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A Stock Flow Ecological Model from A Latin American Perspective

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ABSTRACT

This study aims to develop an ecological stock-flow consistent (SFC) model based on the Latin American–stylized facts regarding economic, financial, and environmental features. We combine the macro-financial theoretical framework by Pérez-Caldentey et al. (2021, 2023) and the ecological modeling of Carnevali et al. (2020) and Dafermos et al. (2018). We discuss two scenarios that test exogenous climate-related shocks. The first scenario presents the case in which international regulation on commodity trade becomes more stringent due to environmental concerns, thus worsening the balance-of-payment constraint of the region. The second scenario concerns the increase in frequency and intensity of adverse climate events in the region. Both scenarios show that the financial external constraint that determines the growth path of Latin American economies may be further exacerbated due to environmental-related issues.

KEYWORDS: Climate Change, Energy Transition, Stock Flow Models, Latin America

JEL CODES: Q54; Q43; E12; N16

INTRODUCTION

Many Latin American countries are commodity exporters highly exposed to climate change. As a result, climate-change–related issues are important drivers for many macroeconomic and financial variables, such as export, investment, currency reserves, fiscal spending, debt ratios, and risk premiums, among others (Nordhaus 2013; Wagner and Weitzman 2016). Understanding the interconnection among the climate, economic, and financial spheres became imperative not only to design proper policy agendas for adaptation and mitigation, but also to shape the development path of the region, redirect investment, rethink the production system, and address social and inequality issues. This study is a first effort in developing an ecological stock-flow consistent (SFC) model for Latin America based on the region's stylized facts regarding economic, financial, and environmental features.

The objective of this paper is to provide a theoretical framework capable of including all relevant economic and financial transmission channels of climate change identified by the literature as well as to provide useful insights on their interconnected functioning. The SFC model here presented combines the macro-financial theoretical framework by Pérez-Caldentey et al. (2021, 2023) and the ecological modeling of Carnevali et al. (2020) and Dafermos et al. (2018). As a result, its main contribution is to expand the financial external restriction argument discussed in Pérez-Caldentey et al. (2021, 2023) with an ecological section that allows the study of how such restrictions function, taking into consideration the environmental perspective. The external financial constraint (Perez et al. 2021, 2023) can be described as the pressure on peripheral economies' growth, derived from their financial integration, openness to short-term speculative flows, and foreign currency indebtedness *cum* currency mismatches. Such pressure may intensify with climate change as events such as climate-related shocks (catastrophes), climate-related regulation, and global warming may cause further restriction on the financial and economic soundness of the region.

Besides providing a theoretical SFC framework for the region, the present analysis selected short to medium-run challenges for LAC. The first scenario discusses the case in which international regulation on commodity trade becomes more stringent due to environmental concerns, thus worsening the balance-of-payment constraint of the region. This is the case, for instance, for changes in international commodity trade, related to deforestation recently approved or under discussion in several commodity-consuming countries. A second scenario concerns the increase in the frequency and intensity of adverse climate events in the region. As global temperatures and greenhouse emissions increase, many meteorological events, such as hurricanes, droughts, and floods, are intensifying, especially in Latin America. A growing number of countries in the region are already suffering such adverse events. Scenario analysis shows that shocks in the environmental sphere impact physical assets and cause supply and trade constraints. They also present financial repercussions, such as higher debt ratios and risk premiums spikes—for both public and private sectors.

The following document is divided as follows. Section 1 gives the reader an overview of the model's structure and describe the transmission channels of climate change on real and financial variables. Section 2 describes our provisional baseline results and early policy experiments. Section 3 presents the conclusions of the work.

AN SFC APPROACH FOR THE CLIMATE TRANSITION OF LATIN AMERICAN AND THE CARIBBEAN

There exist two broad transmission channels of climate risk to the economy and finance (Campiglio et al. 2023). The first channel regards the *physical risks,* that is, the damage that arises from natural hazards (e.g., hurricanes, floods, droughts) and impacts productive capital. The primary sources of physical risk are gradual global warming and the increased frequency, severity, and correlation of specific extreme events. Scientists have found that both sources are not independent, but instead there exists a close relationship between global warming and the increase in natural hazards (Van Aalst 2006; Anderson and Bausch 2006). A second channel of climate risk to the economy and finance is *climate transition*, i.e., policies and regulations implemented to achieve climate target. Transition causes certain assets to become stranded, producing several macroeconomic and financial adjustments in the economic system.

Physical and transition risks, in turn, impact the economy through specific channels, which are detailed in Tables 1a and 1b. From a macroeconomic standpoint, the impact of climate-related issues operates through supply and demand shocks, which ultimately lead to financial adjustment and vice versa. Climate change does have impact on infrastructure, trade, and net wealth, ultimately leading to reduction in consumption and investment. Climate change also influences public spending and government debt, impacting the financial sphere through risk premiums. The volatilities of currency and of financial assets are also important factors to consider when assessing the overall macro-financial impact of climate change.

Table 1a. Demand-Side Macroeconomic Channels Due to Climate Change

	Physical impacts		**Transition impacts**
	From extreme weather event	**From gradual global warming**	
Investment	Damage to household and corporate balance sheets causes reduction of investment Lower profit margin due to higher debt service Currency devaluation and risk premiums	Changes to household and corporate balance sheets affect investment Currency devaluation and risk premiums	Lower demand for traditional ("brown") investment Public investment push ("green new deal")
Consumption	Damage to household balance sheets reduce consumption	Effects on household income Wealth effects due to changes in property prices Effects on corporate balance sheets Effects on public finances	Changes of consumption patterns because of a shift in preferences or taxation (e.g., carbon taxes) Wealth effects due to change in share and bond prices
Trade	Disruption to import/export flows due to climate disasters	Changes to patterns and volumes of trade	Distortions from climate international regulation and asymmetric policies Changes to patterns and volumes of trade
Public Spending	Disruption of economic activity may adversely	Increased severity/likelihood of extreme weather events	Higher subsidies for green transition

	affect tax income/ public revenues Increase social transfer payments Devaluation of the currency and increase external debt service costs	increases commodity prices volatility Changes in agricultural prices Reduced income tax revenues	Higher debt due investment for transition Lower income taxes from traditional activities

Source: adapted from Volz et al. (2020).

Table 1b. Financial Channels Due to Climate Change

	Physical impacts		**Transition impacts**
	From extreme weather event	**From gradual global warming**	
Financial market losses	Loss due to economic activity disruption	Price drops in financial assets linked to activities whose returns decrease with global warming	Price drops in financial assets linked to stranded activity
Interest rate risk	Interest rate rises due higher inflation and capital flights		
Credit risk	Borrowers suffer from reduced cash flows	Borrowers have lower margins and revenues due to lower household and corporate expenditures	Borrowers have lower margins and revenues due to lower household and corporate expenditures Lower solvency associated with stranded activities
Liquidity risk	Growing NPLs will lead banks to tighten their lending criteria	Growing NPLs will lead banks to tighten their lending criteria	Shift in consumer preferences for green products leads to growing NPLs
Risk premium	Higher public debt due to repairing and recovery spending Lower solvency associated with activity disruption		Higher debt caused by higher subsidies for green transition Lower solvency associated with stranded activities
Nominal Exchange rate devaluation	Deterioration of the current account position and the lower availability of international capital		

	Capital flights due to higher risk premium		

Source: adapted from Volz et al (2020).

To model the macroeconomic and financial channels reported in Tables 1a and 1b, we extend the SFC model from Pérez-Caldentey et al. (2021, 2023) by including ecological and energetic modules in the spirit of the work from Carnevali et al. (2020) and Dafermos et al. (2018).[1] The transaction-flow matrix (TFM) reported in the annex presents an economy with five sectors (i.e., private sector, financial sector, public sector, the central bank, and the rest of the world, henceforth RoW). It also includes seven financial assets: (i) public debt issued in domestic and foreign currencies; (ii) private debt issued in domestic and foreign currencies; (iii) debt issued by the RoW; iv) bank loans to the private sector for investment and consumer credit; v) public and private deposits; vi) loans from the RoW borrowed by the domestic financial sector; and vii) cash.

We relied on Pérez-Caldentey et al. (2021, 2023) due to their peculiarity to include specific stylized facts for the Latin American region. In particular, they account for:

(i) the close relation between sovereign risk and sovereign premium, and the feedback between the two variables;
(ii) the influence of risk premium on corporate risk premium;
(iii) the role of currency mismatches in the private non-financial sector, their link with risk premiums and nominal exchange rate;
(iv) the importance of expectations for investment, which is captured by the introduction of an investment confidence index;
(v) the non-linear relation existing between debt and investment for Latin American non-financial sector (Pérez-Caldentey et al. 2019);
(vi) the role of terms of trade in determining Thirwall's Law, nominal exchange rate (NER), short-term cross-border flows, and risk premiums;

[1] From an SFC perspective, we identified and reviewed different Ecological SFC contributions relevant in encompassing ecosystem relationships with the economy. We report in Table 4 in the annex several works with heterogenous levels of detail in describing environmental issues.

(vii) the high penetration of foreign investors into domestic markets whose shift in preferences are often followed by outflows and currency depreciation; and

(viii) the concern of central banks in the region on the level of exchange-rate volatility, here captured by a volatility index that determines, together with the Taylor's rule, the target-bond level central banks want to hold.

By including ecological and energetic modules in the spirit of the work from Carnevali et al (2020) and Dafermos et al. (2018), we are able to include additional important stylized facts for the region, namely:

(i) the effect of extreme weather events on commodity exporters;
(ii) foreign investors' shift in demand for debt instruments due to climate-related concerns;
(iii) the empirical evidence that government makes exceptional outlays when facing extreme events; and
(iv) the role of debt ratios for small economies facing adverse climate events.

In the following subsection, we introduce the model emphasizing its ability to capture climate-change–related issues. For a more comprehensive description of the traditional functioning of the financial and real variables, we recommend reviewing Pérez-Caldentey et al. (2021, 2023).

Production, Income, Wealth, and Consumption

Consumption, private investment, public spending, and trade with RoW determine firms' sales levels. In turn, firms' expectations of the level of sales depends on the previous level of sales adjusted for the world GDP growth. As the system does not operate at full employment, each period there exists a target of inventories the production sector accumulates. Expected sales and the misalignment of inventories from their target determine the production level. Private-sector consumption is specified as a function of private expected disposable income and households' wealth. The former is a proportion of household disposable income, which, in turn, is defined as the sum of wages and profits distributed from firms to households. Households' profits determine the consumption level, the demand for money, and the demand for financial assets.

Household profits depend on the wage bill, remittances, interest received on deposits and government bonds, and net interest paid on consumer credit.

Net wealth (assets minus liabilities) is an important channel in transmitting the effect of climate change on the economy (see Table 1a). Households may lose net wealth directly by suffering damages to physical capital as a result of extreme weather events. In addition, they may also suffer loss in net wealth from price drops in financial assets linked to sectors whose returns decrease with global warming (such as agriculture) or come from activities that will be stranded by transition policies. In the model, household loss of net wealth leads to a demand shock in consumption, as agents tend to reduce consumption to compensate for the loss of wealth. Lower consumption will cause lower revenue inflows for firms, exacerbating the physical damage to their productive capacity via climate change. Finally, the public sector may also suffer a loss in net wealth due to damages in public infrastructure caused by climate change.

Public Sector: Government

The public sector collects taxes on income and imports, and a portion of these taxes goes to repaying the public debt principal. Real spending fluctuates each year according to the growth rate of government spending, the latter being conditioned by domestic GDP growth. The total amount of public debt issued depends on the public sector budget constraint, i.e., the difference between public inflows and outflows alleviated by central bank profits earned by holding reserves. A fraction of the debt is issued in foreign currency. The debt supply equals the minimum between sectoral demands and total-public financial needs.

Shock in public spending is a crucial demand-side macroeconomic channel for climate change. Extreme weather events and global warming may adversely affect tax income and public revenues, leading to a reduction of aggregate demand via the multiplier effect. For instance, extreme weather events reduce tax revenues as a result of households' and firms' losses in income and wealth; on the other hand, global warming causes commodity price volatility (Peersman 2018)—a crucial variable for the Latin American region in terms of economic performance and public revenues. Transition and mitigation policies also have fiscal implications. On the one hand, the transition will require the commitment of public investment to achieve a more sustainable and resilient economy; without proper financing, higher debt ratios are to be expected. Also, for many countries in the region, transition toward a greener economy involves lower income taxes from traditional activities (OECD/The World Bank 2019).

Private Sector: Firms

Firms' profits are fundamental in determining the level of investment and corporate debt issuance. A proportion of firms' net profits is retained for investment in physical capital. If retained profits exceed investment, the surplus will be used to acquire financial assets. Also, part of the non-retained profits is used for consumption. An important contribution of the model is the role of expectations in investment decisions. In each period, investment flows vary according to the evolution of capital depreciation and the performance of the investment confidence index. Prospects of future returns, jointly with the growth rates of the domestic and foreign economies, are the determinants of the investment confidence index. Profits expectations are a function of two elements: the return on investment (ROI) and the corporate risk premium (CEMBI).

The impact of profit expectations and domestic and RoW growth rates on the investment confidence index depends on specific sensitivities, a nonlinear function of a firm's leverage-to-output ratio, and domestic and RoW growth. If the investment level exceeds profits retained for investment, firms issue debt; a proportion of this debt is issued in local currency and the remainder in foreign currency. Local currency debt can take the form of loans or corporate bonds.[2]

Climate change and transition policies impact firms' investments through real and financial channels. Intuitively, firms may suffer wealth losses facing adverse climate events that damage physical assets and infrastructure. They could also experience lower sales and revenues due to a decrease in household expenditures associated with wealth loss caused by climate change or transition policies. Profitability is an important channel too. Climate change or transition policies may cause debt in the private or public sector to rise (OECD/The World Bank 2019) – indeed, as

[2] The financial sector mainly purchases the latter; if the issuance of corporate bonds is greater than the financial sector demand, then foreign investors will buy the difference.

a result of shifts in policy, technology, and market preferences, firms may experience lower profit margins and unstable cash flows, leading them toward a higher debt ratio (Volz et al. 2020). As we will shortly introduce, debt ratios are drivers of country risk and corporate premiums. As a result, higher risk premiums— which in turn raise the cost of borrowing—are a consequence of climate change (Kling et al. 2020). The latter makes the ROI index fall and drags down the confidence index, ultimately affecting firms' investment decisions and reducing capital accumulation.

Currency devaluation may also be linked to catastrophes, global warming, or stranded activity (Hale 2022), which is of particular interest for Latin America as the region has substantially increased foreign leverage in the corporate sector (Pérez-Caldentey et al. 2019; Nalin and Yajima 2021). Within this context, currency depreciation could decrease firms' balance sheet and lead to further contraction in investment.[3]

Trade and Balance of Payment (RoW)

Thirlwall's law governs trade with RoW; that is, the export and import quantity demanded is conditioned to foreign and domestic–GDP growth and the performance of the exchange rate and relative prices. As usual, current and capital accounts track the movement of financial and real flows between RoW and the domestic economy. Concerning the RoW portfolio, on the one hand, the RoW demand for government bonds issued in local currency depends on global GDP growth, interest spreads, and exchange rate expectations. On the other hand, the demand for government bonds issued in foreign currency is determined by interest rate differentials. The sum of government and private bonds purchased by RoW is equal to world financial flows (WFF).

The total supply of RoW bonds to the domestic economy is the sum of bonds demanded as reserves accumulation by the private and public sectors. In this case, the model assumes that supply always matches demand and that the international interest rate is exogenous, as is world GDP growth.

[3] There exists a financial channel that unfortunately is yet to be modelled in our work, but still deserves a mention. Recall that firms retained a proportion of their profits to acquire financial instruments. Thus, drops in the price of financial assets generate balance-sheet loss and, thus, their investment adjusts downward to lower firms' wealth.

Trade flows and cross-border finance are also directly influenced by climate change (Dellink et al. 2017; UNCTAD 2019) and may ultimately redefine the BoP constraint of the Latin American region. Physical damage and disruptions to critical transport infrastructure and activities impose constraints on international trade due to the physical impossibility of shipping goods from or to damaged infrastructure, increased transportation costs, or the longer time required to deliver goods internationally. Aside from physical damages, a new global trend for greener products may gradually shift consumer preferences. Also, new environmental standards associated with global trade are currently emerging and will impact the region over longer horizons, permanently changing patterns and volumes of trade.

As a result of either environmental regulation or changes in international trade patterns, the current account position may deteriorate. Whether the economy is already showing a current account deficit, a deterioration in the current account position pressures public financing, raising the stock of debt and its service. Nevertheless, raising external financing when global financial markets shift toward ESG portfolio dynamics may be challenging. Because of climate concerns, capital may face permanent exclusion from foreign direct investment, portfolio investment, and debt flows (Löscher and Kaltenbrunner 2023). Ultimately, the deterioration of the current account position and the lower availability of international capital generates a worrisome reduction in inflows that could couple with the enlargement of the sovereign risk (Pérez-Caldentey et al. 2021; Moreno-Brid et al. 2022). Additionally, climate-related losses in the banking system—which will be explained shortly —could lead to capital flights that may negatively disrupt both the exchange rate and the balance of payments. Transition policies may further drive the balance-of-payments constraint. Indeed, countries currently dependent on fossil fuel exports (imports) may experience the deterioration (improvement) of their constraint concerning whether they can substitute fossil fuels with domestic renewable energy (Volz et al. 2020).

Financial Sector

The financial sector's main function is lending resources to the private sector. On the one hand, it provides consumer credit when households' wage bills are lower than their consumption. It also finances private sector investments with loans. In this case, the demand for loans depends on profits and capital expenditures. It is assumed, for simplicity, that the financial sector's supply of consumer credit and loans always matches demand. The sum of consumer credit and loans corresponds to the total volume of private sector deposits in the financial sector.

Interest payments received on holdings of financial assets and foreign reserves represent the financial sectors' inflows, while interest paid on foreign loans and central bank advances corresponds to outflows. The difference between inflows and outflows determines profits. A part of the profits is used to accumulate wealth through financial assets: government bonds (in local and foreign currency), private debt (only in local currency), and foreign debt used as reserves. The demand for each type of asset reflects the arbitrage conditions postulated by Godin and Yilmaz (2020).

The financial sector covers its financial needs by issuing two types of liabilities. These are advances from the Central Bank and foreign currency bonds bought by RoW. The advances are calculated as a proportion of the sector's financial needs, which is exogenously given. The remaining financial needs are covered by bonds issued in foreign currency and sold to the RoW.

There are several implications of climate change and transition policies for the financial sector. To start with, credit risk may rise with physical climate risks, as borrowers suffer from reduced cash flows during the adverse event or even during climate transition (Boissinot et al. 2016). As non-performing loans (NPLs) grow, banks experience more liquidity risk. Overall, growing NPLs will lead banks to tighten their lending criteria. A similar situation is given with transition policies, as a shift in consumer preferences for green products leads to growing NPLs in stranded activities. Unfortunately, at this stage the present model we are unable to capture these effects. A new version, coming out in the foreseeable future, will include them.

Risk Premiums, Nominal Exchange Rates, and Interest Rates

Risk premiums (corporate and government), nominal exchange rates, and interest rates represent critical channels through which climate change can affect a developing country (Volz et al.

2020). Empirical estimates (Hilscher and Nosbusch 2010) suggest that the debt-to-GDP ratio, foreign debt-to-GDP ratio, reserves, and exchange rate variations are the main determinants of sovereign premium (here defined by EMBI). In turn, corporate risk is a function of EMBI, the currency mismatch—one of the growing concerns in the Latin American region (Pérez-Caldentey et al. 2019; Nalin and Yajima 2021)— in the ratios of foreign liabilities to foreign assets, and the loans-to-GDP ratio.

The nominal exchange rate follows an autoregressive process of the first order, affected by FX traders' expectations—we include speculative versus fundamentalist traders (Lavoie and Daigle 2011)—financial flows from the RoW, sovereign risk, and the terms of trade (TOT). The domestic interest rate depends on the international rate and government risk (EMBI). It also varies according to the demand and supply of bonds (Godin and Yilmaz 2020); whenever an excess demand exists, the interest rate will decrease as a consequence. The nominal interest rate on foreign-denominated debt is obtained by adding a premium to the international interest rate, where the latter is a function of EMBI. Private sector nominal rates on domestic and foreign debt work similarly.

Climate change increases disaster risk, which, in turn, undermines economic prosperity and stability. Thus, higher propensity to climate risk is also associated with higher risk premiums (Mallucci, 2020; Voz et al., 2020). Climate change and transition may cause negative feedback loops among government debt-to-GDP ratios, sovereign risk, outflows, and exchange rate—what may generate "a climate Minsky moment."

Central Bank

The central bank follows a classic Taylor rule: it determines its desired monetary policy rate according to inflation and output growth deviations from its target level. Monetary policy functions through government bond purchases. The central bank demands domestic bonds according to a target level, which depends on the behavior of the credit market and exchange rates. As the interest rates is a function of the interaction between the demand and supply of bonds, an increase in the target of domestic bonds purchased by the central bank will put downward pressure on rates, which will adjust consequently, changing the demand for domestic bonds and influencing the behavior of the exchange rate. The ideal amount of bonds the central bank is willing to hold depends on the interest rate differential between the current rate and the central bank's target rate and the observed volatility in the exchange rate (calculated as the moving average standard deviation of the nominal exchange rate). When volatility exceeds three standard deviations, its coefficient will take a value of one, and the demand for bonds will adjust accordingly. The amount of domestic government bonds allocated to the central bank is the maximum between its demand for bonds and the unallocated residual to the financial sector, private and external. RoW's supply of international reserves to the central bank is unlimited. Central bank profits are employed for purchasing financial assets. Central bank savings correspond to uninvested profits. Finally, the amount of money issued is the residual of the central bank's budget constraint; that is, it is issued to finance the difference between profits before portfolio investment and portfolio purchase.

Climate change has several implications for monetary policy. Indeed, central banks may raise interest rates to counter inflation resulting from climate-related phenomena. When a tight monetary policy increases, borrowing costs rise for the private and public sector, likely leading to a contraction in profits. As a result, consumption and investment are subdued.

Environmental Relationships

We follow the approach by Dafermos et al. (2018) and Carnevali et al. (2020) to model the impact caused by global warming on the economy. In particular, we postulate a damage function *a'la* Nordhaus (2013), who describes the impact of the increase in atmospheric temperatures over flow variables such as real consumption, labor productivity, and private investment. All of the abovementioned variables are affected negatively by a rise in temperatures.

An important innovation of the present model is the inclusion of a dummy variable that accounts for extreme weather events by adopting that takes the value of one for observed adverse events such as hurricanes, floods, and droughts. The dummy variable takes a value from one to five according to the intensity of floods, hurricanes, and drought. If enacted, the dummy negatively affects real consumption, business sales confidence, the elasticity of demand of RoW for the government debt denominated in both local and foreign currency – respectively equations (7), (13), (32), (68), (124), (126), (138), and (139) in the annex. The introduction of the dummy also allows the system to increase short-term government spending following disasters and the risk premia for both the public and the private sectors.

Ecosystem Module

The ecosystem module is the core of our simulation as it connects the activity level with the physical flow of material and energy and the accumulation and depletion of physical stocks. Table 2 is a graphical depiction of the first and second laws of thermodynamics, as the sum of the material inputs (resources) such as matter and energy (both renewable and non-renewable) shall equal the change in socioeconomic stock such as the sum of CO_2 emissions, waste, and dissipated energy. The fact that some energy inputs, such as fossil fuels, are dissipated captures into our model the second law of thermodynamics. Table 3 encompasses the evolution of human-related stock of matter for, namely, material and non-renewable energy reserves, atmospheric CO_2 concentration, and the socioeconomic stock. Each year's opening stock of matter is augmented by their net addition, such as emissions (plus the absorption of the biosphere) or the conversion of reserves into resources (net of the use or extraction of energy and matter) to obtain its final stock.

Similarly, the difference between the socioeconomic stock for each year is given by the production of material goods minus their disposal. Conversely, hazardous waste is accumulated over time by non-recyclables. In an open-economy setting, we should count the physical stocks and flows for the local economy or region and the rest of the world into the two matrices.

Looking at the behavior of material resources and reserves, producing material goods and extracting matter in each area depends on the respective activity level. The recycled socioeconomic stock is a fraction of discarded socioeconomic stock, which depends on flows of durable goods. The latter evolves according to the local demand net of the trade balance. Hence, the accumulation of the socioeconomic stock is given by the production of material goods net of the depletion of the socioeconomic stock. Waste is given by matter exaction minus the change in socioeconomic stock. The conversion of material resources into reserves takes place at an exogenous rate. Finally, the mass of oxygen is given by emissions, minus the carbon mass of non-renewable energy, which is also a fraction of emissions.

The activity level gives the energy requirement for production in each area. Energy comes from both renewable and non-renewable sources, as their shares over the total energy demand are exogenously given. The evolution of the stock of energy reserves depends upon their conversion minus the demand for non-renewables, as their conversion into reserves reduces the stock of energy over time. Industrial emissions are a function of non-renewable demand, while the worldwide emission is augmented by the annual CO_2 emission from land, which grows at an exogenous rate. CO_2 concentrations at the three global layers (atmosphere, biosphere/upper ocean, and deep ocean) are interrelated but driven by the atmospheric concentration of CO_2, which depends upon their emissions. Finally, the atmospheric temperature adjusts to its previous values corrected by the radiative forcing over pre-industrial levels, as the lower ocean temperature follows.

Energy and material resources impact on the economic system via three channels: a) they constrain investment decisions and thus output once the matter and the energy-determined capacity utilization surpass their normal or equilibrium level—the former being defined as the ratio of output over the matter (energy)-determined potential output; b) they affect prices via the mark-up on historical unit cost, which is modelled as a positive function of both the matter and the energy determined capacity utilization; c) they influence directly financial risk premia and credit.

BASELINE RESULTS AND SCENARIO ANALYSIS

Baseline Scenario

We run a preliminary scenario to verify the ability of the model to capture ecological and macro-financial–stylized facts for the region. The simulation runs from 2008 to 2021, and parameters are taken from Pérez-Caldentey et al. (2021, 2023) and Carnevali et al. (2020) but are also arbitrarily defined to stabilize the model and replicate the stylized facts for the region. To run the baseline estimates, we use observed data for industrial emissions from Ritchie et al. (2020), whereas data for both atmospheric and lower ocean temperatures are taken from IEA (2022). Gross fixed-capital formation, public debt, exchange rates, interest rates, and GDP data are drawn from CEPALSTAT (2022).

All budget restrictions derived from the transaction matrix for each institutional sector, reported in the annex, show a null value, suggesting the model is stock-flow consistent and properly accounts for the intersectoral exchange of flows and the associated variation in stocks.

The annex reports a set of graphs for the baseline scenario with the main macroeconomic, financial, and environmental variables and their comparison with the observed series. The objective of running a baseline scenario is to verify the ability of the model to replicate stylized facts and shed light on how transmission channels work and interact among them. However, some caution is needed in interpreting its results; they are intended to explore the theoretical links among climate and economic spheres rather than being interpreted as econometric forecasts.

Preliminary results capture trends and turning points of several observed variables, such as gross fixed-capital formation, total public debt (both in local and foreign currency), exchange-rate variation, domestic policy rate and GDP-growth rate. Results are validated through cross correlation tests, reported in the annex (Figures 12, 13, and 14).

Concerning macroeconomic variables, Figure 2 in the annex presents the behavior of investment, public debt, variations in the exchange rate, the interest rate, and economic growth. Variables such as GDP growth, capital formation, EMBI, and interest rate report an average correlation ranging 0.6 to 0.8, indicating the baseline scenario fits properly with real data. Others, such as debt ratios, can capture the upward trend reported in observed series, yet they still need to approximate the correct magnitude.

From an environmental perspective, the baseline scenario reflects what is known as the “business as usual” scenario—i.e., a situation in which production and consumption follow current patterns, and no mitigation or transition measures are in place. By extending the simulation to 2030, preliminary results suggest that the model captures the upward trend observed in growth averages for atmospheric temperature, ocean temperature, and emissions in Latin America and RoW. In line with existing literature, the baseline suggests that without any policy action, the business-as-usual model is bound to cause further temperature increases in the atmosphere and the oceans.

Figure 6 in the annex reports the behavior of relevant financial variables—nominal exchange rate, volatility index, CEMBI, EMBI, mismatch index, investment-to-GDP ratio, profit-to-sale ratio, private-debt–to-GDP ratio and debt-to-GDP ratio—including their projections until the year 2030. A crucial preliminary conclusion from the baseline simulation concerns the fact that climate change deteriorates the financial conditions of the region, suggesting climate change does not only represent an environmental phenomenon but should be considered a macro-financial element for the region's long-term stability and development. The baseline simulation indeed suggests that as long as global temperatures increase, so would public debt ratios and premium risk, while the nominal exchange rate would suffer from depreciation and volatility. Furthermore, the private sector would experience lower return on investment, higher debt, and currency mismatches. Capital in the region would be scarce, and piling stock of foreign debt could induce a negative financial external constraint. As a result, lower investment ratios would negatively affect economic growth, employment, and wages. All in all, the result suggested by the baseline scenario is in line with the main literature (Nordhaus 2013; Wagner and Weitzman 2016).

Scenario Analysis

The present section evaluates two scenarios in which Latin American countries may be involved in the near term, namely:

(i) shocks in export elasticity resulting from environmental trade regulation (demand shock); and

(ii) changes in the frequency and intensity of extreme weather events joined with a drop in the normal energy and matter utilization rate (demand and supply shock)

Shocks in the Elasticity of Exports Result from Changes in the Rest of the World

The first scenario evaluates the role of external constraints when the economy faces changes in international environmental regulation that influence the country's ability to export. The Deforestation Free Products regulation, the Forest Act, and the Environment Act—respectively put forward by the EU, the US, and the UK—are examples of such legal shift in commodity trade standards. According to these regulations, commodities such as beef, soy, wood, coffee, cocoa, and palm oil, will only be imported if there is valid proof of the absence of deforestation. Considering that these regulations also include derivatives and by-products of these commodities (i.e., leather, pulp wood, biofuels, etc.), their potential impact on the trade balance of Latin American economies may be considerable, as they are relatively undiversified in exports of agricultural products. For those countries that will fail to comply with this regulation within the next few years—i.e., developing proper traceability systems with georeferentiation of their products—regulation will restrict access to important international markets.[4]

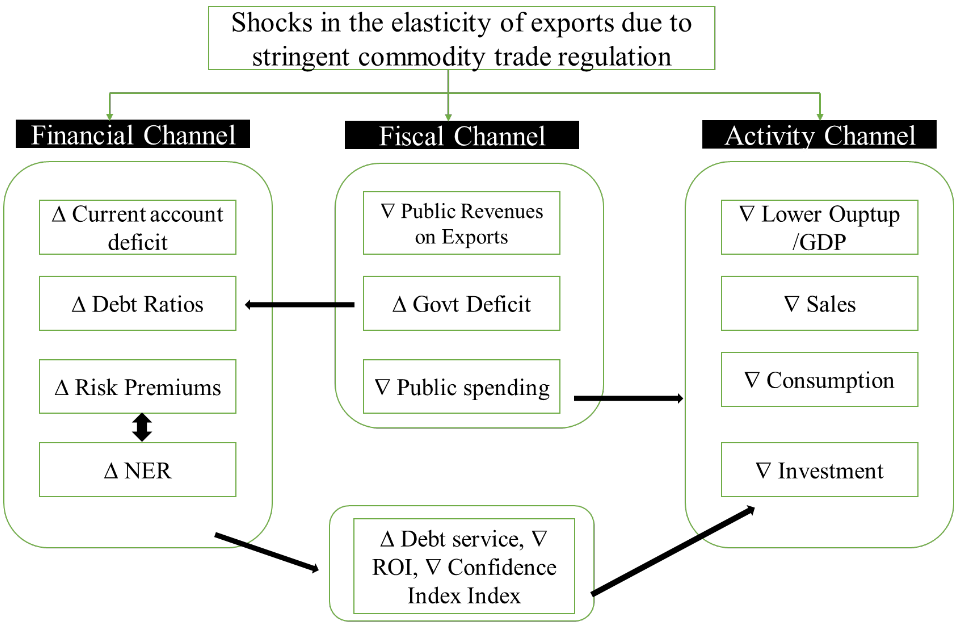
If commodities are restrained from some markets, they will be forced to be absorbed by other regions. Nevertheless, finding new commercial routes may take some time, and these may not have the same absorption capacity as previous partners; in other words, commodity-export countries could face a worsening of the terms of trade if they lose access to specific markets. In the coming years, international standards may also focus on manufacturing products, with higher carbon prices levies on imported manufactured goods from countries with or without lower carbon prices (Volz et al. 2020).

We simulate a deterioration of the terms of trade due to environmental standard, we reduce the income elasticity of exports by decreasing (from 1.14 to 1.1) the parameter η_1 in equation (113) alongside an increase in the income elasticity of imports (the parameter η_4 in equation [114])

[4] The case of coffee will be particularly relevant for Colombia, Peru, and Honduras as the European Union is the main global consumer and importer. A similar impact will be felt by cocoa-export countries such as in Ecuador and Peru. In Mercosur countries, while bovine beef is mainly consumed domestically or exported to China, other commodities such as timber, leather, soybean, and biodiesel will be at risk as they are mainly exported to the US, Europe, and UK.

from 1.4 to 1.5, starting in 2022. Figure 1 depicts transmission channels through which such shock propagates in the economy.

Figure 1. Trasmission Channels for Scenario 1



Source: own elaboration

The shock propagates to the economy through three important channels: financial, fiscal, and activity. Initially, slowing export growth (given by the reduction of the elasticity parameters) provokes a negative impact on output growth. Figure 6 (in the annex) shows a fall of 16 percent of GDP following the shock, then absorbed within four fictional years—suggesting a V-shaped economic contraction. It is worth noticing that the model does not discriminate among commodities and other exported goods. Thus, simulation results show what would happen if all exports were commodities influenced by the upcoming environmental regulation, an unrealistic assumption that overestimates the drop in exports. Yet, it sends a clear signal: changes in international environmental standards may have a medium-term negative impact on GDP through the reduction in commodity exports. Coordination with affected countries is essential, to give them the time to properly prepare for changes in trade standards. On the contrary, unilateral imposition would harm commodity producers.

The fall in exports due to environmental trade restriction deteriorates the current account, increasing external financial requirements to finance. Also, lower export taxes reduce the government's fiscal space. Both effects increase debt ratios. By definition, higher debt ratios are associated with higher risk premiums—simulations report an upward trend in EMBI and CEMBI indexes. The combination of higher risk premium and a deterioration of the terms of trade leads to a sharp depreciation of the nominal exchange rate (NER). The currency reacts by overshooting and increasing its volatility by two standard deviations. In order to avoid further depreciation, the central bank intervenes by sharply increasing the domestic nominal interest rate within the two years following the shock and maintaining it higher (compared to the baseline scenario) throughout the period under analysis.

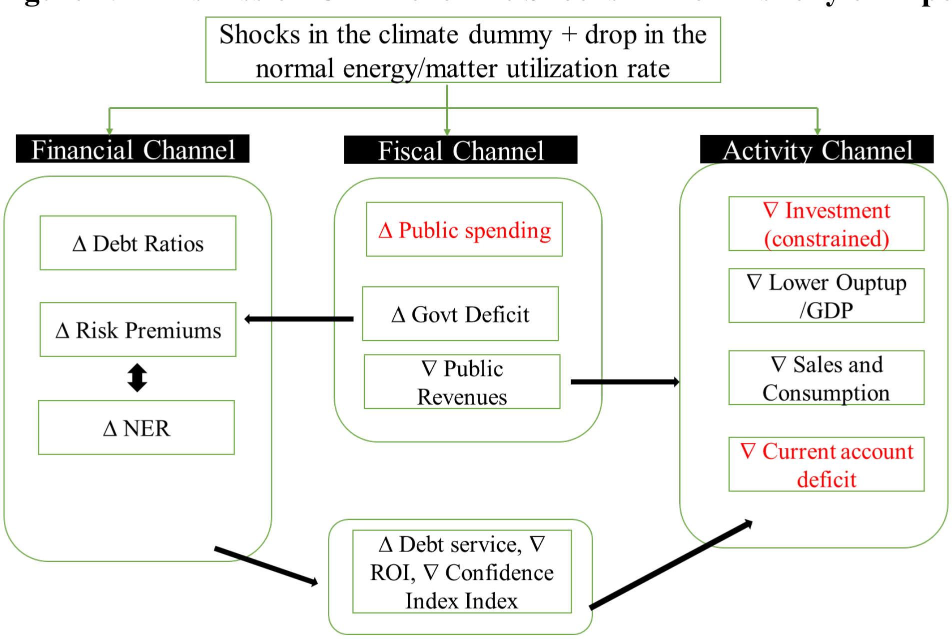
The combination of a higher interest rate, higher debt level, and currency depreciation increases firms' service of debt at the expenses of profits and investment confidence. Indeed, the profit-to-sales ratios drop from 90 to roughly 65 points, dragging with them the investment confidence index. Despite a marginal recovery, neither profits nor confidence completely restore over the period simulated. In response to lower profit and confidence, firms record a five GDP-point fall as a result of the commodity trade restriction. The investment-to-GDP ratio slowly recovers and stabilizes around 14.5 GDP points, which is roughly 1.5 GDP points lower than the baseline scenario, suggesting a possible long-lasting effect (hysteresis).

Changes in the Frequency and Intensity of Extreme Weather Events and Drop in the Normal Energy and Matter Utilization Rate

According to the latest IPPC report (2023), extreme weather events are becoming more frequent and intense than predicted, a phenomenon that could cause losses and damages to nature, economic activity, and wealth. To replicate the growing frequency of extreme weather events, we impose a shock in the extreme event dummy for the out-of-sample period. Recall the dummy takes the value from one to five according to the intensity of floods, hurricanes, and drought.

The objective of the second simulation is to portray a scenario in which every year the LAC region suffers more frequent environmental catastrophes, a likely outcome if temperature surpasses climate thresholds and extreme weather events become out of order.[5] To model the growing frequency and intensity, we set random values for the period out of the sample; the probability of a catastrophic events has a normal distribution, but the random assignment of data is set to have higher values as time passes. In this way, it is possible to replicate more damaging events. Specifically, we contemplate three intervals: from 2022 to 2025, the dummy could take at most the value of three, a medium-intensity value. After that, and until 2025, the dummy max value could take up to four (medium/high intensity). Starting in 2026, the randomly assigned intensity value could reach five, the most intense effect. To reproduce a more realistic result, we also assume a drop in the normal utilization rate of energy and matter (ue_r and um_r, respectively) for the out-of-sample observations. Extreme weather events may damage valuable infrastructure and impose restriction in the supply of energy and matter; it turns out that firms would suffer from restricted capacity utilization. As the latter fall behind the normal level, they bring about a reduction in investment (equations [34], [35], and [36]). Figure 2 depicts transmission channels through which such shock propagates in the economy.

Figure 2. Transmission Channel of the Shocks in the Elasticity of Exports



Source: own elaboration

[5] The present scenario attempts to shed light on the mechanism potentially undermining small, vulnerable countries in the region exposed to catastrophic climate events. This is the case, for instance, of the Caribbean region, whose economy is dependent on the productivity of its agricultural sector. But it also can be interpreted as a proxy for southern countries, where recent droughts hit bovine and soybean production, among others.

We detect three elements that differ from the picture depicted in the previous example. A first differentiation occurs in the fiscal channel, as public spending raises in response to the shock. Secondly, the investment ratio drops constantly over time due to the combination of demand and supply shocks. Finally, the current account deficit improves in response to lower imports.

Recall from equation (68), that the weather-event dummy makes public spending increase in response of catastrophic events—this was introduced to replicate the tendency of public intervention to compensate for infrastructural damages. Therefore, in the present scenario, public spending raises by 4 percent of GDP. An increase in government deficit (higher than the previous scenario) follows as higher public spending couples with lower public revenues.

Climate catastrophes generate a fall in private consumption while wealth, one of its determinants, is hardly hit by physical loss. Simulation shows a drop in private consumption (also influenced by the dummy variable) of as much as 30 GDP points over a decade. Lower consumption contributes to lower tax revenues. Thus, larger fiscal deficit is recorded. The latter worsen by 10 GDP points from 2022 to 2030. As previously shown, the worsening of public financing put upward pressure on public debt, which increases by three-fold over the period under analysis. The 20 percent increase in EMBI premium risk reflects the deterioration of public financing and leads to higher corporate risk.

The negative, self-reinforcing vicious cycle caused by debt and risk premiums also has implications for the nominal exchange rate, which in levels, is roughly 10 percent more devaluated than the baseline scenario. In terms of volatility, the standard deviation of the nominal exchange rate is, at its peak, 1.5 times higher than the baseline scenario. A new feature in the present scenario is the tendency of the volatility index to grow over time. This is explained by the fact that the currency volatility index is also affected by the dummy variable (in order to capture the overshooting in NER that often follows weather-related events). As a result in the present scenario, the central bank undertakes a longer tightening cycle due to the growing volatility index that triggers the central bank intervention by raising the target of domestic bonds it wants to hold.

The external financial constraint triggered from natural catastrophes has repercussions on firms. Indeed, as in the previous scenario, they suffer from lower profits due to higher debt service caused by the increase in risk premiums and interest rates. Notice, however, that firms' profits fall less than the previous simulation. Yet, the investment-to-GDP falls constantly over time and stabilizes at three GDP points lower as a result of financial and resource constraints. The result is explained by the supply constraint that follows the occurrence of extreme weather events. Differently from the previous scenario, the current simulation assumes that there exists a drop in the normal energy and matter utilization rate—for instance due to physical damage to energy infrastructure. The assumption represents a further constraint for investment decisions as firms dispose of lesser quantity of matter and energy and have to downward adjust production accordingly. All in all, firms' investment contracts in the face of these multiple factors never recover to the pre-shock level. Being that investment is a crucial engine of economic growth, GDP drops take longer to recover to pre-shock levels than in Scenario 1; lower investment, together with lower consumption and GDP growth, cause imports to fall. As result, in the current scenario the account shows improvement.

Table 2 reports a comparison between the two scenarios. The summary shows that NER, CEMBI, EMBI, and debt ratio have a common trend in both scenarios, a result empirically confirmed in the literature. Other variables report differences, mainly caused by the interaction of demand and supply proposed in the latter scenario.

Table 2. Result comparison among the two simulated scenarios

Variables	**S1. Commodity Trade Regulation**	**S2. increase in Frequency and Intensity of Extreme Weather events, together with resource constraint**
GDP	Short-term contraction in economic activity, followed by a recovery	GDP drops gradually and takes longer to recover
Public Deficit	Increase	

Interest Rate	Sharply increases, then stabilizes	Longer tightening cycle due to longer currency volatilty
NER	Upward trend (depreciation)	
NER Volatility	Overshoot to 2.4 SD, then stabilize to 0.8 (higher than baseline)	Costantly increase to 1.8 SD
EMBI	Increase	
CEMBI	Increase	
Current Account	Deteriorates	Improve as import are reduced due to lower investment, consumption, and economic activity
Debt Ratio	Increase	
Currency Mismatch	Grows over time	Grows, then follows below baseline as investment demand decreases and no more debt issued
Investment Ratio	Hysteresis; it falls sharply (5% GDP), then recovers, but doesn't reach pre-shock level	Hysteresis; it falls constantly over time due to demand and supply constraint. It stabilizes at 3 GDP points lower

Source: own elaboration

CONCLUSION

The present work introduced an ecological macrodynamic model stock-flow consistent, based on stylized facts for the Latin American region, aimed to evaluate the impact of climate-related issues on the region's real and financial external constraints. The theoretical framework is built upon Pérez-Caldentey et al. (2021, 2023), Carnevali et al. (2020), and Dafermos et al. (2018).

Despite representing a first attempt to be further expanded, the baseline scenario obtained from the model replicated observed financial and economic variables. The model was then used to perform two scenario analyses and to explore the implications of the short- and medium-term impacts of climate-related issues on the external constraint of the LAC region.

The first scenario focused on the international framework of sustainable trade and, specifically, on the regulation to halt deforestation derived from commodity consumption. Suppose producer countries, such as the LAC region, cannot comply with such regulations. In that case, consumer countries may shift their consumption to another region, thus negatively influencing the propensity of the region to export. Results obtained from model simulations show the repercussions of such an event will be felt not only on the trade balance and economic output, as expected, but also on debt ratios, risk premiums, and, ultimately, investment decisions through lower confidence, expected profits, and higher debt service. The second scenario focused the existence of more frequent and intense adverse climate events accompanied by lower availability of matter and energy—thus testing the model with a combination of demand and supply shocks. As a result of these climatic shocks, investment falls for longer periods than in the previous scenario. Both simulations coincide in showing that, due to climate-related events (trade restriction or adverse climate shocks), the region potentially suffers from an external financial constraint: that is, debt ratios, sovereign and corporate premiums, as well as a debt burden constrain private firms' investment and, in turn, long-term growth.

The present exercise represented a first effort for modelling, within an SFC framework, relevant financial and ecological constraints that the Latin American region faces. Yet, additional work is required to include additional productive sectors (for instance, the agricultural sector), the role of non-performing loans for the stability of the banking sector, asset prices, and the impact of changes in land use (i.e., deforestation).

Despite its limitations, the current work allows us to make some important conclusions from a policy perspective. First, when considering environmental and financial elements, the external constraint of LAC countries becomes even more binding. Second, the coexistence of a limited productive structure and increasingly extreme weather events is a source of concern for the region. Its high dependence on the export of commodities exposes it to growing economic and financial vulnerability as temperatures raise. Third, coordination in environmental trade regulations is required. Climate change is a global issue and unilateral actions are not optimal solutions. On the contrary, our scenario analysis shows that many pitfalls might exist for commodity-producing countries. Finally, a new international financial architecture is a must. Adaptation and mitigation will be fiscally challenging for commodity exporters if financial instruments do not evolve and provide flexibility for borrowers, by adapting repayment schedules to their (vulnerable) cash flows and fiscal deficit position.

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APPENDIX - MODEL EQUATIONS, FIGURES AND ACCOUNTING MATRICES

Table 1: Transaction Flow Matrix

		Production	**Private Sector**		**Financial Sector**		**Govt Sector**		**Central bank**		**ROW**	**Σ**
			Current	Capital	Current	Capital	Current	Capital	Current	Capital		
Consumption		$+C_d$	$-C_d$									0
Investment		$+I^k$		$-I^k$								0
Government Spending		$+G_d$					$-G_d$					0
Imports		$-IM$									$+IM$	0
Exports		$+X$									$-X$	0
[GDP]		$[-Y]$	$[+Y$									$[Y]$
Interest on	Govt Bonds (domestic currency)		$+in$		$+int_{f}^{g}$		$-int^{g}$		$+int_{b}^{g}$		$+int_{row}^{g}$	0
	Govt Bonds (FX currency)		$+in$		$+int_{f}^{\$}$		$-int^{\$}$				$+int_{row}^{\$g}$	0
	Private Debt		$-in$		$+int_{f}^{p}$		$+int_{g}^{p}$				$+int_{row}^{p}$	0
	Priv Debt FX		$-in$								$+int_{row}^{\$p}$	0
	Bonds ROW		$+in$		$+int_{f}^{r}$				$+int_{b}^{r}$		$-int^{row}$	0
	Public Deposits						$+int_{m}^{c}$		$-int_{m}^{c}$			0
	Private deposits		$+in$		$-int_{m}^{f}$							0
	Consumption Credit		$-in$		$+intc$							0
	Advances				$-int^{a}$				$+int_{cl}^{a}$			0
	Loans		$-in$		$+int^{l}$							0
	Loans (FX)				$-int^{\$}$						$+int^{\$lf}$	0
Financial gains(dividends)			+ F- fr-				$+FB_{g}^{b}$		$-FB^{b}$			0

		fd c									
[Gross National Income]		$[GN$		$[GNI_F$		$[GNI_G$					$[GN$
Taxes		$-T$		$-T$		$+T$					0
Savings		$[S_{PS}$		$[S_{FS}]$		$[S_{GS}]$				$[S_{RoWS}]$	0
Capital		$+K$									$-K$
Inventories		$+IN$									$-IN$
Govt Bonds (domestic currency)			$-\Delta B_p^{\$}$		$-B\Delta_f^g$		$+\Delta B$		$-\Delta B_b^{\$}$	$-\Delta B_{row}^g$	0
Govt Bonds (FX currency)			$-\Delta B_p^{\$}$		$-\Delta B_f^{\$}$		$+\Delta B$			$-\Delta B_{row}^{\$g}$	0
Private Debt			$+\Delta D$		$-\Delta D_f^p$		$-\Delta D$			$-\Delta D_{ro}^p$	0
Priv Debt FX			$+\Delta D^{\$}$							$-\Delta D_{row}^{\$}$	0
Bonds ROW			$-\Delta B_p^r$		$-\Delta B_f^r$				$-\Delta B_b^r$	ΔB^{row}	0
Public Deposits							$-\Delta M$		$+\Delta M$		0
Consumption Credit			$+\Delta Cc$		$-\Delta Cc$						
Advances					$+A\Delta^f$				$-\Delta A$		0
Loans			$+\Delta L_p^f$		$-\Delta L_p^f$						0
Loans (FX)					$+\Delta L_f^{\$}$					$-\Delta L_{fs}$ $	
Private Deposits			$-\Delta M$		$+\Delta M$						0
High power money			$+\Delta H$		$+\Delta H$				$-\Delta H$		
Σ	0	0	0	0	0	0	0	0	0	0	0

Source: own elaboration

Table 2: Physical flow matrix of the two-area economy (consolidated).

	Worldwide material balance	Worldwide energy balance
Inputs		
Extracted matter	$+ mat_{latam} + mat_{row}$	
Renewable energy		$+ er_{latam} + er_{row}$
Non-renewable energy	$+ cen_{row} + cen_{latam}$	$+en_{row} + en_{latam}$
Oxygen	$+ o2_{latam} + o2_{row}$	
Outputs		
Industrial CO2 emissions	$-(emis_{latam} + emis_{row})$	
Waste	$-(wa_{latam} + wa_{row})$	
Dissipated energy		$-(ed_{latam} + ed_{row})$
Change in s.e.s.	$-(\Delta k_{se}^{latam} + \Delta k_{se}^{row})$	
sum	0	0

Source: own elaboration

Table 3: Physical stock-flow matrix of the two-area economy (consolidated).

	Global material reserves	Global non-renewable energy reserves	Global atmospheric CO2 concentration	Global socioeconomic stock
Initial stock	$+ k^{m}_{latam,(-1)} + k^{m}_{row,(-1)}$	$+k^{e}_{latam,(-1)} + k^{e}_{row,(-1)}$	$+ co2_{at,(-1)}$	$+ k^{latam}_{se,(-1)} + k^{row}_{se,(-1)}$
Resources converted into reserves	$+ conv^{m}_{latam} + conv^{m}_{row}$	$+ conv^{e}_{latam} + conv^{e}_{row}$		
CO2 emissions (Global)			$emis_{latam} + emis_{l} + emis_{row}$	
Production of material goods				$+y^{mat}_{latam} + y^{mat}_{row}$
Extraction/ use of matter/ energy	$-(mat_{latam} + mat_{row})$	$-(en_{row} + en_{latam})$		
Net transfer to oceans/ biosphere			$(phi_{11} - 1) * co2_{at(-1)} + phi_{21} * co2_{up(-1)}$	
Destruction of Socioeconomic stock				$-(dis_{latam} + dis_{row})$
Final stock	$+ k^{m}_{latam} + k^{m}_{row}$	$+k^{e}_{latam,} + k^{e}_{row,}$	$+ co2_{at,}$	$+ k^{G}_{se} + k^{B}_{se}$

Source: own elaboration

<u>Income Identities</u>

Real Sales

(1) $s_{real} = \frac{c+ i+g+\mathrm{m}}{p\_d}$

Real Consumption

(2) $c_{real} = \frac{c}{p\_d}$

Real Inventories

(3) $inv_{real}=Y \ - r\_s$

Real Investment

(4) $i_{real}=\frac{i}{p\_d}$

Real public Spending

(5) $g_{real}=\frac{g}{p\_d}$

Real disposable income

(6) $yd_{real}=\frac{yd}{p\_d}$

I. PRODUCTION

Total Production

(7) $y = \left(1-(D^{y}+\vartheta_{y}.dummy\right)).(s^{e} + (in^{T} - in_{-1}))$

Target Inventories

(8) $in^{T} = \gamma.s^{e}$

Expected Inventories

(9) $inv^{e} = inv_{s_{-1}} + \text{ß}_{inv_{1}}.(in^{T} - inv_{s_{-1}})$

Expected Sales

(10) $\boldsymbol{s^e} = ß\,.\,\boldsymbol{s_{-1}} + (\mathbf{1} - ß)\,.\,\Delta \boldsymbol{Y_{row}}$

Nominal Inventories

(11) $\boldsymbol{inv} = \boldsymbol{inv_{real}} * \boldsymbol{uc}$

II. PRIVATE SECTOR

Private Sector: Income and Consumption

Households' disposable income

(12) $yd^h = WB + Fd_c + \ intfs_{mm}$

Consumption

(13) $c = \alpha_{1c} c_{-1} + \alpha_{2c} c_{-1} * \left(1 + \alpha_{3c} * \frac{(yd^e_{-1} - yd^h_{-1})}{yd^h_{-1}}\right) + \alpha_2 v_{-1} + \alpha_2 . Dummy$

Sales

(14) $s = c + \ i + g + (x - m)$

Expected income

(15) $yd^e = ß\,.\,yd^h_{-1} + (1 - ß)\,.\,yd^h_{-1}.(1 + \ \Delta Y_{row})$

Wealth

(16) $v \ = \ \mathrm{mm} - \mathrm{cc}$

Private sector: capital accumulation

Sales Price

(17) $p_s = (1 + \pi) * HUC$

Sales Price

(18) $\pi = f(ue, um)$

Historical Unitary Cost (HUC)

(19) $HUC = (1-\gamma_{nuc}) * NUC + \gamma_{nuc} * N_{-1}$

Nominal Unitary Cost

(20) $NUC = \frac{W}{pr}$

Unitary Cost

(21) $UC = \frac{(WB+M)}{y}$

Wage Bill

(22) $WB = W.N$

Employment Level

(23) $N = N_{-1} * (1 + \Delta Y_{RoW}) + \Omega_n.(N_{-1} - N^T)$

Employment Target

(24) $N^T = N_{-1}^T + \Omega_{n_1}(\Delta y - gr)$

Productivity

(25) $pr = pr_{-1}.(1 + gr - D^l)$

Nominal Wage

(26) $W = w_{-1}.(1 + gr)$

Capital Accumulation

(27) $\Delta k = i - (d + D^k).k_{-1}$

Private Investment

(28) $i = \left((dp + D^k + A).k_{-1}\right).p_d + i_{-1}.ic$

Confidence Index

(29) $i_c = \delta.\pi^e + \delta_1.\Delta Y_{RoW} + \delta_2.\Delta Y - \delta_3.dummy$

$Confidence\ Index\ Sensibility\ to\ Expected\ profits$

(30) $$\delta = \begin{Bmatrix} if\ \frac{D_{-1}^{T}}{Y_{-1}} > 0{,}6 & 0{,}55 \\ . & \\ if\ \frac{D_{-1}^{T}}{Y_{-1}} \leq 0{,}6 & 0{,}65 \end{Bmatrix}$$

Confidence Index Sensibility to World growth rate

(31) $$\delta_1 = \begin{Bmatrix} if\ \Delta y_{RoW} > 0 & 0{,}3 \\ . & \\ if\ \Delta y_{RoW} \leq 0 & 2{,}5 \end{Bmatrix}$$

Confidence Index Sensibility to domestic growth rate

(32) $$\delta_2 = \begin{Bmatrix} if\ \Delta y > 0 & 0{,}3 \\ . & \\ if\ \Delta y \leq 0 & 2{,}5 \end{Bmatrix}$$

Expected Profits

(33) $$\pi^e = \varsigma_1 . \frac{F_{-1}}{I_{-1}} + (1 - \varsigma_1) . \Delta cembi_{-1}$$

Constraint on Investment

(34) $$A = A_0 - \gamma_1(um_{-1} - um_r) - \gamma_2(ue_{-1} - ue_r)$$

(35) $$\gamma_1 = \gamma_{10} \qquad if\ um_{-1} > um_r;\ else\ \gamma_1 = 0$$

(36) $$\gamma_2 = \gamma_{20} \qquad if\ ue_{-1} > ue_r;\ else\ \gamma_2 = 0$$

(37) $$um = \frac{Y}{Y_M^*}$$

(38) $$ue = \frac{Y}{Y_E^*}$$

(39) $$Y_M^* = \frac{k_{latam,-1}^{m} + rec_{latam}}{mu_{latam}}$$

(40) $$Y_E^* = \frac{k_{latam,-1}^{e}}{(1 - eta_{latam}) epsilon_{latam}}$$

<u>Private Sector: Retained and Distributed Profits</u>

Private Sector's profits before depreciation and taxes

(41) $Fp = F + F_h$

Firms Profits

(42) $F_{firm} = c + i + g + (x - m) - \left(int^p + int^p_{row} + int^p_{loan}\right) - WB + inv + (int^g_p + int^g_{pFX} + int^{row}_p) + (D_{CP_d} - CP_d)$

Firms' profits after taxes

(43) $F = F_{firm} - tax - depr$

Households Profits

(44) $F_{hog} = WB - c + int^{fs}_{mm_p} - intc^p_{fs}$

Retained Profits

(45) $Fr = \theta_f . F$

Retained Profits

(46) $Fd = (1 - \theta_{fdc}). Fdt$

Non-retained profits

(47) $Fdt = (1 - \theta_{f)}). F$

Profits distributed for consumption

(48) $Fdc = \theta_{fdc}. Fdt$

Excess Profits (retained profits not invest in capital)

(49) $Frn = Fr - i \quad if\ Fr > i$

Private Sector: Retained and Distributed Profits

Private budget constraint (equivalent to total private debt issued in each period)

(50) $\Delta \boldsymbol{D^t} = \boldsymbol{I} + \boldsymbol{inv} - \boldsymbol{Fr}$

Total Private debt (local currency)

(51) $\Delta \boldsymbol{D^{tlc}} = \boldsymbol{\delta_{cd}}. \Delta \boldsymbol{D^t}$

Bonds issued by firms (local currency)

(52) $\boldsymbol{\Delta D^{p} = \delta_{d}.\Delta D^{tlc}}$

Loans demanded by firms (local currency)

(53) $\Delta L_{p}^{d} = \delta_{cd}.\Delta D^{tlc}$

(54) $CP_{d} = \theta_{cp}.L_{-1}^{f}$

(55) $D_{CP_{d}} = \theta_{d_{cp}}.CP_{d}$

(56) $\theta_{d_{cp}}$=¿?

Bonds issued by firms (in local currency) held by the financial sector

(57) $\boldsymbol{\Delta D_{fs}^{p} = min\,[\Delta D_{fsd}^{p}, \Delta D^{p}]}$

Bonds issued by firms (in local currency) held by RoW

(58) $\boldsymbol{\Delta D_{row}^{p} = \Delta D^{p} - \Delta D_{fs}^{p}}$

Total Private debt in foreign currency

(59) $\boldsymbol{\Delta D^{\$p} = (1 - \delta_{cd}).\Delta D^{t}}$

<u>Private Sector: Portfolio</u>

Private Sector Demand for Govt bonds (local currency)

(60) $\Delta B_{p\_d}^{g} = \epsilon_{1}.F_{d}$

Private Sector Demand Sensitivity for govt bonds (local currency)

(61) $\epsilon_{1} = \epsilon_{1_{0}} + \epsilon_{1_{1}}\left(\frac{1+i^{g}}{1+\pi^{e}}\right)^{\sigma_{b}}$

Private Sector Demand for govt bonds (foreign currency)

(62) $\Delta B_{p\_d}^{\$g} = \epsilon_{2}.F_{d}$

Private sector demand sensitivity for domestic bonds (foreign currency)

(63) $\epsilon_2 = \epsilon_{2_0} + \epsilon_{2_1}\left(\frac{1+i^{g\$}}{1+i^{row}}\right)^{\sigma_{b\$}}$

Private sector demand for ROW bonds

(64) $\Delta B_{pd}^{row} = \epsilon_3 . F_d$

Private sector demand sensitivity for ROW bonds

(65) $\epsilon_3 = \epsilon_{3_0} + \epsilon_{3_1}\left(\frac{1+i^{row}}{1+i^{g\$}}\right)^{\sigma_{row}}$

Private sector demand for Cash

(66) $\Delta H_h^{bc} = \left(\Delta B_{p_d}^{g} - \Delta B_p^{g}\right) + \left(\Delta B_{p_d}^{\$g} - \Delta B_p^{\$g}\right).E + \left(\Delta B_{p_d}^{row} + \Delta B_p^{row}\right).E + Frn$

III. PUBLIC SECTOR

a. Central Government

Government: Taxes and Spending

Govt spending

(67) $G = G_{-1} + gr^g$

Government spending growth rate

(68) $gr_g = \varphi_0 + \varphi_1 . \Delta Y + \varphi_3 . dummy$

Taxes

(69) $T = \theta . Y$

Tax used for debt repayment

(70) $T_d = \theta_{T_d} . T$

Budget and debt supply

Public sector budget restriction

(71) $PSBR = G - T - int_B^g - int_{Bfx}^g + int_{d_g}^p + int_{Bg}^{row} \; +\!-FB^{bc}$

Govt Debt Supply (local currency)

(72) $\Delta B = \zeta . PSBR$

Govt Debt Supply (foreign currency currency)

(73) $\Delta B^{\$} = (1 - \zeta). PSBR$

Govt Debt Supply to Financial Sector (Local Currency)

(74) $\Delta B^{g}_{fs} = min\ [\Delta B^{g}_{fsd}, \Delta B]$

Government Debt Supply to Private Sector (Local Currency)

(75) $\Delta B^{g}_{p} = min\ [(\Delta B - \Delta B^{g}_{fs}), \Delta B^{g}_{pd}]$

Government Debt Supply to ROW (Local Currency)

(76) $\Delta B^{g}_{row} = \min\ [\varsigma_{row}. (\Delta B - \Delta B^{g}_{fs} - \Delta B^{g}_{p}), \Delta B^{g}_{rowd}]$

Government Debt Supply to RoW (foreign currency)

(77) $\Delta B^{g\$}_{row} = \min\ [\Delta B^{\$}, \Delta B^{g\$}_{rowd}]$

Government Debt Supply to Financial sector (foreign currency)

(78) $\Delta B^{g\$}_{fs} = min\ [\varsigma_{fs}. \left(\Delta B^{\$} - \Delta B^{g\$}_{row}\right), \Delta B^{g\$}_{fsd}]$

Government Debt Supply to Private Sector (Foreign Currency)

(79) $\Delta B^{g\$}_{p} = min\ [(\Delta B^{\$} - \Delta B^{g\$}_{fs} - \Delta B^{g\$}_{row}), \Delta B^{g\$}_{pd}]$

Government deposits to financial sector

(80) $M^{g} = public\ super\acute{a}vit$

b. CENTRAL BANK

Central Bank Profits

(81) $FB^{bcp} = int^{g}_{bc} + int^{row}_{bc} + int^{g\$}_{bc} + int^{afs}_{bc} - int^{cb}_{mm_g} + dep_{cb}$

Central Bank's profits not invested (after asset accumulation)

(82) $FB^{bc} = FB^{bcp} - afs - B^{g}_{cb}. E - B^{g}_{cb} + M^{g}$

High power money supplied

(83) $H = -FB^{bc} \quad si \qquad FB^{bc} < 0$

Central bank target demand for domestic government bonds

(84) $B_{cb}^{g*} = B * \left(\vartheta_{bc}\left(i_{-1}^{g} - i_{-1}^{cb}\right) + \vartheta_{e^{risk}}.\ e^{risk}\ \right)$

Taylor's Rule

(85) $i^{cb} = \pi_t + i_t^{cb*} + \vartheta_1(\pi_t - \pi_t^*) + \vartheta_2\ (\Delta y_t - \Delta y_t^*)$

Potential Output

(86) $\Delta y_t^* = 5\ years\ moving\ average$

Central Bank interest rate target

(87) $i_t^{cb*} = i^{row} + \varphi^{cb}$

Currency volatility indicator

(88) $e^{risk} = \begin{Bmatrix} if\ s.d.\ of\ E \geq 3, & 1 \\ if\ s.d.\ of\ E < 3, & 0 \\ if\ s.d.\ of\ E \geq -3, & -1 \end{Bmatrix}$

Public sector supply of bond to Central Bank

(89) $\boldsymbol{\Delta B_{cb}^{g} = max[\Delta B - \Delta B_{fs}^{g} - \Delta B_{row}^{g} - \Delta B_{p}^{g},\ B_{cb}^{g*}]}$

RoW supply of debt to CB

(90) $\boldsymbol{\Delta B_{g}^{row} = -CAB + WFF + B_{P}^{row}.E - depreciation_{RoW}}$

Public sector supply of bonds to Central Bank

(91) $\Delta B_{cb}^{g} = max[\Delta B - \Delta B_{fs}^{g} - \Delta B_{row}^{g} - \Delta B_{p}^{g},\ B_{cb}^{g*}]$

ROW supply of bonds to Central Bank

(92) $\Delta B_{g}^{row} = -CAB + WFF + B_{P}^{row}.E - dep_{RoW}$

Domestic Inflation

(93) $\pi_t = \left(\frac{\Delta p_s}{p_{s_{-1}}}\right)$

Public deposits to Central Bank

(94) $mm_g = -PSBR$ if $PSBR < 0$

IV. FINANCIAL SECTOR

Financial Sector: Profits and Budget Constraint

Financial sector's profit

(95) $f_{fs} = int_{fs}^{g} + int_{fs}^{\$g} + int_{fs}^{p} + int_{fs}^{row} - int_{mm_p}^{fs} + intc_{fs}^{p} - int^{afs} + int^{lp} - int^{\$lfs} + (CP_d - D_{CP_d})$

Financial sector's budget constraint

(96) $\Delta\boldsymbol{FN_{fs}^{t}} = \boldsymbol{T} + \Delta\boldsymbol{B_{fs}^{g}} + \Delta\boldsymbol{B_{fs}^{\$g}} + \Delta\boldsymbol{D_{fs}^{p}} + \Delta\boldsymbol{D_{fs}^{\$}} + \Delta\boldsymbol{B_{fs}^{row}} + \Delta\boldsymbol{L_{p}^{fs}} + \Delta\boldsymbol{Cc_{fs}^{p}} - (\boldsymbol{1} - \boldsymbol{\sigma_{Rb}})\boldsymbol{M^{p}} - \boldsymbol{f_{fs}} + \boldsymbol{R_{p}}$

Financial sector's retained profit

(97) $fr_{fs} = if_{fs}.\vartheta_{fs}$

Loans demanded by financial sector in foreign currency

(98) $\Delta L_{fs}^{\$row} = \frac{\left((1-\delta_{afs}).\Delta FN_{fs}^{t}\right)}{E}$ where δ_{afs} *is exogenous*

Financial Sector's Advances from Central Bank

(99) $\Delta A^{fs} = \delta_{afs}.\Delta FN_{fs}^{t}$

Financial Credit Supply (Consumer Credit and Loans)

Deposits

(100) $\boldsymbol{mm} = \mathbf{cc} + (\mathbf{f_{hog}} - \mathbf{cc})$ $\boldsymbol{if}$ $\mathbf{f_{hog}} - \mathbf{cc} > \mathbf{0}$

Demand for consumer credit

(101) $\boldsymbol{Cc_d^p} = \mathbf{cons} + \mathbf{intcp_{fs}} - \mathbf{fdc} - \mathbf{wb} - \mathbf{intfs_{mm}}$

(102) $\boldsymbol{CC_{D_{CP}}} = \boldsymbol{\theta_{CC_{D_{CP}}} CC_{D_{CP}}}$

Supply of consumer credit

(103) $\boldsymbol{Cc_s^p} = \boldsymbol{Cc_d^p}$

Loans supplied by financial sector to private sector (local currency)

(104) $\Delta L_p^s = \Delta L_p^d$

<u>Financial Sector's Portfolio</u>

$Financial\ Proportion\ of\ assets\ bought\ by\ the\ financial\ sector$

(105) $\boldsymbol{fa_{fs}} = \boldsymbol{\sigma_{Rb}.fr_{fs}}$

Financial Sector Demand for government bonds (local currency)

(106) $\Delta B_{fs\_d}^{g} = \epsilon_{f_1}.fa_{fs}$

Financial Sector demand sensitivity for government bonds (local currency)

(107) $\epsilon_{f_1} = \epsilon_{f_{1_0}} + \epsilon_{f_{1_1}} \left(\frac{1+i^g}{1+i^{g\$}}\right)^{\sigma_{f_b}}$

Financial Sector demand for government bonds (foreign currency)

(108) $\Delta B_{fs\_d}^{\$g} = \epsilon_{f_2}.fa_{fs}$

Financial Sector demand sensitivity for government bonds (foreign currency)

(109) $\epsilon_{f_2} = \epsilon_{f_{2_0}} + \epsilon_{f_{2_1}} \left(\frac{1+i^{g\$}}{1+i^{row}}\right)^{\sigma_{f_{b\$}}}$

Financial Sector demand for ROW bonds

(110) $\Delta B_{fsd}^{row} = \epsilon_{f_3}.fa_{fs}$

Financial Sector demand sensitivity for RoW bonds

(111) $\epsilon_{f_3} = \epsilon_{f_{3_0}} + \epsilon_{f_{3_1}} \left(\frac{1+i^{row}}{1+i^{g\$}}\right)^{\sigma_{f_{row}}}$

(112) $\Delta D^{p}_{fs\_d} = \epsilon_{f_4} . fa_{fs}$

Financial Sector demand sensitivity for government bonds

$$\boldsymbol{\epsilon_{f_4} = \epsilon_{f_{4_0}} + \epsilon_{f_{4_1}} \left(\frac{1+i^p}{1+i^g}\right)^{\sigma_{f_d}}}$$

V. EXTERNAL SECTOR

External Sector: Trade

Exports growth

(113) $\Delta x = \eta_0 \, . Y_{row}^{\eta_1} . (TOT)^{\eta_2}$

Imports growth

(114) $\Delta m = \eta_3 \, . \frac{Y^{\eta_4}}{(TOT)^{\eta_5}}$

Real exports

(115) $X = x.p$

Real imports

(116) $M = m.p_i$

Imports prices

(117) $X = x.p$

World Growth Rate

(118) $Y_{row} = Y_{row_{-1}} + gr_{row} + \dot{A}_{row}$

Current account

(119) $CAB = X - M - int^{g}_{B_{row}} - int^{g}_{BFX_{row}} - int^{p}_{d_{row}} - int^{p}_{dFX_{row}} + int^{row}_{B}$

Capital account

(120) $KAB = \Delta B_{row} + \Delta B^{\$}_{row} + \Delta D_{row} + \Delta D^{\$}_{row} - \Delta B^{row}$

External Sector: Portfolio

RoW Demand for private debt (local currency)

(121) $\Delta D^{p}_{row} = (1-\lambda).D^{p}$

ROW demand for private debt (foreign currency)

(122) $\Delta D^{\$p}_{row} = \Delta D^{\$p}$

RoW demand for government debt (local currency)

(123) $\Delta B^{g}_{row\_d} = \xi_1.(Y^{row})$

(124) $\xi_1 = \xi_{1_0} + \xi_{1_1}.(i^{\$g} - i^{\$}) + \xi_{1_2}.\Delta E^{e} - \xi_{1_3}.dummy$

RoW demand for government debt (foreign currency)

(125) $\Delta B^{g\$}_{row\_d} = \xi_2. \quad ^{Grow}$

(126) $\xi_2 = \xi_{2_0} + \xi_{2_1}.(i^{\$g} - i^{\$}) - \xi_{2_2}.dummy$

RoW supply of debt

(127) $\Delta B^{row} = \Delta B^{row}_{p} + \Delta B^{row}_{g} + \Delta B^{row}_{fs}$

World Financial Flows (WFF)

(128) $WFF = \Delta B^{g\$}_{row} + \Delta B^{g}_{row} + \Delta D^{\$p}_{row} + \Delta D^{p}_{row}$

RoW GDP

(129) $Y^{row} = exogenous$

International interest rate

(130) $i^{row} = exogenous$

Constraint on Investment RoW

(131) $A_{row} = A_{0,row} - \gamma_{1,row}(um_{row,-1} - um_{row,r}) - \gamma_2(ue_{row,-1} - ue_{row,r})$

(132) $\gamma_{1,row} = \gamma_{10,row}\ iff\ um_{row,-1} > um_{row,r};\ else\ \gamma_{1,row} = 0$

(133) $\gamma_{2,row} = \gamma_{20,row}\ iff\ ue_{row,-1} > ue_{row,r};\ else\ \gamma_{2,row} = 0$

(134) $um_{row} = \frac{Y}{Y^*_{M,row}}$

(135) $ue_{row} = \frac{Y}{Y^*_{E,row}}$

(136) $Y^*_{M,row} = \frac{k^m_{row,-1} + rec_{row}}{mu_{row}}$

(137) $Y^*_{E,row} = \frac{k^e_{row,-1}}{(1 - eta_{row})epsilon_{row}}$

VI. RISK PREMIUMS, INTEREST RATES, AND EXCHANGE RATE

Risk Premiums

(138) $embi = \varepsilon_0 + \varepsilon_1.\left(\frac{B^g}{Y}\right) + \varepsilon_2.\left(\frac{B^{\$g}}{B_g^{row}}\right) + \varepsilon_3.\Delta E + \varepsilon_4.dummy$

(139) $cembi = \phi_0 + \phi_1\left(\frac{D^{\$p}}{B_p^{row} + B_p^{\$g}}\right) + \phi_2.embi + \phi_3.\left(\frac{D^{\$p} + D^p}{Y}\right) + \phi_3.\left(\frac{L_{fs}^{\$row}}{Y}\right) +$
$\phi_3.dummy$

Interest Rates

Government Nominal Rate (domestic currency)

(140) $i^g = i^{row} + \tau_1.\left(\frac{\Delta B - \Delta B^g_{p\_d} - \Delta B^g_{row\_d} - \Delta B^g_{cb\_d}}{\Delta B}\right) + (1 - \tau_1).\Delta embi + \varphi^g$

Government Nominal Rate (foreign currency)

(141) $i^{\$g} = i^{row} + \varphi^{\$g}\ ,\ where\ \ \varphi^{\$g} = \varphi_0^{\$g} + \varphi_1^{\$g}\Delta embi_g$

Private Nominal Rate (domestic currency)

(142) $i^p = i^g + \varphi^p, \ where \ \varphi^p = \varphi_0^p + \varphi_1^p . \Delta cembi_p$

Private Nominal Rate (foreign currency)

(143) $i^{\$p} = i^{\$g} + \varphi^{\$p}, \quad where \ \varphi^{\$p} = \varphi_0^{\$p} + \varphi_1^{\$p} . \Delta cembi_p$

<u>Nominal Exchange Rate</u>

Nominal Exchange Rate

(144) $E = E_{-1} + \psi . \Delta E^e + \psi_{wff} . \Delta WFF^*$

Nominal exchange rate expectations(fundamentalist)

(145) $\Delta E_f^e = \psi_{f1}(E_{-1} - E_{-1}^T) + \psi_{f_2} . \Delta EMBI_{-1} + \psi_{f_3} . \Delta TOT$

Nominal exchange rate expectations(chartist)

(146) $\Delta E_c^e = \psi_{c1} \Delta E_{-1} + \psi_{c_2} . \Delta EMBI_{-1} + \psi_{c_3} . \Delta TOT$

Total Expectations

(147) $\Delta E^e = \omega_f . \Delta E_f^e + \omega_c . \Delta E_c^e$

Exchange Rate Target

(148) $E^T = 5 \ year \ Moving \ Average$

<u>Stock: Depreciation Due to Nominal Exchange Rate Fluctuations</u>

(149) $depreciation_p = \Delta E . B_p^{RoW}{}_{-1} + \Delta E . B_p^{\$g}{}_{-1} - \Delta E . D_{row_{-1}}^{\$p}$

(150) $depreciation_g = -\Delta E . B_{-1}^{\$g}$

(151) $depreciation_{row} = -\Delta E . B_{-1}^{RoW} + \Delta E . B_{row_{-1}}^{\$g} + \Delta E . D_{row_{-1}}^{\$p} + \Delta E . L_{fs}^{\$row}$

(152) $depreciation_{cb} = \Delta E . B_{cb}^{RoW}{}_{-1}$

(153) $depreciation_p = \Delta E.B_{fs}^{RoW}{}_{-1} + \Delta E.B_{fs}^{\$g}{}_{-1} - \Delta E.L_{fs}^{\$row}$

<u>*Damage Function*</u>

(154) $D = 1 - \frac{1}{1+\pi_{d_1}T+\pi_{d_2}T^2+\pi_{d_3}T^{\varsigma_{d_3}}}$ $\pi_1;\ \pi_2;\ \pi_3;\ \zeta_3\ \geq\ 0.$

(155) $D^k := f_K.D \quad f_K \in (0;\ 1)$

(156) $D^l = f_l.D \quad f_l \in (0;\ 1)$

(157) $D^y = 1 - \frac{1-D}{1-D^k}$

VII. THE ECOSYSTEM

<u>*I - Material Resources and Reserves*</u>

Production of material goods in Latin America

(158) $y_{latam}^{mat} = mu_{latam} * y_{latam}$

Production of material goods in RoW

(159) $y_{row}^{mat} = mu_{row} * (y_{row})$

Extraction of matter in Latin America

(160) $mat_{latam} = y_{latam}^{mat} - rec_{latam}$

Extraction of matter in RoW

(161) $mat_{row} = y_{row}^{mat} - rec_{row}$

Recycled socioeconomic stock in Latin America

(162) $rec_{latam} = rho_{latam} * dis_{latam}$

Recycle d socioeconomic stock in RoW

(163) $rec_{row} = rho_{row} * dis_{row}$

Discarded socioeconomic stock in Latin America

(164) $dis_{latam} = mu_{latam} * \left(dp * k_{-1} + zeta_{latam} * dc_{latam_{-1}}\right)$

Discarded socioeconomic stock in RoW

(165) $dis_{row} = mu_{row} * \left(zeta_{row} * dc_{row_{-1}}\right)$

Stock of durable goods in Latin America

(166) $dc_{latam} = dc_{latam_{-1}} + cons - (x - m) - zeta_{latam} * dc_{latam_{-1}}$

Stock of durable goods in RoW

(167) $dc_{green} = dc_{row_{-1}} + (y_{row}) + (x - m) - zeta_{row} * dc_{row_{-1}}$

Socioeconomic stock in Latin America

(168) $k_{latam}^{se} = k_{se_{latam_{-1}}} + y_{mat_{latam}} - dis_{latam}$

Socioeconomic stock in RoW

(169) $k_{row}^{se} = k_{se_{row_{-1}}} + y_{mat_{row}} - dis_{row}$

Waste generated by production activities in Latin America

(170) $wa_{latam} = mat_{latam} - d(k_{latam}^{se})$

Waste generated by production activities in RoW

(171) $wa_{row} = mat_{row} - d(k_{row}^{se})$

Stock of material reserves in Latin America

(172) $k_{latam}^{m} = k_{latam(-1)}^{m} + conv_{latam}^{m} - mat_{latam}$

Stock of material reserves in RoW

(173) $k_{row}^{m} = k_{row(-1)}^{m} + conv_{row}^{m} - mat_{row}$

Worldwide stock of material reserves

(174) $k^m = k^m_{latam} + k^m_{row}$

Material resources converted to reserves in Latin America

(175) $conv^m_{latam} = sigma^m_{latam} * res^m_{latam(-1)}$

Material resources converted to reserves in RoW

(176) $conv^m_{row} = sigma^m_{row} * res^m_{row(-1)}$

Stock of material resources in Latin America

(177) $res^m_{latam} = res^m_{latam(-1)} - conv^m_{latam}$

Stock of material resources in RoW

(178) $res^m_{row} = res^m_{row(-1)} - conv^m_{row}$

Worldwide stock of material resources

(179) $res^m = res^m_{brown} + res^m_{green}$

Carbon mass of (non-renewable) energy in Latin America

(180) $cen_{latam} = \frac{emis_{latam}}{car}$

Carbon mass of (non-renewable) energy in RoW

(181) $cen_{row} = \frac{emis_{row}}{car}$

Mass of oxygen in Latin America

(182) $o2_{latam} = emis_{latam} - cen_{latam}$

Mass of oxygen in RoW

(183) $o2_{row} = emis_{row} - cen_{row}$

<u>II - ENERGY RESOURCES AND RESERVES</u>

Energy required for production in Latin America

(184) $e_{latam} = epsilon_{latam} * y_{latam}$

Renewable energy in Latin America

(185) $er_{latam} = eta_{latam} * e_{latam}$

Non-renewable energy in Latin America

(186) $en_{latam} = e_{latam} - er_{latam}$

Dissipated energy at the end of the period in Latin America

(187) $ed_{latam} = er_{latam} + en_{latam}$

Energy required for production in RoW

(188) $e_{row} = epsilon_{row} * (y_{row})$

Renewable energy in RoW

(189) $er_{row} = eta_{row} * e_{row}$

Non-renewable energy in RoW

(190) $en_{row} = e_{row} - er_{ror}$

Dissipated energy at the end of the period in RoW

(191) $ed_{row} = er_{row} + en_{row}$

Stock of energy reserves in Latin America

(192) $k^e_{latam} = k^e_{latam_{-1}} + conv^e_{latam} - en_{latam}$

Stock of energy reserves in RoW

(193) $k^e_{row} = k^e_{row(-1)} + conv^e_{row} - en_{row}$

Worldwide stock of energy reserves

(194) $k^e = k^e_{latam} + k^e\ row$

Energy resources converted to reserves in Latin America

(195) $conv^e_{latam} = sigma^e_{latam} * res^e_{latam_{-1}}$

Energy resources converted to reserves in RoW

(196) $conv_{row}^{e} = sigma_{row}^{e} * res_{row_{-1}}^{e}$

Stock of energy resources in Latin America

(197) $res_{latam}^{e} = res_{latam}^{e}(-1) - conv_{latam}^{e}$

Stock of energy resources in RoW

(198) $res_{row}^{e} = res_{row(-1)}^{e} - conv_{row}^{e}$

Worldwide stock of energy resources

(199) $res^{e} = res_{latam}^{e} + res_{row}^{e}$

III - EMISSIONS AND CLIMATE CHANGE

Industrial emissions of CO2 in Latin America

(200) $emis_{latam} = beta_{latam}^{0} + beta_{latam} * en_{latam}$

Industrial emissions of CO2 in RoW

(201) $emis_{row} = beta_{row}^{0} + beta_{row} * en_{row}$

Annual CO2 emissions from land

(202) $emis_{l} = emis_{l(-1)} * (1 - g_{land})$

Worldwide industrial emissions of CO2

(203) $emis = emis_{latam} + emis_{l} + emis_{row}$

Atmospheric CO2 concentration

(204) $co2_{at} = emis + phi_{11} * co2_{at(-1)} + phi_{21} * co2_{up(-1)}$

Upper ocean/biosphere CO2 concentration

(205) $co2_{up} = phi_{12} * co2_{at(-1)} + phi_{22} * co2_{up(-1)} + phi_{32} * co2_{lo(-1)}$

Lower ocean CO2 concentration

(206) $co2_{lo} = phi_{23} * co2_{up(-1)} + phi_{33} * co2_{lo(-1)}$

Radiative forcing over pre-industrial levels (W/m^2)

(207) $f_1 = f_2 * @logx\left(\frac{co2_{at}}{co2_{at_{pre}}}, 2\right) + f_{ex}$

Radiative forcing over pre-industrial levels (W/m^2) due to non-CO2 greenhouse gases (W/m^2)

(208) $f_{ex} = f_{ex(-1)} + fex$

Atmospheric temperature

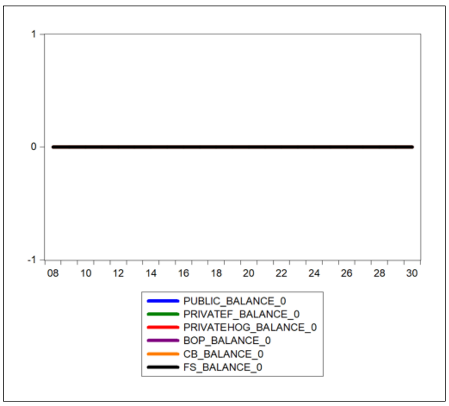
(209) $temp_{at} = temp_{at(-1)} + t_1 * \left(f1 - \left(\frac{f2}{sens}\right) * temp_{at(-1)} - t_2 * \left(temp_{at(-1)} - temp_{lo(-1)}\right)\right)$

Lower ocean temperature

(210) $temp_{lo} = temp_{lo(-1)} + t_3 * \left(temp_{at(-1)} - temp_{lo(-1)}\right)$

FIGURES FOR BASELINE MODEL AND SCENARIO ANALYSIS

Figure 2. Consistency (Baseline)

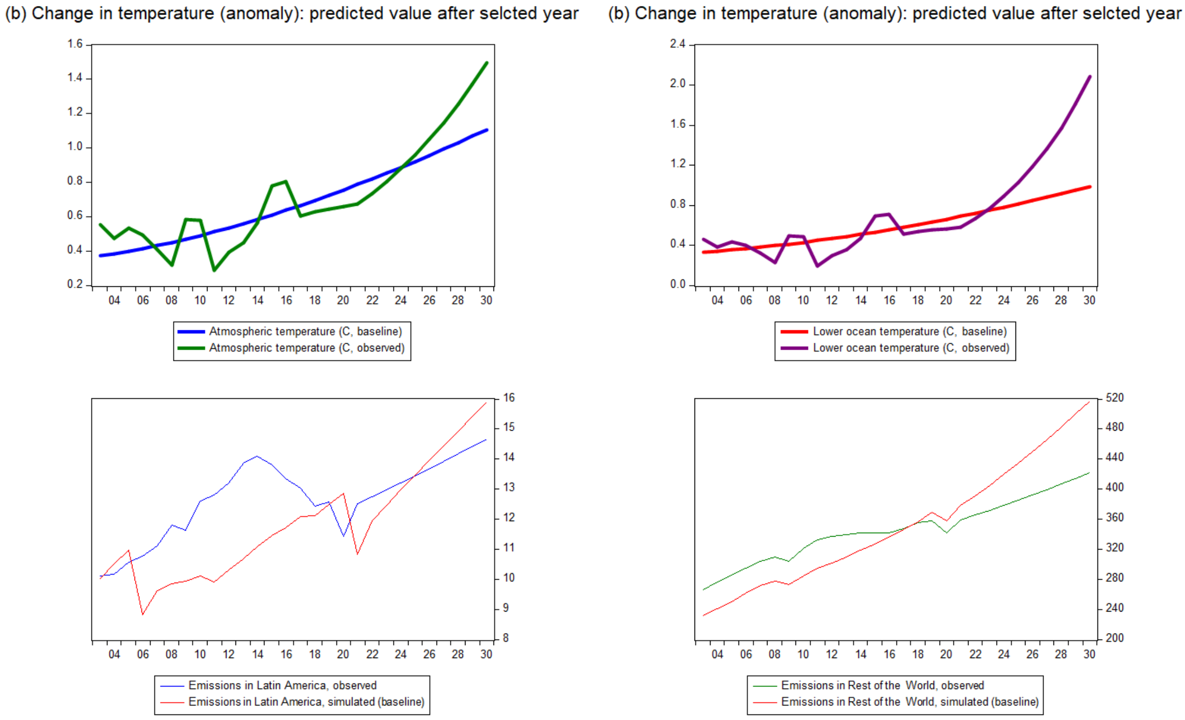


Source: own elaboration

Figure 3. Simulated and Observed Macroeconomic Variables (Baseline)

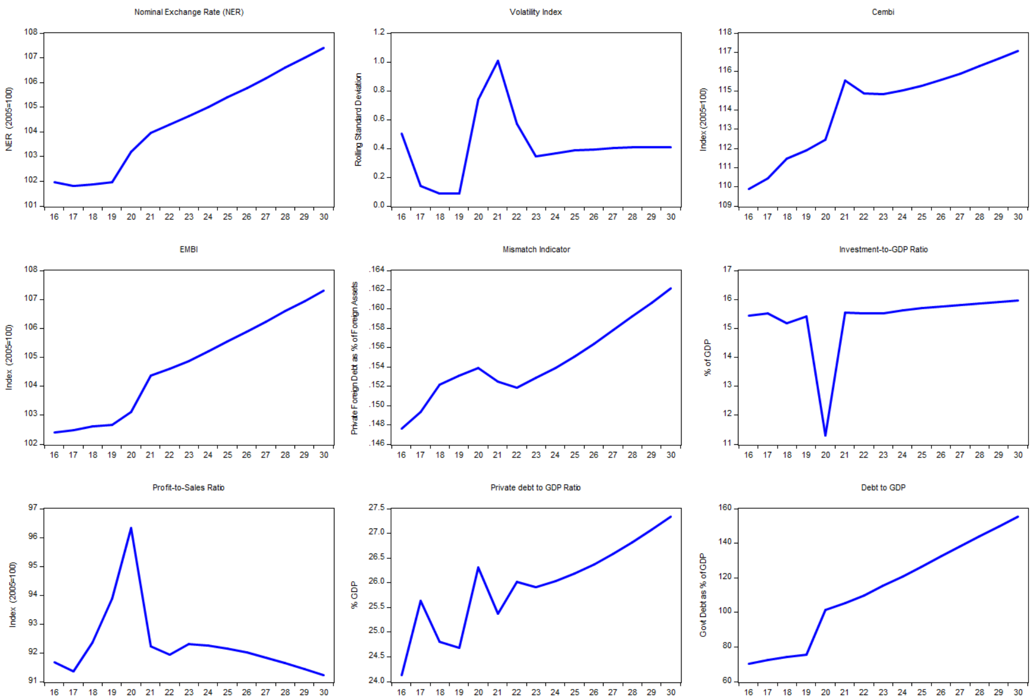
Source: own elaboration from CEPALSTAT (2022)

Figure 4. Simulated and Observed Environmental Variables (Baseline)



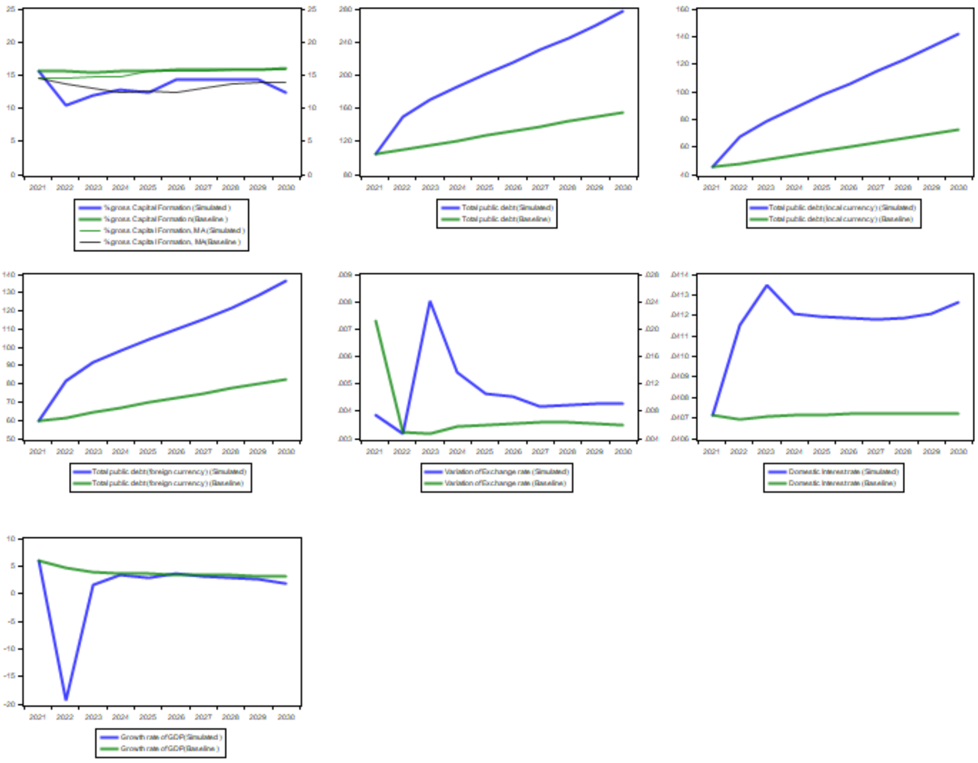
Source: own elaboration from CEPALSTAT (2022) and Ritchie, Roser and Rosado (2020).

Figure 5. Simulated Financial Variables (Baseline)



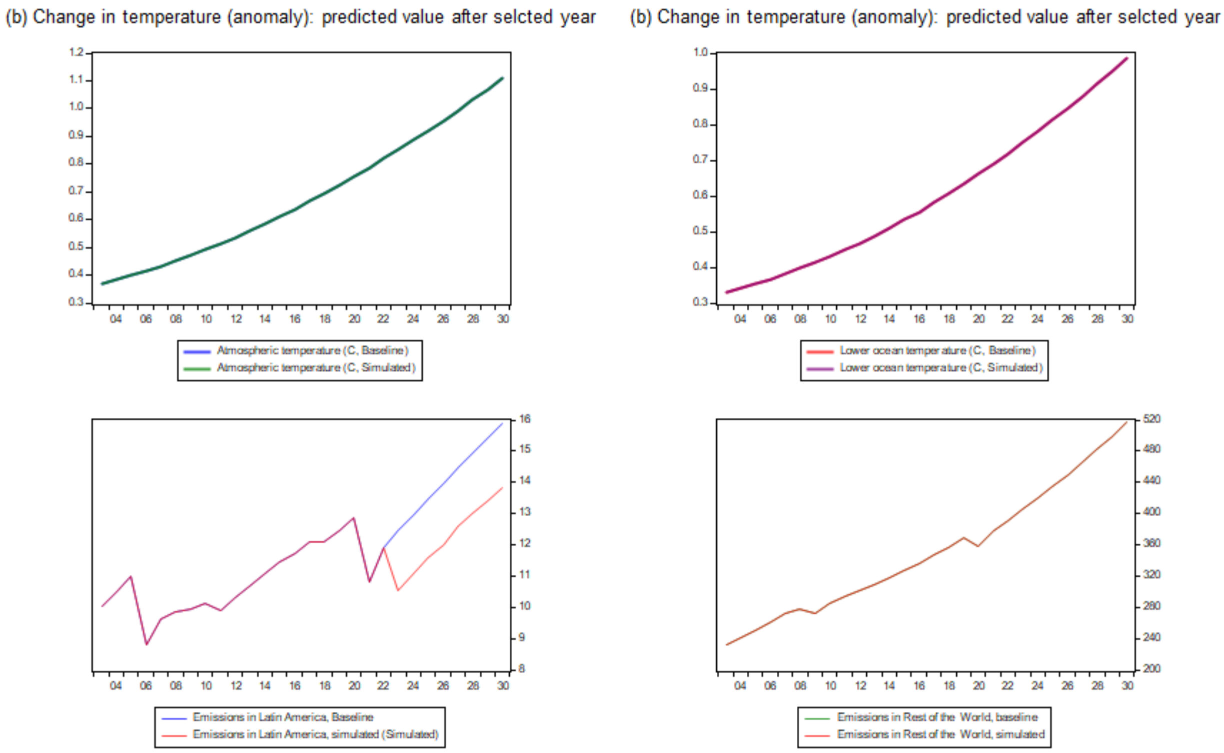
Source: own elaboration from CEPALSTAT (2022)

Figure 6. Simulated and observed macroeconomic variables (Scenario I)



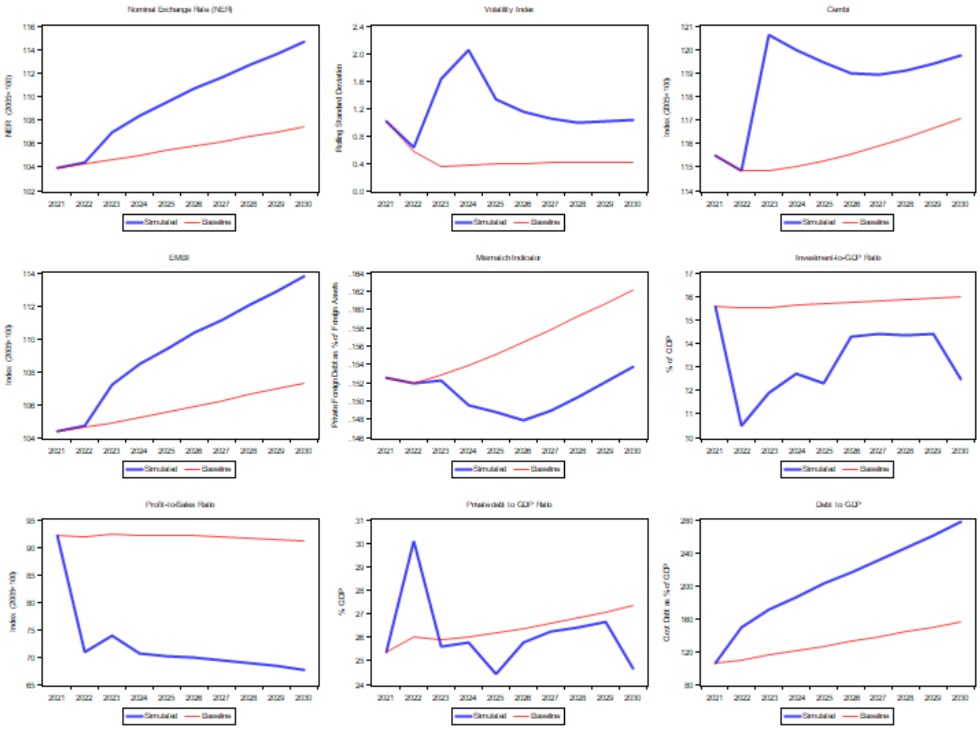
Source: own elaboration from CEPALSTAT (2022)

Figure 7. Simulated and Observed Environmental Variables (Scenario I)



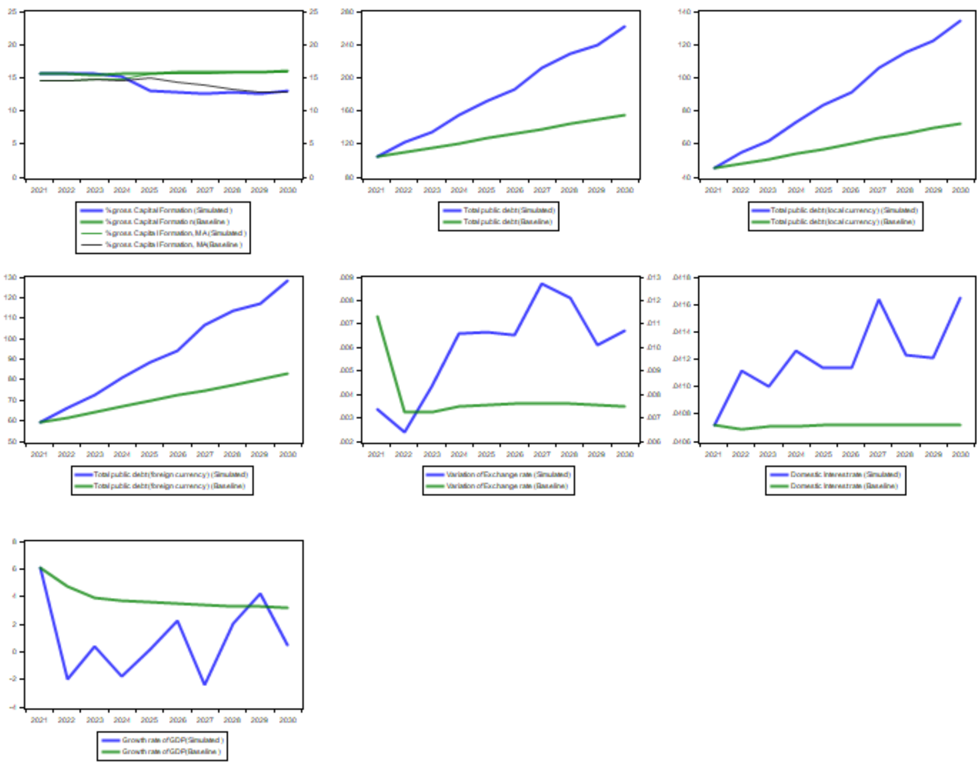
Source: own elaboration from CEPALSTAT (2022) and Ritchie, Roser and Rosado (2020).

Figure 8. Simulated Financial Variables (Scenario I)



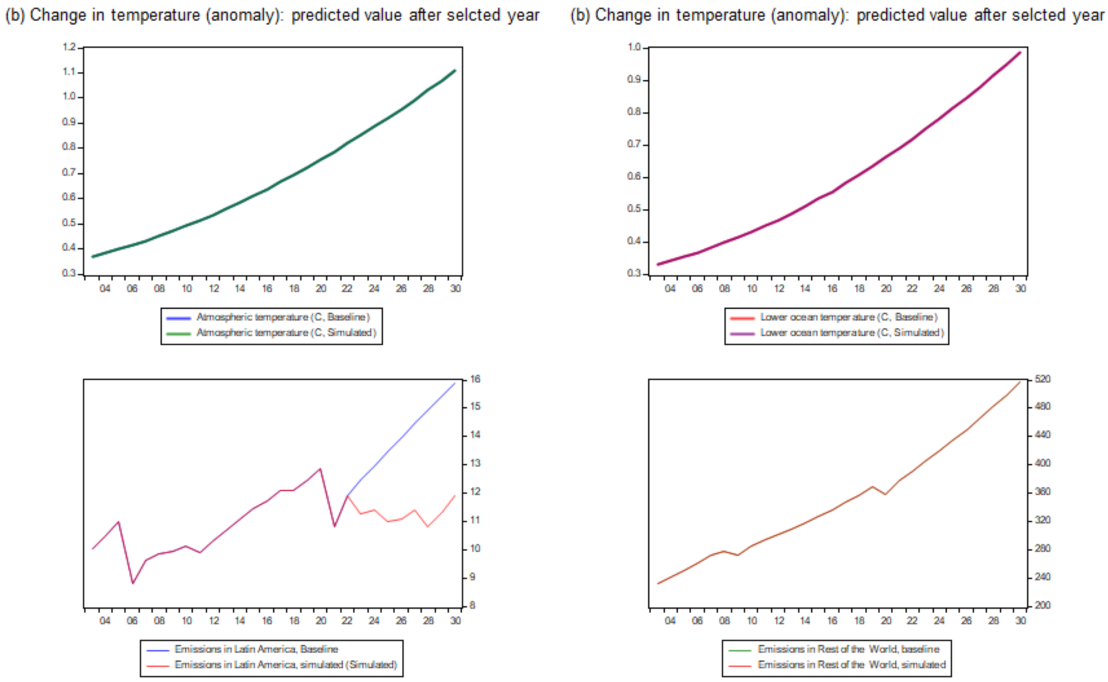
Source: own elaboration from CEPALSTAT (2022)

Figure 9. Simulated and Observed Macroeconomic Variables (Scenario II)



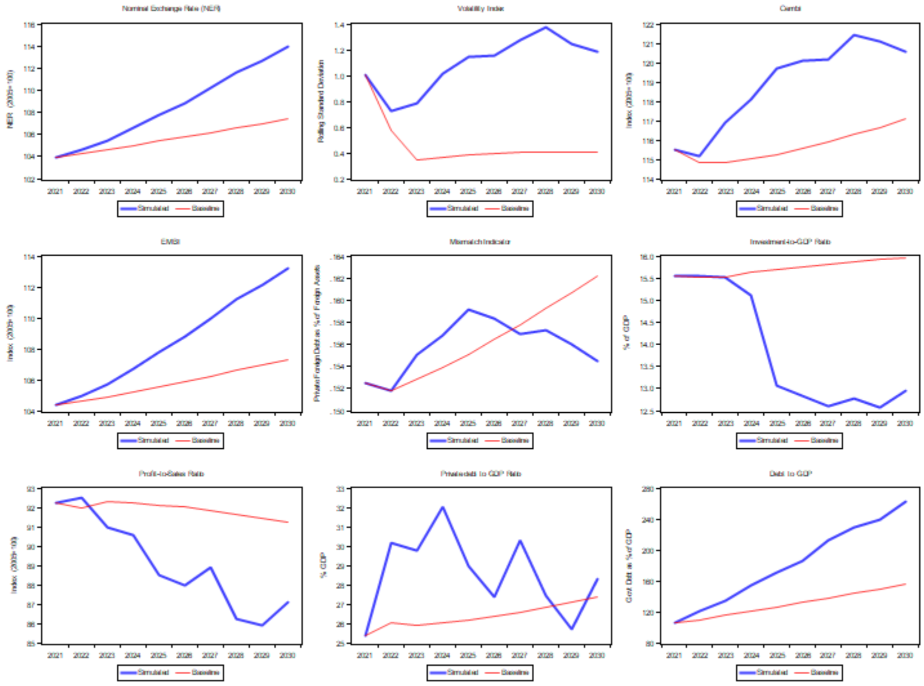
Source: own elaboration from CEPALSTAT (2022)

Figure 10. Simulated and Observed Environmental Variables (Scenario II)



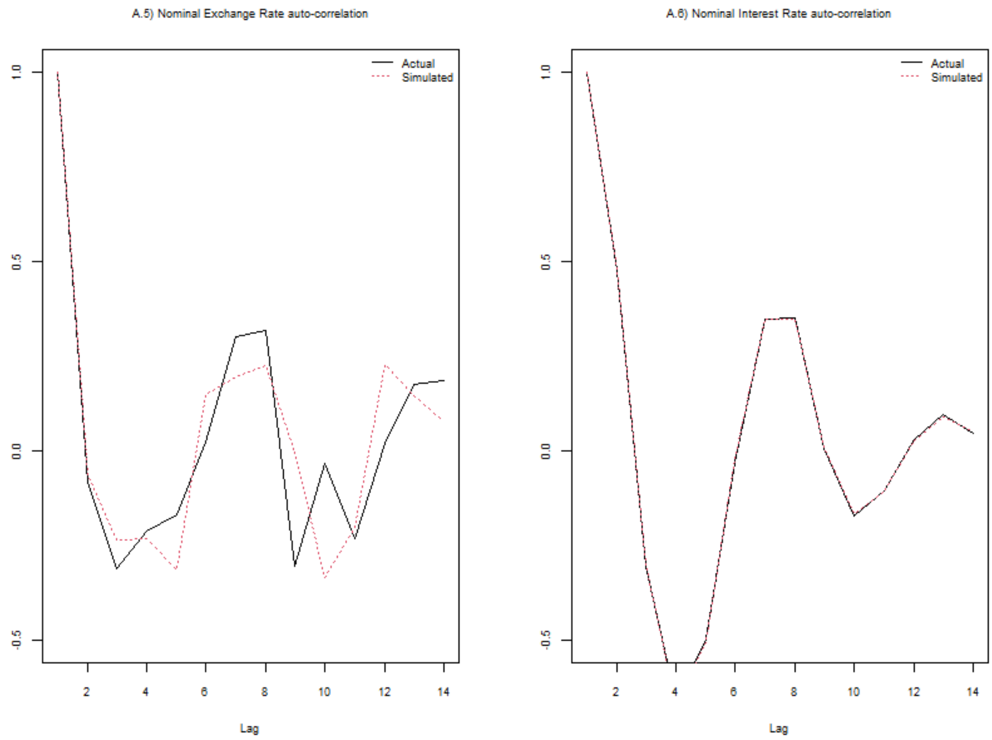
Source: own elaboration from CEPALSTAT (2022) and Ritchie, Roser and Rosado (2020).

Figure 11. Simulated Financial Variables (Scenario II)



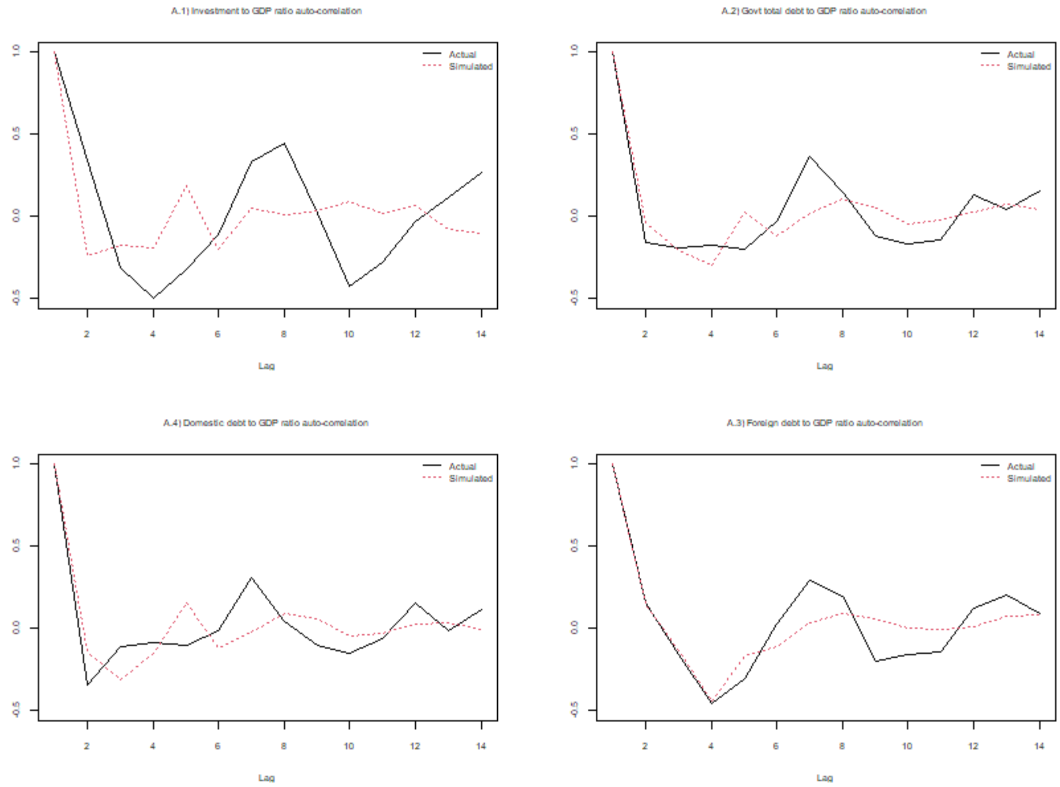
Source: own elaboration from CEPALSTAT (2022)

Figure 12. Autocorrelation Aanalysis for Selected Variables (Baseline Scenario)



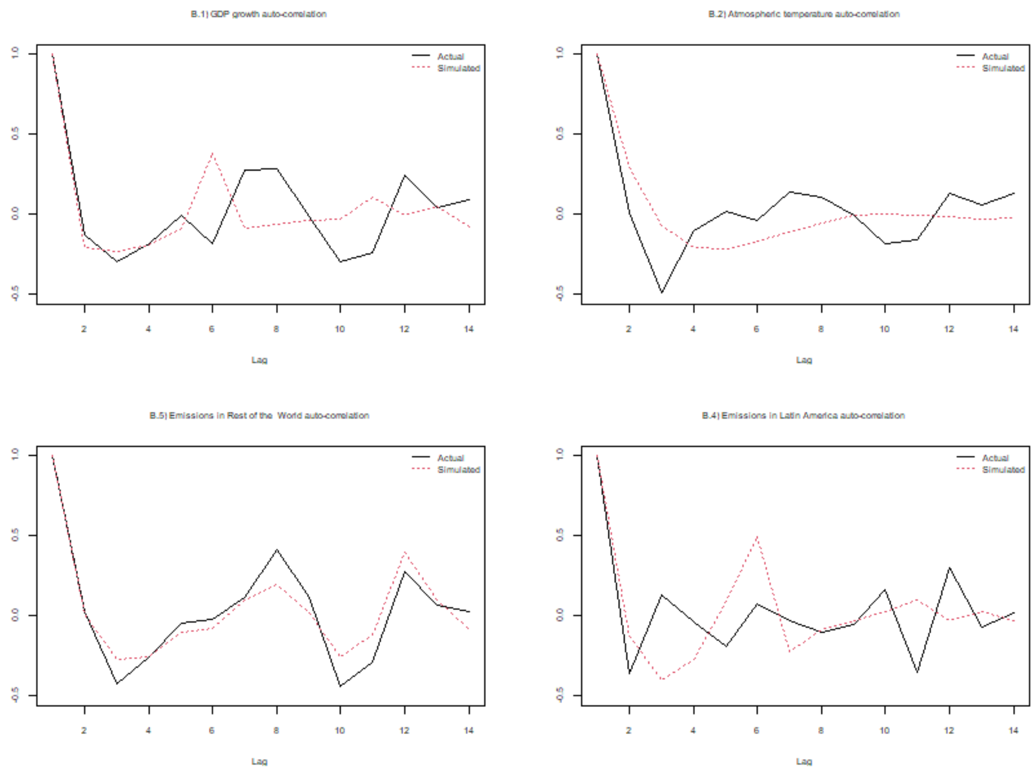
Source: own elaboration from CEPALSTAT (2022)

Figure 13. Autocorrelation Analysis for Selected Variables (Baseline Scenario)



Source: own elaboration from CEPALSTAT (2022)

Figure 14. Autocorrelation Analysis for Selected Variables (Baseline Scenario)



Source: own elaboration from CEPALSTAT (2022) and Ritchie, Roser and Rosado (2020).

Table 4. Climate And Energy Transition Risks in Traditional SFC Models

Authors	Type of Model	Application	Results /Main conclusions
Monasterolo and Raberto (2018)	Hybrid SFC model with interacting agents without a climate module but with an energy sector. Their framework is close to one of Agent-Based Models (ABM)	Evaluate green fiscal policies and sovereign bonds to display their effects on firms' investments, unemployment, and the credit and bonds market	1) Green Incentives/Bonds represe green economy; 2) The "Business a of firms' capital accumulation, emp trade-off between short-term result Incentives/Taxes" scenario the gov cost of the green policy and meet t
Dunz et al. (2021)	Traditional SFC model	Adoption of a global Carbon Tax (CT) and the revision of the micro-prudential banking framework via a Green Supporting Factor (GSF)	1) the GSF could represent an effe investments only in the short term; welfare and redistribution measure 4) a single policy might not be eno the pace needed
Godin (2013; 2014)	Multisectoral SFC model without a climate module but with an energy sector	Evaluate the Employer of the Last Resort Scheme in the context of the Energy Transition	1) JG is less costly than Keynesian employment; 2) JG may effectivel structural change.
Yajima (2023)	Traditional SFC model without a climate module but with an energy sector	Evaluate the Employer of the Last Resort Scheme in the context of the Energy Transition	Carefully designed scheme of dire state—addressing both the low- an permanent effects and promote the
Yilmaz et al. (2023)	Traditional SFC model without a climate module but with an agricultural sector	Asses the effect of climate change under different scenarios for the Tunisian economy	Climate change under different sce agricultural sector in Tunisia leadi deficits and a looming currency cr external deficits through FX borro country risk.
Godin et al. (2023)	Traditional SFC model	Assess the effect of climate transition policies under different scenarios for the Colombian economy	The authors develop three transitio and Global). In all cases, the decli impacts on the real and external sectors of the Colombian financial conditions.

Table 5. Emissions modeling in an SFC macro setting

Authors	Type of Model	Application	Results /Main conclusions
Naqvi and Stockhammer (2017)	SFC ecological model with a CO2 emission function	Develop a SFC ecological model that combines three strands of literature: the directed technological change mechanism developed in mainstream endogenous growth theory models, the ecological economic literature which highlights the role of green innovation and material flows, and the post-Keynesian school.	1) a continuously increasing resour technological processes to increase resource tax increase. 2) directing R in higher growth while also pursuin public R&D-to-GDP expenditure ra

Valdecantos (2021)	SFC-Input Output (SFC-IO) model with e emission function for each sector, fully calibrated for the Argentinian economy.	Test two different shapes that a green transition based on the structural reform of the energy sector could take for Argentina and identify if these can be consistent with the balance of payments constraint.	1) the external constraint limits the p dilemma between economic growth characterizes the Argentinean econo reduce greenhouse gas emissions in from the primary export sector; 3) a combined with a process of structura reduces its technical dependence on possible to escape the trilemma.
Passarella (2022)	SFC-IO model with a simple emission function for each sector.	Impact of a "circular economy" innovation on output, employment, income inequality, waste, and CO2 emissions	1) the model allows dealing with cro model allows endogenizing technica cannot rely just on higher productio

Table 6. Stock-Flow-Fund models

Authors	Type of Model	Application	Results /Main conclusions
Berg et al. (2015)	SFC-IO	Estimate anthropogenic heat flux to highlight the linkages between the physical environment and the economic system	1) a stationary economy can be ass rates, depending on the interplay o parameters; ii) rising energy prices demand, and trigger recessions.
Bovari et al. (2018)	SFC model made of a 16-dimensional nonlinear dynamical system	Evaluate economic impact of climate change and the role of private debt	1) the +2° C target for temperature instability coupled with financial a unintended planet-wide economic effective if zero net emissions are to contain warming to +3°C.
Dafermos et al. (2018)	SFC with the flow-fund model of Georgescu-Roegen (1973)	Introduce a new theoretical framework to encompass the feedback between the ecosystem and the economy	1) when the contractionary effects become stronger, the economic da environmental changes are reinfor have favorable effects on environn financial fragility of firms. 3) Thes enhanced when a conventional cre green credit expansion. In a simila
Deleidi et al. (2023)	Sraffian super multiplier approach, the Schumpeterian framework, and the SFC principles	Examine the impact of government spending on private innovation, economic growth, and sustainability	1) Government can be successful i growth while limiting material and The over-consumption of material government policy effectiveness;
Carnevali et al. (2020)	Two-area SFC model	Evaluate impact of green investment on climate change and vice versa	1) The search for safe financial ass related uncertainty) can affect eco stability; 2) The search for green fi climate change if capitals are free fully floating; 3) If governments o (green) spending, the net effect on sensitivity of imports to governme

			strong coordination, green innovat policies are likely to generate adve