			0
ΔConventional external credit				$+d(Fca)*\sigma$		$+d(Fcf)*\sigma$				$-d(FSc)*\sigma$	0
ΔGreen external credit				$+d(Fva)*\sigma$		$+d(Fvf)*\sigma$				$-d(FSv)*\sigma$	0
ΔIIRR									$-d(Rp)*\sigma$	$+d(Rf)*\sigma$	0
Totals		0	0	0	0	0	0	0	0	0	

Stock-flow consistent modelling is well-suited to addressing this issue due to its explicit interactions between stocks and flows. In this case, the flow of ecosystem services — such as air and water filtration or flood regulation (Laterra et al., 2011) — is directly contingent upon the quantity and quality of the underlying stock of natural ecosystems. Conversely, anthropogenic flows, specifically greenhouse gas emissions, accumulate in atmospheric stocks that disrupt environmental balance, leading to reduced economic productivity and increased depreciation rates for physical capital. This systemic interaction creates a critical feedback loop: as the flow of ecosystem services diminishes, the resulting environmental stress further accelerates the depletion of natural stocks, potentially leading to a self-reinforcing cycle of ecological and economic degradation.

The final component of the model is the physical flow matrix (Table 3), which builds on recent research on land-use dynamics (Farrokhi et al.,

“Stock-flow consistent modelling is well-suited to addressing this issue.“

2025), incorporating several key mechanisms relevant to commodity-dependent economies. Agricultural frontier expansion — driven by production decisions made by the agricultural sector — occurs at the expense of natural land. Urban expansion primarily comes at the expense of natural land and to a lesser extent, agricultural land. This mechanism reflects the encroachment of real estate developments onto carbon-rich natural ecosystems — such as wetlands — which are critical for biodiversity and greenhouse gas capture. Furthermore, these developments compete with displaced agricultural activities, such as livestock farming, creating a reinforcing feedback loop of land degradation (Totino and Quintana, 2022). Decreased agricultural activity allows natural land regeneration due to reduced pressures from farmland. However, land-use changes exhibit asymmetry: urban land expands with economic growth but does not contract during recessions, i.e. in this model cities are not taken back by nature.

Both agricultural and urban land emit greenhouse gases, depending on the composition of their capital stock: green capital emits lower volumes of greenhouse gases than brown or conventional capital. Natural land and (to a lesser extent) agricultural land absorb greenhouse gases.

Land degradation — affecting both natural and agricultural land — intensifies through two channels: fertiliser application in the agricultural sector and rising atmospheric carbon dioxide concentration. These dynamics create feedback loops with direct implications for agricultural productivity and, consequently, for macroeconomic stability in agriculture-dependent economies.

"Land degradation — affecting both natural and agricultural land — intensifies through two channels: fertiliser application in the agricultural sector and rising atmospheric carbon doxide concentration."

Table 3. Physical flow matrix

	Total land				
Impacts from/ impacts on	**Natural**	**Urban**	**Agriculture**	**Degraded**	**Atmospheric CO_2**
Agricultural land expansion	-		+		
Fertilisers			-	+	
Urbanisation	-	+			
Regeneration	+		-		
Variation of CO_2 atmospheric stock	-		-	+	$\Delta(atCO_2)$
Variation of land stocks	Δ(NLS)	Δ(ULS)	Δ(ALS)	Δ(DLS)	

2.2. Model dynamics and baseline scenario

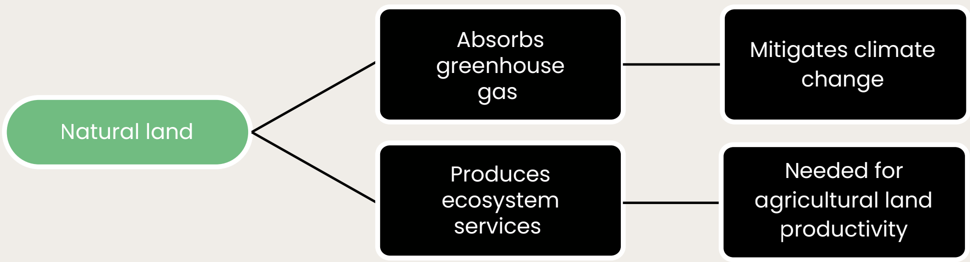
The model is driven by one primary external (exogenous) factor: the economic growth rate in the rest of the world. This affects the economy through two channels: external credit availability (both green and conventional) and agricultural export demand. External credit determines the composition of productive capital stock — specifically, the share of green versus conventional technology — which directly influences carbon dioxide emissions.

The impact on agricultural exports is more complicated, as they and their impact on agricultural output and prices trigger several interconnected mechanisms:

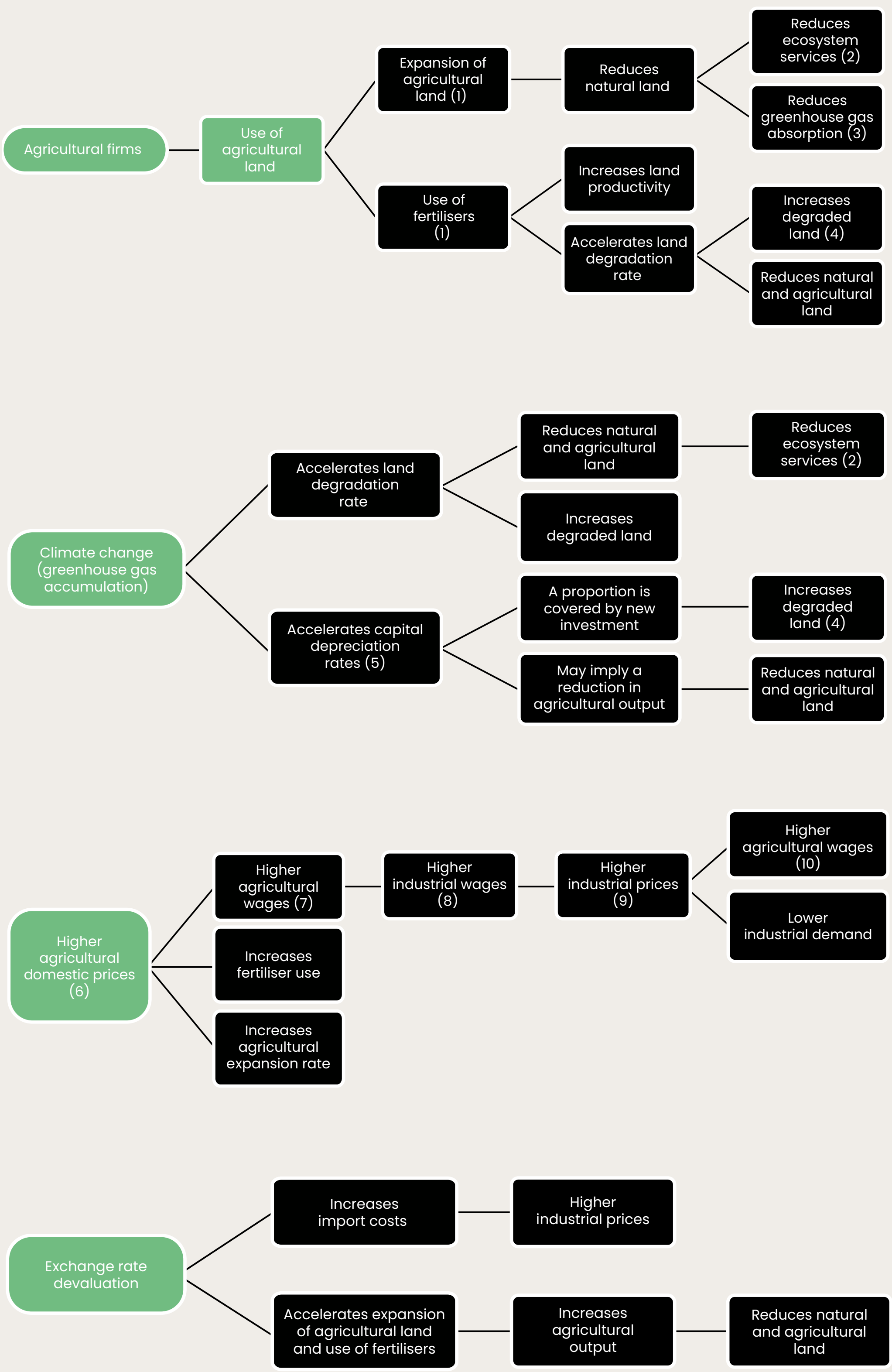
- **Land use dynamics:** Higher levels of agricultural exports drive expansion of the agricultural frontier because of the improved profitability expectations of producers who, as a result, want to expand their output by converting natural land to agricultural use. The resulting fall in the stock of natural land reduces carbon absorption capacity in this economy and increases net carbon emissions.
- **Fertiliser use:** Declining land productivity (due to higher concentrations of carbon dioxide in the atmosphere) increases fertiliser use because producers want to maintain high yields in the short run. However, at the same time, greater fertiliser use accelerates carbon dioxide emissions from land degradation because it leads to less water capture, more weed growth, single-crop farming and poorer soil health.
- **Agricultural productivity (output per area of cultivated land):** Three factors interact to determine yields (harvested crops in relation to cultivated land): (1) frontier expansion reduces productivity due to diminishing returns; (2) atmospheric carbon dioxide concentration further degrades productivity, and (3) fertiliser use provides temporary productivity gains.
- **Capital stock adjustment:** Both types of firms (i.e. agricultural and industrial) have a potential output function restricted by their capital stock. Agricultural firms have an additional potential output function restricted by the amount of land in cultivation and its productivity. Effective agricultural production is equal to the minimum of both potential outputs, as they both produce as much as possible. If the capital stock is the binding constraint determining the sector's production, firms will accelerate investment to approach or reach the output restriction imposed by the land.
- **Price transmission:** Export demand relative to domestic consumption drives agricultural prices, which transmit to wage adjustments and prices in the industrial sector. These price dynamics feed back into land use decisions and fertiliser use.

The diagrams in Figure 1 illustrate several of the model's key transmission channels.

Figure 1. Transmission channels for the model



"Higher levels of agricultural exports drive expansion of the agricultural frontier because of the improved profitability expectations of producers who, as a result, want to expand their output by converting natural land to agricultural use."



(1) Agricultural land expansion and use of fertilisers increase when agricultural firms expect more income (higher domestic or external prices or a depreciation of the exchange rate). Use of fertilisers also increases when agricultural land productivity decreases (a case of 'bad adaptation').

(2) Agricultural land produces ecosystem services, but less than natural land.

(3) Agricultural land absorbs greenhouse gases, but less than natural land.

(4) Degraded land does not produce ecosystem services nor absorb greenhouse gases.

(5) Conventional capital depreciates at a faster rate than green capital, and it is more affected by climate change.

(6) Agricultural product prices fluctuate to ensure equilibrium between domestic demand and the supply remaining after exports.

(7) Agricultural wages increase alongside agricultural prices, but at a less-than-proportional rate.

(8) Industrial wages are a proportion of agricultural wages, with a coefficient greater than unity.

(9) Industrial prices are equal to average variable costs (which include wages) plus a markup.

(10) Agricultural wages increase with industrial prices too, but at a lower proportional rate than for agricultural prices.

2.3. Shocks and policy simulations

Three policy-relevant simulations examine how the economy reacts to domestic monetary policy, to international financial shocks, and to a green financial policy. **The first simulation** endogenises the policy interest rate according to a Taylor Rule (Taylor, 1993), with more sensitive and less sensitive responses to output gap and inflation deviations from the inflation target. The **second simulation** examines changes in the external financing conditions by increasing the international interest rate from a baseline of 2.7% to 7%. The **third simulation** explores low-carbon transition dynamics through changes in external green credit supply and variations in conventional credit costs — domestically, internationally and combined.

Simulation 1: A Taylor Rule experiment

Implementing a Taylor Rule — with sensitive and less sensitive responses — produces broadly similar macroeconomic dynamics but reveals important tensions for policymakers. Initially, the policy interest rate rises above the baseline, but it starts to fall as capacity utilisation remains below the 'neutral range', accompanied by similar movements in industrial prices. Lower interest rates lead to modest output gains, but these translate into persistently higher imports and current account deterioration.

Exchange rate dynamics shift significantly under policy rules. Devaluation occurs earlier than in the baseline scenario (and earlier still in the more sensitive Taylor Rule), though it peaks somewhat earlier (one period before than in the baseline) and at a lower exchange rate level. This earlier devaluation triggers asymmetric sectoral effects: industrial sector output contracts while prices rise due to higher import costs and external debt servicing burdens (Albertazzi et al., 2025). Real wages fall, compressing industrial sector profits. In contrast, profits in the agricultural sector increase, stimulating agricultural investment — though with a higher share of emissions-intensive conventional technology. Rising agricultural profits, partially distributed to households, support consumption and agricultural prices. The overall impact on agricultural prices therefore depends on the retention ratio of profits; simulations confirm that higher profit retention by both sectors moderates agricultural price pressures.

Environmental outcomes worsen in the short term. The earlier devaluation accelerates natural land conversion and increases carbon dioxide concentration. The initial growth slowdown leads to lower (domestic) green credit availability, constraining green investment. However, as the economy stabilises after the devaluation with interest rates below the baseline, investment recovers — particularly in the industrial sector, and the economy functions at a slightly higher pace, in both types of scenarios, but at different levels. Green credit eventually expands ahead of investment decisions, particularly in the agricultural sector, gradually leading to a higher green capital ratio. In short, applying a Taylor Rule for stabilisation in the context of foreign exchange scarcity hastens devaluation, rendering any stability merely temporary. The impact on natural land remains negative because of foreign exchange devaluations, while climate mitigation gains are mediated by economic contraction and are contingent upon the implementation of active green credit policies.

"Applying a Taylor Rule for stabilisation in the context of foreign exchange scarcity hastens devaluation, rendering any stability merely temporary."

Simulation 2: Higher international interest rates

An increase in the international interest rate generates balance-of-payments pressures but reveals complex interactions between external financing conditions, sectoral dynamics and environmental outcomes. Higher borrowing costs increase foreign interest payments, deteriorating the current account and depleting reserves, triggering a devaluation. The exchange rate stabilises at a higher (more depreciated) level, relative to the baseline, creating divergent sectoral responses. Agricultural sector profits rise while industrial sector profits and real wages decline due to higher interest payments, particularly on foreign debt.

Currency devaluation creates opposing environmental effects. The devaluation triggers two countervailing mechanisms with distinct implications for atmospheric carbon dioxide. On the one hand, currency devaluation stimulates agricultural expansion, converting natural land — which provides carbon absorption services — into productive agricultural use. This reduces the ecosystem's carbon absorption capacity, thus increasing net atmospheric carbon dioxide concentrations. On the other hand, devaluation raises domestic prices, particularly for industrial goods. This price increase suppresses domestic demand and, consequently, domestic production (particularly in the industrial sector). This contraction leads to a reduction in carbon dioxide emissions from the industrial sector. However, these effects are also nuanced by distribution of profits and the consumption associated with it. Lower agricultural prices discourage land conversions.

The net environmental impact is ambiguous, depending on several structural factors. Economy-wide outcomes are determined by: (1) the relative size of the agricultural sector; (2) the elasticity of land conversion to price signals; (3) the elasticity of the composition of the capital stock; (4) the green to brown capital ratio as it directly affects the carbon intensity of production (carbon dioxide emissions per unit of output) in the industrial sector. A larger share of green capital would mitigate the industrial emissions, thereby influencing which of the two opposing effects dominates.

> "An increase in the international interest rate generates balance-of-payments pressures but reveals complex interactions between external financing conditions, sectoral dynamics and environmental outcomes."

Simulation 3: Green credit and brown interest rates

Phasing out of brown credit in favour of green credit produces the expected environmental benefits — increasing the share of green capital and reducing carbon dioxide emissions — since the primary constraint on green investment is financial access rather than demand concerns or access to technology. Three additional scenarios explore how different pricing mechanisms (Premiums 1, 2 and 3) for brown credit affect the transition pathway and macroeconomic stability.

Premium 1 raises the cost of international brown credit from 15% above the international reference rate to 30% in 2050. **Premium 2** applies a similar pressure for domestic brown credit, with its rate rising from 50% above the domestic reference rate to 80% in 2050. **Premium 3** combines both international and domestic brown credit premiums simultaneously.

External financing costs critically determine adjustment timing. Scenarios involving higher international brown credit costs (Premiums 1 and 3) generate a contractionary effect on output and imports without additional inflows. As a consequence, this dynamic delays exchange rate devaluation substantially compared to the baseline. Across all simulated scenarios, the exchange rate devaluation occurs either later than (in Premiums 2 and 3) or simultaneously with (in Premium 1) the baseline, driven by a contraction in imports.

Since green credit is cheaper, the debt service burden is reduced in credit conversion scenarios, lowering firms' financial costs and favouring price stability. However, this mechanism exerts pressure on bank balance sheets due to reduced interest income. Notwithstanding, the positive effects on nature are more pronounced than in scenarios where conventional interest rates are penalised and increased. Higher conventional rates lead to price instability, which — in the agricultural sector — incentivises the expansion of the agricultural frontier and intensifies fertiliser use. In scenarios where external debt faces higher servicing costs (Premiums 1 and 3), exchange rate devaluation continues even further than in the baseline, and leads to a higher equilibrium exchange rate, and a higher level of reserves.

3. Econometric tests: evidence from Argentina

The literature shows that physical climate risks pose a significant threat to agricultural production, because of disruptions from rainfall and temperature changes. This is further corroborated by interviews we conducted with farming stakeholders about the challenges posed to different crops. These interviews were very informative for the design of the model (particularly with regard to farmers' price expectations, and the relationship between use of fertilisers, productivity and land degradation). Interviews were also important for identifying the impact of climate change indicators on different crops. We interviewed eight people: an economist specialised in agriculture; a biologist specialised in natural ecosystems; three agronomists with professional backgrounds in the public and private sectors; a geographer specialised in extreme climate events, a politician with experience in public policy regarding the agricultural sector, and a meteorologist. This range of expertise was used for the theoretical model and for the empirical approach developed in this section.

"The impact of physical risks on agricultural exports is not restricted to the balance of trade. The impact of lower agricultural exports on exchange rates can also translate into wage and price decisions."

As mentioned above, the impact of physical risks on agricultural exports is not restricted to the balance of trade. The impact of lower agricultural exports on exchange rates can also translate into wage and price decisions. This paper focuses on a very important variable for monetary policy in EMDEs, specifically management of foreign exchange reserves. To validate the model's predictions and the importance of physical climate risks for the implementation of monetary policy, this section presents econometric evidence from Argentina — a major agricultural exporter where commodity exports critically affect central bank operations, particularly with regard to foreign exchange management and reserves accumulation. Since Argentina's official exchange rate was under strict controls for most of the period under analysis (2011–15 and 2019–2023, see Bortz et al., 2021), we focus on reserves accumulation. The analysis employs a proxy vector autoregression (VAR) approach using quarterly data spanning 2003–23. The stages of this estimation are described below.

3.1. Stage 1: Estimating climate impacts on agricultural productivity

In the first stage, we establish how climate events affect agricultural productivity across Argentina's four main export crops: soya, corn, wheat and sunflower. These commodities comprise the core of Argentina's agricultural export basket and thus directly influence foreign exchange earnings. Climate impacts are captured through four dimensions: droughts and excess precipitation (i.e. rainfall extremes) and heat and cold events (i.e. temperature extremes).

To isolate climate effects from other productivity drivers, we control for fertiliser application, pesticide use and fixed capital investment in agriculture. Using a panel regression, we estimate predicted yields for each crop, region and year, allowing climate-driven productivity shocks to be identified separately from changes in input intensity or capital stock.

Table 4 describes each variable considered, with its frequency and source. As the dataset combines information of different frequencies they have been harmonised to ensure usability.

To estimate the climate impacts on agricultural productivity, a 'predicted yields' variable was constructed for each region and year, capturing climate-driven productivity variation independent of input decisions (see Box 1). This predicted yield measure was converted to an output value by combining it with harvested area per crop and region, and crop-specific prices.

Measuring extreme rainfall events presents methodological challenges. Excess precipitation reduces harvested area — the denominator for yield calculations — creating a measurement constraint: a planted area that cannot be harvested records zero yield rather than reflecting productive potential. This measurement issue tends to weaken the statistical power for detecting impacts of extreme rainfall events. Despite this limitation, Table 5 shows estimates for the impact of each type of extreme weather event on each type of crop.

"Soya, corn, wheat and sunflower comprise the core of Argentina's agricultural export basket and thus directly influence foreign exchange earnings."

Table 4. Variables considered

Variable	Description	Frequency	Source
Agricultural output data	Planted and harvested area, output and yield per hectare per crop since 1968/69	Annual	Ministry of Agriculture
Dry and wet events	Dry and wet events since 1961, calculated by Index of rainfall	Monthly	South America Drought Information System
Daily rainfall and temperatures	Maximum, minimum and average daily rainfall and temperature per weather station since 1961	Daily	National Weather System
Agricultural inputs and investment	Fertilisers since 1961, pesticides since 1990, capital stock and capital investment since 1995	Annual	UN Food and Agriculture Organization
Genetically modified organisms	Share of genetically modified seeds of corn and sunflower on planted area since 1990	Annual	ArgenBio
Prices	Soya, wheat and corn prices since 1990. Sunflower seed prices since 1993	Monthly	Federal Reserve Economic Data, Agrofy News
Foreign exchange reserves	Average and end-of-the-month data	Monthly	Central Bank of Argentina
Financial account data	Portfolio flows, foreign exchange demand by private financial and non-financial sector	Monthly	Central Bank of Argentina

Box 1. Predicted yields variable

The *predicted yields* variable was calculated drawing on expert consultation with the interviewees mentioned above. Drawing on their analyses of the impacts of climate change on the production of different crops, the following regression estimates climate impacts on yields (with $v_{y,i,r}$ as an error term):

$$yields_{y,i,r} = \gamma_0 + \gamma_1\ extremeevents_{y,i,r} + \gamma_2\ inputs_{y-1} + \gamma_3\ tech_{y-1} + v_{y,i,r}$$

i = soy, corn, wheat, sunflower

r = "Pampeana" region, "Chaqueña" region, Northwest Argentina, Northeast Argentina

y = 2003 - 2023

Input control includes fertiliser application, pesticide use, adoption rates of genetically modified organisms for corn and sunflower, and gross fixed capital formation in agriculture. These controls ensure that the climate impact estimates reflect productivity shocks rather than changes in production technology or input intensity.

Table 5. Indicator of adverse extreme weather events for each crop

Crop	Adverse extreme weather events	Explanation	Results
Soy	Summer drought (December, January and/or February)	During this stage, pod development is underway, but a drought condition impedes it	-208.395* (119.489)
	Late extreme cold in spring (October and November)	Soy is a very heat-tolerant crop, but a late frost during the year can affect it	Insufficient information to obtain a significant result
Corn	Wet events (from October to April)	Corn is very susceptible to diseases when exposed to severe rain during almost its entire life cycle	Insufficient information to obtain a significant result
	Spring drought (October, November or December)	During this period, the plant is vulnerable to extreme drought events because it must prepare to enter its reproductive stage	-406.987** (165.771)
	Late extreme cold in spring (October and November)	A frost prior to the reproductive period has a negative effect on the plant's yield	Insufficient information to obtain a significant result
	Extreme heat in spring (October and November)	High temperatures during this period damage flowering	-26.118* (15.652)
Wheat	Wet or drought events in autumn (from April to June)	Wheat is the only winter crop surveyed. These crops are vulnerable to severe climatic conditions prior to their planting	Insufficient information to obtain a significant result
	Wet events in winter (from June to September)	An excess of rainfall during this period drowns the seeds	Insufficient information to obtain a significant result
	Extreme heat in spring (from September to November)	During this stage, extremely high temperatures prevent wheat from transitioning from the vegetative stage to the reproductive stage (in which it generates grains)	-26.292*** (7.541)
Sunflower	Summer drought (from January to March)	Sunflower is the most drought-resistant crop, but during flowering it is vulnerable: its height causes droughts to have a negative impact on yields	-235.145** (104.314)
	Extreme heat in summer (from January to March)	Extreme heat has a negative effect during its flowering stage	Insufficient information to obtain a significant result

*Note: Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.*

3.2. Stage 2: Linking agricultural productivity to reserve accumulation

In stage 2, a proxy variable was constructed for agricultural exports — which captures seasonally adjusted predicted output value per quarter — using four components: harvested surface area, prices per crop, predicted yields per crop (obtained from stage 1) and each crop's weight in the annual distribution of exports. This composite variable, called predicted output value per quarter or vap_t (see Box 2), serves as the proxy for agricultural exports in the VAR analysis, allowing direct estimation of how climate-driven productivity shocks transmit to foreign exchange reserve accumulation. The proxy variable takes different values for each quarter, using the quarterly average of international prices.

Box 2. Predicted output value per quarter

This variable is composed as follows:

$$\widehat{vap}_{y,I} = \widehat{yields}_{y,i,r} * harvestedland_{t,i,r} * prices_{t,i}$$

$$\widehat{vap}_t = \sum_{i=1}^{4} \widehat{vap}_{t,i} * annualdistofexports_{t,i}$$

t = quarters I, II, III y IV

i = soy, corn, wheat, sunflower

r = "Pampeana" region, "Chaqueña" region, Northwest Argentina, Northeast Argentina)

3.3. Stage 3: Impact on reserves

Foreign exchange reserve accumulation responds to multiple external financial account flows, some of which may be considered exogenous. However, two financial flows have direct (endogenous) implications for reserve dynamics. Portfolio flows — dominated by foreign investors — and foreign exchange demand by the non-financial sector (households and corporations) are highly volatile in Argentina (Bortz et al., 2021) and respond to changes in agricultural output. Portfolio investors react quickly to the news of impending droughts or production shocks, adjusting their positions based on anticipated macroeconomic impacts. Foreign exchange demands by residents present more ambiguous dynamics: positive agricultural shocks may increase foreign exchange demand through income effects as producers convert earnings into foreign exchange, while negative shocks to agricultural output can also lead to increased foreign exchange demand, if producers anticipate a devaluation and seek to protect asset values.

"Portfolio flows — dominated by foreign investors — and foreign exchange demand by the non-financial sector (households and corporations) are highly volatile in Argentina and respond to changes in agricultural output."

The VAR specification captures these feedback mechanisms. The model estimates three endogenous variables: foreign exchange reserves (stock variable), portfolio flows (flow variable) and external asset formation (flow variable) by both the financial and non-financial sectors. The exogenous control variable of interest is (the log of) the seasonally adjusted predicted output value per quarter — the agricultural export proxy constructed in stage 2. Four exogenous controls from financial external accounts are also used: (i) *Loans* stands for financial loans, debt securities and lines of credit, (ii) *IMF* for operations with this entity, (iii) *OtherOfficial* for loans from other international organisations and other bilateral sources, and (iv) *FX swaps* for inward/outward use of currency swaps (the main swap lines are with China and the Bank for International Settlements). The specification uses three lags reflecting Argentina's short financial cycles and time horizons for financial decision-making (Bortz et al., 2021; Corso, 2021).

Model validation confirms robust specification

Diagnostic tests confirm the VAR model's stability and stationarity. The framework is validated by a highly significant Granger causality ($p<0.001$), proving the variables' joint predictive power. Furthermore, the specification shows robust explanatory power, with global statistical significance across all individual equations. The results are presented in Table 6.

Table 6. Results of the VAR estimation

	$\Delta IntRes$	$Portfolio$	ΔEAF_{nf}	ΔEAF_{f}
$\Delta IntRes_{-1}$	– (**)	–	– (***)	+
$\Delta IntRes_{-2}$	–	– (*)	– (***)	– (*)
$\Delta IntRes_{-3}$	–	+ (***)	– (**)	–
$Portfolio_{-1}$	+ (***)	+ (***)	+ (**)	+
$Portfolio_{-2}$	– (***)	+ (***)	– (**)	+
$Portfolio_{-3}$	+ (***)	– (***)	+ (***)	+
ΔEAF_{nf-1}	+ (*)	–	+ (***)	+
ΔEAF_{nf-2}	+	+ (**)	+(**)	– (*)
ΔEAF_{nf-3}	–	–	+	+
ΔEAF_{f-1}	– (**)	+	+	–
ΔEAF_{f-2}	+ (***)	+	+	– (***)
ΔEAF_{f-3}	+ (**)	+ (**)	+	+ (**)
$\widehat{vap}$	+ (**)	+ (**)	–	–
$Loans$	+ (***)	+ (***)	–	+ (***=
IMF	+ (***)	– (***)	–	–
$OtherOfficial$	+	+	– (*)	– (***)
$FX\ swaps$	+ (***)	+	+	–

*Note: Since the predicted output value is given in log terms, results report coefficient signs and significance levels: * p < 0.10, ** p < 0.05, *** p < 0.01.*

4. Results and discussion

The econometric analysis confirms that predicted agricultural output value — incorporating extreme climate events for Argentina's four main agricultural exports — has a significant and positive impact on reserve accumulation. While this may sound trivial, the policy implications are profound: extreme climate events identified as statistically significant in the initial panel regression exert negative pressure on the central bank's international reserves through the agricultural export channel. The central bank faces an important constraint to ensure exchange rate stability.

"Extreme climate events identified as statistically significant in the initial panel regression exert negative pressure on the central bank's international reserves through the agricultural export channel."

Central banks can be forced to let the exchange rate devalue or, as in the case of Argentina, implement strict exchange controls. This alternative policy has collateral effects, such as the development of parallel markets and different channels to avoid these controls (i.e. by increasing authorised imports in the official foreign exchange market to get cheaper foreign currency). This further restricts the monetary authority's capacity to contain exchange rate instability, because it has lower foreign exchange supply (due to falling exports) and increased foreign exchange demand (due to increased imports).

Climate risks create dual balance-of-payments vulnerabilities. Beyond the current account channel, predicted agricultural output value also exerts a positive and statistically significant impact on non-resident portfolio investment. This implies that extreme climate events affecting agricultural production threaten stability through two reinforcing mechanisms: deteriorating trade balance (current account) and capital flight risks (financial account). This dual exposure amplifies reserve depletion pressures during climate-related agricultural downturns (such as droughts, floods or abnormal temperatures), potentially forcing earlier or sharper exchange rate adjustments with associated inflationary and external debt servicing consequences, on top of the direct impact of lower exports on economic activity).

Additional findings reveal complex financial dynamics warranting further investigation. In particular: (a) portfolio flows demonstrate lag-dependent effects on both reserves and external asset formation, with coefficients switching signs across periods pointing towards a cyclical pattern (i.e. short-term cycles of exchange rate appreciation, speculative investment and risk-off outflows); (b) IMF loan disbursements have a negative impact on portfolio flows, consistent with evidence that IMF programmes do not facilitate a return to private debt markets (Chapman et al., 2015). Climate-induced reserve pressures may require IMF support to avoid defaults, but the implications can be long-lasting in terms of difficulties to access international debt markets and prolonging financial instability.

5. Policy implications and recommendations

Climate change and nature degradation can significantly affect economic activity and consequently, macroeconomic policy responses, particularly in EMDEs. While many of these effects are analysed widely in existing literature, their impact on the balance of payments and monetary policy in an open economy remains underexplored. This paper contributes by analysing the impact of extreme weather events (particularly, droughts, floods and high temperatures) on agricultural output and reserve accumulation in an agricultural commodity-exporting middle-income economy such as Argentina.

In terms of policy implications for the conduct of monetary policy, reserve accumulation and exchange rate management policies should include potential impacts of climate change and nature degradation in their considerations. In countries like Argentina that have long-standing agreements with the IMF, these should also include safeguards and exceptions for extreme climate weather events, for instance in foreign reserves accumulation and fiscal targets. The concern on exports is aggravated by the impact on portfolio flows. Portfolio flows tend to abandon the country coincidentally with adverse climate events.

"In terms of policy implications for the conduct of monetary policy, reserve accumulation and exchange rate management policies should include potential impacts of climate change and nature degradation in their considerations."

On a macroprudential level, we make policy recommendations to address some of these vulnerabilities. Agriculture is a credit-intensive activity, with exposures for both producers and lenders. Therefore, the development of resilient agricultural insurance coverage and future lending markets in EMDEs should be a top priority to address producers' exposure to climate- and nature- shock events. Moreover, in terms of banking regulation, there are vulnerabilities for banks' balance sheets (Aguirre and Sangiacomo, 2025) that may warrant a policy of climate-related loan loss provisioning and/or a climate-related capital buffer to enhance the stability of the banking sector. Establishing general precautionary loan loss provisions can be complementary to or substitute for environmental risk pricing in loans, as the non-linear dynamics associated with global warming complicate the reliable estimation of risk-based costs (Ozili, 2023). If these measures have downside effects on banks' profitability, they could be complemented with positive measures like subsidies or a lower reserve requirement on climate-adaptation loans. Finally, better models and scenario analysis can help improve banks' exposure to extreme climate events.

In summary, in any expected transition to a low-carbon economy, the issue of external financial stability of agriculture-dependent exporting countries is a very relevant concern. These countries are not only exposed to commodity price fluctuations but also to extreme climate events, which requires precautionary measures. Regarding domestic financial stability (also affected by extreme climate events), green credit policies are a necessary but insufficient policy measure to align a credit lending policy with banks' profitability requirements and for financial resilience.

"Estabilishing general precautionary loan loss provisions can be complementary to or substitute for environmental risk pricing in loans, as the non-linear dynamics associated with global warming complicate the reliable estimation of risk-based costs."

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