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Financial instability and exchange rate dynamics in an agent-based model

Instabilidade financeira e dinâmica cambial em um modelo baseado em agentes

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Co-orientadora: Lílian Nogueira Rolim

São Paulo
2024

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The purpose of studying economics is not to acquire a set of ready-made answers to economic questions, but to learn how to avoid being decieved by economists.

Joan Robinson

Resumo

As taxas de câmbio podem ser uma fonte importante de instabilidade financeira e econômica. A dissertação desenvolve um novo modelo baseado em agentes e liderado pela demanda para compreender a dinâmica conjunta entre o endividamento externo de firmas e as variações da taxa de câmbio. Estudamos o efeito balanço, que é uma reavaliação de passivos externos com consequências negativas para a estabilidade financeira e potenciais impactos negativos na atividade econômica. Conclui-se que o impacto na economia real dependerá da força relativa entre os canais financeiros e comerciais, mas as consequências financeiras negativas são sempre observadas.

Palavras-chaves: Economias emergentes, Modelos baseados em agentes, Efeito balanço, Fragilidade financeira, Minsky

Abstract

Exchange rates can be an important source of financial and economic instability. The dissertation develops a novel demand-led agent-based model to understand the joint dynamics between firm-level foreign indebtedness and exchange rate movements. In particular, we study the balance sheet effect, understood as a revaluation of foreign liabilities after an exchange rate shock, with potential negative consequences to economic activity. We find that the impact on the real economy will depend on the relative strength between the financial and trade channels, but we always observe the negative financial consequences.

Key-words: Emerging economies, Agent-based models, Balance sheet effect, Financial fragility, Minsky

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Variables

K_t	Aggregate capital stock at period t
Q_t	Aggregate output at period t
D_t	Aggregate demand at period t
I_t	Aggregate investment at period t
C_t	Aggregate consumption at period t
M_t^*	Aggregate imports at period t (in foreign currency)
X_t^*	Aggregate exports at period t (in foreign currency)
$M_{W,t}^*$	Aggregate households imports at period t (in foreign currency)
$M_{F,t}^*$	Aggregate firms imports at period t (in foreign currency)
$Y_{W,t}$	Aggregate households income at period t
W_t	Wage bill at period t
Π_t^g	Aggregate gross profit at period t
Π_t^r	Aggregate retained profit at period t
Θ_t	Aggregate distributed dividends at period t
$\pi_t^{g,j}$	Gross profit of firm j at period t
$\pi_t^{r,j}$	Retained profit of firm j at period t
θ_t^j	Distributed dividends of firm j at period t
k_t^j	Capital stock of firm j at period t
q_t^j	Production of firm j at period t
d_t^j	Demand of firm j at period t
$q_t^{e,j}$	Expected demand of firm j at period t
$\bar{q}_t^j$	Maximum level of production of firm j at period t

s_t^j	Preferential attachment shock of firm j at period t
$\tilde{s}_t^j$	Demand shock of firm j at period t
l_t^j	Employment of firm j at period t
u_t^j	Capacity utilization of firm j at period t
$u_t^{e,j}$	Expected capacity utilization of firm j at period t
$i_t^{d,j}$	Desired investment level of firm j at period t
i_t^j	Realized investment of firm j at period t
$m_t^{d,j*}$	Desired imports of firm j at period t (in foreign currency)
m_t^{j*}	Imports of firm j at period t (in foreign currency)
$b_t^{d,j*}$	Debt demand of firm j at period t (in foreign currency)
b_t^{j*}	Debt stock of firm j at period t (in foreign currency)
r_t^{j*}	Interest rate on debt stock of firm j at period t
ρ_t^j	Probability of default of firm j at period t
e_t	Exchange rate at period t
ϵ_t	Exchange rate shock at period t
Q_t^{f*}	Foreign output at period t (in foreign currency)
R_t^*	Aggregate foreign reserves at period t (in foreign currency)
	Parameters
ι	Labor technical coefficient
υ	Capital technical coefficient
γ	Flexible accelerator parameter
u^n	Normal level of capacity utilization
η	Additional share of imported investment
δ	Depreciation rate
ω	Wage
p	Price level

μ	Mark-up
c_W	Workers' propensity to consume out of wages
c_Θ	Workers' propensity to consume out of dividends
m_0	Workers' imports level coefficient
m_1	Workers' imports elasticity to wage income
m_2	Workers' imports elasticity to exchange rate
r^*	Foreign interest rate
ϕ	Credit supply rationing parameter
β	Interest rate sensitivity to firms probability of default
g^f	Foreign output growth
x_0	Exports level coefficient
x_1	Exports elasticity to foreign income
x_2	Exports elasticity to exchange rate
λ_1	Exchange rate sensitivity to BoP disequilibrium
λ_2	Exchange rate sensitivity to foreign shock
s_σ	Normal standard deviation of demand shock
e_σ	Normal standard deviation of exchange rate shock
τ	Minimum market share threshold

1 Introduction

The accumulation of foreign liabilities is a common strategy to fund investment plans and, more broadly, development strategies. A notable example is the Asian developmental states. The Asian Tigers -Hong Kong, Singapore, South Korea, and Taiwan- experienced successful development through export-led growth. However, this success was accompanied by extensive financial liberalization and the opening of capital accounts to fund the necessary investments, creating conditions for the Asian financial crisis of the 1990s (ARESTIS; GLICKMAN, 2002; WADE, 1998). In recent years, emerging economies have once again seen an increase in foreign-currency denominated liabilities on the balance sheets of many non-financial corporations (IMF, 2015; CHUI; KURUC; TURNER, 2018). This increase coincides with a renewed focus on industrial policy and aspirations for export-led growth (CHANG; ANDREONI, 2020; JUHÁSZ; LANE; RODRIK, 2023). Many of those strategies include a undervaluated currency as a tool to push manufactured production and stimulate foreign demand (BRESSER-PEREIRA, 2012).

This context revives the relevance of studying the combination of foreign debt accumulation with export-led growth, a strategy previously employed by the Asian Tigers. We aim to understand the challenges to macroeconomic and financial stability that an export-led economy might face when foreign debt is its primary source of investment finance, specially in the presence of volatile and abrupt exchange rate movements. This raises the question of whether these exchange rate movements can significantly impact balance sheets, influencing investment capacity and the broader domestic economy. On one hand, a devalued currency stimulates export demand through the traditional trade channel of exchange rates. On the other hand, it can lead to the revaluation of foreign liabilities and increase financial instability, negatively affecting the real economy. This is known as the balance sheet effect, a financial channel of exchange rates.

Besides the historical account of the Asian crisis (i.e., Ahmed et al. (2000)), several studies have recently observed the negative impact of devaluations and undervaluated currencies in countries with a high stock of foreign liabilities. Kearns and Patel (2016) and Banerjee, Hofmann and Mehrotra (2022) find that the financial channel can (partly) offset the trade channel[1], with stronger effects in emerging economies. Also, there is evidence that depreciation decreases cross-border bank loans (KADIRGAN, 2023), reducing real investment in emerging economies (AVDJIEV et al., 2019). Caldentey, Negront and Lobos (2019) document that beyond a leverage threshold, firms' investment contracts after a devaluation. Kohler and Stockhammer (2023) also find that exchange rates are drivers of

[1] The trade channel reflects the expansionary effect of exchange rates devaluations through an increase in net exports.

procyclical interactions with output, while Cordella and Gupta (2015) find that countries with procyclical capital flows tend to have procyclical exchange rates. This phenomenon was broadly referred to as *balance of payments dominance* (OCAMPO, 2016).

Inspired by this idea, we develop a novel agent-based model (ABM) with heterogeneous firms that rely on foreign debt to finance their investment decisions. We aim to study the balance sheet effect and to understand how a small export-led open economy responds to external shocks. We frame this problem in a Minskyan fashion (MINSKY, 1976) and use the Financial Instability Hypothesis (FIH) to understand capital flows and, more broadly, boom-bust dynamics in emerging markets. Other studies have also proposed Minskyan interpretations of open economies (KOHLER, 2019; KALTENBRUNNER, 2015; BONIZZI, 2017; RAMOS, 2019; ARESTIS; GLICKMAN, 2002). Previous work was essentially based on aggregated models. We depart from them by using an ABM, which allows us to map balance sheets' interconnectedness among the various economic units at the micro level. This is at the core of the FIH. In this sense, agent-based modeling, which accounts for agents' heterogeneity and interactions, can easily frame Minskyan ideas in a bottom-up framework.[2]

Our contribution is threefold. First, we propose a novel ABM to study Minsky's FIH in an open economy. We contribute to the literature modeling Minsky's insights, which has neglected open economy problems (NIKOLAIDI, 2017). To the best of our knowledge, no paper has integrated financial flows à la Minsky into an open economy ABM yet. Specifically, we show that firm-level exposure to foreign-currency denominated liabilities can endogenously generate cycles à la Minsky. The model also endogenously produces heterogeneity in firm distribution between Hedge, Speculative, and Ponzi units. Second, we study how this economy responds to external shocks, particularly an exchange rate devaluation. We show that a devaluation negatively impacts financial stability and can decrease real economic activity depending on the relative strength of the trade and financial channels. This is particularly relevant in a scenario of rising corporate foreign indebtedness in emerging markets characterized by export-led growth. In this context, exchange rate movements are both a driver and a channel of transmission of business and financial cycles through their effect on borrowers' balance sheets. Finally, we contribute more broadly to post-Keynesian literature by providing new emergent insights into demand-led growth from an ABM.

The dissertation is structured as follows. Chapter 2 reviews the related literature. We present the model in Chapter 3. Results of simulations are discussed in Chapter 4. Chapter 5 provides a sensitivity analysis of the model. Finally, Chapter 6 concludes the dissertation and points toward future developments.

[2] For example, Reissl (2020) and Pedrosa and Lang (2021).

2 Related literature

The research deals primarily with two blocks of literature: theoretically, with studies backed by Minsky's Financial Instability Hypothesis (FIH), and methodologically, with research in agent-based modeling. The current section will present them and their intersection. We pay special attention to open economy studies.

The FIH was introduced by Minsky (1976) and refers to how financial fragility grows endogenously in the economy throughout the business cycle. In the boom phase, economic units become more optimistic and take more debt to finance their demand decisions, which boosts the economy, making debt cheaper and/or more available. However, higher indebtedness increases the whole economy's leverage and makes it more vulnerable to shocks. In this scenario, any event (or perception) that stimulates a generalized (attempt of) de-leverage is dubbed the Minsky moment. The fire-sale of financial assets has a contagion effect, pushing the whole economy into a recession. Then, the cycle repeats itself.

The FIH can also be seen as the co-evolution of Minsky's typology of Hedge, Speculative, and Ponzi units. Hedge financing units fulfill all of their contractual payment obligations using cash flows. Speculative units meet interest payments with cash flows but must roll over debt repayment. Ponzi firms borrow to meet some of their interest payments.[1] A single firm can (and usually does) navigate through these types during the business cycle. The more Speculative and Ponzi units an economy has, the more financially fragile it is.

A similar process happens when debt is denominated in foreign currency. However, an additional variable is added to the equation: the nominal exchange rate (ARESTIS; GLICKMAN, 2002). Any strong enough exchange rate devaluation can have balance sheet effects that lead a Hedge-financing unit to a Speculative or Ponzi position in domestic currency. This increases their exposure to external shocks. Further, exchange rate movements themselves can be understood in light of Minsky's framework once we take foreign currency as an asset and its movements driven by financial (capital flows) cycles (KALTENBRUNNER, 2015; BONIZZI, 2017; RAMOS, 2019, and AGOSIN; HUAITA, 2011; MACALÓS; ROSSI, 2022 for empirical evidence).

A few papers in the formal Minskyan literature have applied these ideas to an open economy. Foley (2003) presents a model of how cyclical dynamics are generated

1 There are multiple ways of defining Hedge, Speculative, and Ponzi units. We follow Minsky (1992) closely, but it is worth mentioning that Minsky (1977) himself has a different definition to classify Hedge, Speculative, and Ponzi firms based on *expected* cash flows.

endogenously by the interaction of foreign debt and interest rate hikes. Taylor (2004, Chap. 10) highlights the interplay between international reserves, current accounts, and interest rates. Gallardo, Moreno-Brid and Anyul (2006) shows how deviations from an international reserve critical level might generate business cycles.

Special attention is drawn to Kohler (2017, 2019)'s work. In his 2017 paper, Kohler develops a post-Kaleckian open economy model to study the impacts of currency devaluation in countries with foreign currency indebtedness. He finds that, in the presence of balance sheet effects in the investment function, currency devaluations are usually contractionary and have stabilizing effects only when they can boost domestic capital accumulation in an accelerator effect wherein higher exports stimulate demand, stimulating investment. In the 2019 paper, he expands his original model so that exchange rate appreciation (or depreciation) fuels balance sheet soundness (or fragility) creating endogenous business cycles.

Lastly, Nalin and Yajima (2024) studies the balance sheet effect of an exchange rate depreciation in an open economy SFC for Mexico. They observe the operation of balance sheet effects through a new steady state with a higher level of foreign debt and real economy hysteresis. These papers heavily inspire the model presented in Chapter 3 but differ fundamentally in the methodology used. All models mentioned until now are aggregate models, in opposition to agent-based models.

Agent-based modeling interprets the economy as a complex system. Tesfatsion (2003) defines agent-based modeling as the computational modeling of economic processes as open-ended dynamic systems of interacting agents. The economy is populated by heterogeneous agents connected in non-trivial networks. Interactions between agents make the system evolve in an unanticipated way. In that sense, these are bottom-up models, where the systems proprieties can not be derived from any agent's behavior in particular. This is particularly relevant to Minsky (1976)'s FIH, that heavily relies on the balance sheets' interconnectedness among the various economic units to explain the business cycles. For Minsky, the evolution of Hedges to Speculative and Ponzi units in the economy determines its level of macro-financial fragility.

Taylor and O'Connell (1985, p. 871) remark that "shifts of firms among classes as the economy evolves in historical time underlie much of its cyclical behavior. This detail is rich and illuminating but beyond the reach of mere algebra". Traditional modeling techniques based on optimization or differential equations fall short of Minskyan ideas. Agent-based modeling allows for higher degrees of complexity, better fitting the effort of formalizing macro-financial relations.

Minskyan's ideas have received special attention, and several papers have applied agent-based modeling to study the FIH. One of the first and most popular papers is

Delli Gatti et al. (2005), further extended by Delli Gatti et al. (2007, 2010), Gallegati et al. (2007), Russo et al. (2007), among others. Delli Gatti et al. (2005) introduces an agent-based version of Greenwald and Stiglitz (1993) financial accelerator model with heterogeneous firms that interact through the credit sector. Due to its New-Keynesian inspiration, the model is fully supply-driven in the long run, which departs from traditional Minskyan demand-led models.

From a demand-led perspective, agent-based modeling has also grown rapidly in the post-Keynesian literature in the last couple of years,[2] such as Bassi et al. (2022), Fanti (2021), Rolim, Baltar and Lima (2023), Reis, Lima and Carvalho (2020), Gibson and Setterfield (2018), among others. Introducing Minskyan ideas, first and most important to the present dissertation, Pedrosa and Lang (2021) build an ABM to study aggregate and firm-level financial fragility. They find that the existence of Minskyan firms depends on the joint distribution of debt and profits, with the possibility for both Minskyan and Steindlian debt regimes. In this same take, Michell (2014) build an ABM to investigate Steindlian monopolization theory, reconciling Kalecki's profit equation and Minsky's FIH. Reissl (2020) formalizes Minsky's two price system in an ABM. Chiarella and Di Guilmi (2011, 2012, 2017) use the mean-field aggregation method to put forward a Minskyan model where the interaction between different types of firms (Hedge, Speculative, and Ponzi) generate business cycle dynamics. Di Guilmi and Carvalho (2017) adapt this approach to a neo-Kalecian demand-driven model, with important influence on the present work. Some other papers introduce Minskyan-inspired financial systems, such as Dosi et al. (2013), Popoyan, Napoletano and Roventini (2017), Lamperti et al. (2018), Cardaci and Saraceno (2019b), Carvalho and Guilmi (2020), Cafferata, Dávila-Fernández and Sordi (2021),among others.

On the other hand, work done to model open economies using ABMs is still recent and modest. Most studies deal with economies in a monetary union, such as Deissenberg, Hoog and Dawid (2008), Dawid, Harting and Neugart (2014), Caiani, Catullo and Gallegati (2018, 2019), and Cardaci and Saraceno (2019a). For open economies outside monetary unions, Busato and Possas (2016) present a Micro-Macro Mulsectoral (MMM) model inspired by Dweck (2006) and Possas and Dweck (2004) to study the balance of payments constraint in an ABM. Dosi, Roventini and Russo (2019, 2021) develop a multi-country ABM based on the Keynes+Schumpeter (K+S) family of models to understand countries' divergence due to technical change. Finally, Rolim, Lima and Baltar (2022) build a small open economy model to investigate the impact of foreign shocks on growth and inequality. The latter is the one that most influences the model shown in Chapter 3.

Both aggregate Minskyan models and ABMs have neglected open economy questions. To the best of our knowledge, no paper has integrated financial flows à la Minsky into

[2] For a survey, see Di Guilmi (2017).

an open economy ABM yet. This is particularly important for emerging economies which historically suffer from external fragility(ANDRADE; PRATES, 2013, and KOHLER; BONIZZI; KALTENBRUNNER, 2023 for empirical evidence). Recently, this risk has also shifted from sovereign foreign debt to private corporate foreign indebtedness (CHUI; KURUC; TURNER, 2018). In this context, the model presented in the next Chapter fills this gap in the literature and contributes to understanding this problem.

3 Model

We develop a export-led agent-based macroeconomic model to assess the joint dynamics of leverage, capital accumulation and exchange rates in a small open economy. The model is populated by five classes of agents: Firms, Households, a Foreign Bank, a Foreign Trade Sector, and a domestic Central Bank. Households, the Foreign Bank, the Foreign Sector, and the Central Bank will be modeled as aggregate sectors, and domestic Firms will be made heterogeneous and modeled at the micro level. The model structure is presented in Figure 1 and transaction flows are presented in Appendix A.[1] Simulations are run in the Laboratory for Simulation Development (LSD) software[2] with assistance of the shell-based program Purpurea[3].

We suppose a single good small open economy. In this scenario, we only analyze the dynamics of the domestic economy and how it is affected by the "rest of the world", taken as exogenous. More precisely, the Foreign Economy (or "rest of the world") is populated by a Foreign Trade Sector (FS) that maintains trade flows with the domestic economy and a monopolistic Foreign Bank (FB) that keeps financial flows. The Foreign Economy is assumed to growth by an exogenous rate.

We simulate the model with 100 firms.[4] Firms set their desired level of investment through a flexible accelerator mechanism. The Foreign Bank offers one period foreign currency loans for firms to finance their investment decisions. This is a simplifying hypothesis to shed light to our research question. There is price and quantity credit rationing. Throughout the simulations, these firms can assume Hedge, Speculative, or Ponzi positions. Hedge firms can meet all their contractual obligations with gross profits. Speculative can cover their interest payments with gross profits and need to roll (some of) their debt. Ponzi firms need credit to pay for some of their payments due.

Finally, firms hire labor based on their expected demand. Households sell their labor force to Firms and receive a wage in return. They receive also dividends from ownership. They spend their income on domestic consumption and imports. The Foreign Trade Sector keeps exports and imports flowing with Firms and Households. The Central Bank holds international reserves and uses them whenever there is a scarcity of foreign currency.[5]

The balance sheet effect is defined as a revaluation of foreign liabilities with negative

[1] Appendix A also provide a discussion on the model's stock-flow consistency.
[2] See https://www.labsimdev.org/download/Manual1/Manual/LSD_documentation.html.
[3] See https://github.com/lirolim/purpurea.
[4] There is exit and entry of firms but every exited firms is immediately substituted by a new entrant.
[5] Stock of international reserves is initially set to always fulfill the Central Bank needs since our interest is not in balance of payments crisis, but rather domestic financial crisis driven by foreign conditions. This could be investigated in future works.

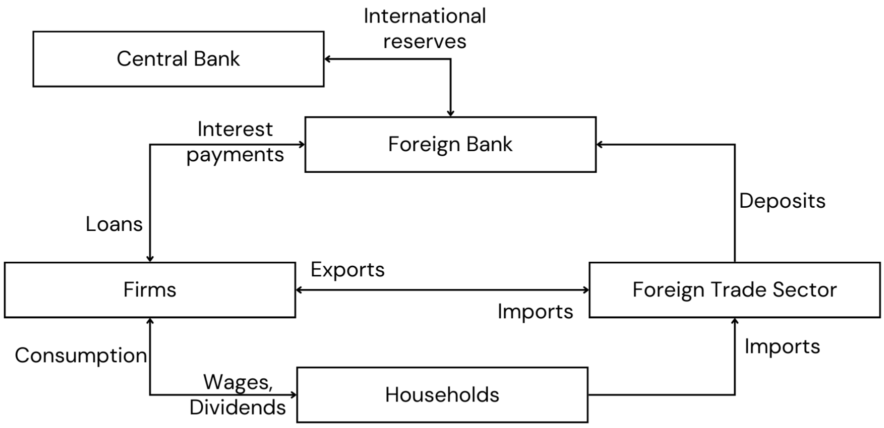


Figure 1 – Model structure

Arrows point from paying sector to the receiver sector.

consequences to domestic financial stability and potential negative impacts on economic activity. The balance sheet effect can be interpreted as a demand or supply side effect. If it is demand driven, a higher leverage will induce firms to reduce their desired investment. If it is supply driven, a higher leverage will increase credit rationing limiting firm's capacity to finance desired investment. There is no consensus in the literature regarding the importance of financial variables to desired investment decisions (PEDROSA; LANG, 2021). For that reason, we choose the model the balance sheet effect through (a decrease in) credit supply.

The model will be calibrated using the indirect calibration approach to generate time series that match qualitatively real-world data (WINDRUM; FAGIOLO; MONETA, 2007). First, we identify a set of stylised facts and macroeconomic regularities that we are interested in reproducing with the model. In sequence, the model is built as close as possible of real behavioral evidence and theoretical consistency. Finally, parameters are chosen consistently with the literature and their economic meaning to entail model output validation. Parameters values are presented in Appendix B. For robustness of results, a sensitivity analysis is presented in Chapter 5. The price level is constant and equal to 1. The foreign price is also assumed constant and equal to 1. Therefore, we mostly deal with real variables, except when the effect of the exchange rate is relevant. All variables with the superscript * are denominated in foreign currency. Small letters refer to individual firm's level (all with superscript j) while the same capital letters refer to aggregate values.

3.1 Firms

Desired investment function for firm j is based in the flexible accelerator mechanism (PEDROSA; LANG, 2021):

$$i_t^{d,j} = \gamma(u_t^{e,j} - u^n)\upsilon k_{t-1}^j \tag{3.1}$$

where γ is a positive parameter, u^n is the normal capacity utilization, equal to all firms, υ is the capital productivity, $u_t^{e,j}$ is the firm j expected capacity utilization, and k_{t-1}^j is firm j capital stock in the previous period. Also, we suppose that for every unit of desired domestic investment, firms must import an additional constant share from abroad as a consequence of technological dependence:

$$m_t^{d,j*} = \eta \; i_t^{d,j} \tag{3.2}$$

where $m_t^{d,j*}$ is the firm j desired imports demand in foreign currency, and η is the additional share of imported investment.

Firms adopt pecking-order criteria to finance their investment decisions, to cover both capital growth and additional imports (MYERS; MAJLUF, 1984). First, they use internal resources (i.e. retained profits from the previous period, $\pi_{t-1}^{r,j}$). If these are insufficient, they seek for credit ($b_t^{d,j*}$). As a simplification, we suppose firms only have access to credit abroad through one period foreign-currency denominated loans, which is the relevant part for our research question. Formally, credit demand in foreign currency is:

$$b_t^{d,j*} = \begin{cases} 0, & \text{if } e_t^{-1}\pi_{t-1}^{r,j} \geq e_t^{-1} i_t^{d,j} + m_t^{d,j*} \\ e_t^{-1}\pi_{t-1}^{r,j} - (e_t^{-1} i_t^{d,j} + m_t^{d,j*}), & \text{otherwise} \end{cases} \tag{3.3}$$

$$\pi_t^{r,j} = \underbrace{q_t^j - w l_t^j}_{\pi_t^{g,j}} - (1 + r_{t-1}^{j*}) e_t b_{t-1}^{j*} \tag{3.4}$$

where w is the constant wage, e_t is the exchange rate,[6] b_{t-1}^{j*} is firm j accumulated foreign debt, and r_{t-1}^{j*} is its bearing interest rate. Also, whenever retained profits are higher than total investment demand, the remainder is distributed to the Households in the form of dividends (θ_t^j):

$$\theta_t^j = \begin{cases} \pi_{t-1}^{r,j} - i_t^{d,j} + e_t m_t^{d,j*}, & \text{if } \pi_{t-1}^{r,j} \geq i_t^{d,j} + e_t m_t^{d,j*} \\ 0, & \text{otherwise} \end{cases} \tag{3.5}$$

The realized level of investment (i_t^j) is determined by:

[6] We define the exchange rate as the price of foreign currency in domestic currency. In this case, a devaluation refers to an increase in the exchange rate. Also, since the domestic and foreign prices are constant and equal to 1, we don't differentiate between real or nominal exchange rates.

$$i_t^j = min\left[\ i_t^{d,j} + e_t m_t^{d,j*},\ \ \pi_{t-1}^{r,j} + e_t b_t^{j*}\ \right] \tag{3.6}$$

Note that it depends on the effective supply of credit set by the Foreign Bank (b_t^{j*}), described in Section 3.3. In this case, credit rationing is the channel through which the balance sheet effect can have an impact on the real economy by reducing realized investment and aggregate demand.

Firms can be classified as Hedge, Speculative or Ponzi according to their potential capacity to repay their oustading debt with gross profits ($\pi_t^{g,j}$). Hedge firms can meet all their contractual obligations with gross profits. Speculative can cover their interest payments with gross profits and need to roll (some of) their debt. Ponzi firms need credit to pay for (some of) their payments due. Mathematically,

- Hedge: $\pi_t^{g,j} \geq (1 + r_{t-1}^{j*}) e_t b_{t-1}^{j*}$
- Speculative: $(1 + r_{t-1}^{j*}) b_{t-1}^{j*} e_t \geq \pi_t^{g,j} > r_{t-1}^{j*} e_t b_{t-1}^{j*}$
- Ponzi: $r_{t-1}^{j*} e_t b_{t-1}^{j*} > \pi_t^{g,j}$

Given the realized investment of firm j and the depreciation rate (δ), the law of motion of capital is:

$$k_t^j = (1 - \delta) k_{t-1}^j + i_t^j \tag{3.7}$$

Firms' production function has fixed coefficients, where $\bar{q}_t^j$ is the maximum production given the stock of capital (k_t^j), the level of employment (l_t^j) and its technical coefficient υ and ι, respectively:

$$\bar{q}_t^j = min[\upsilon k_t^j, \iota l_t^j]$$

Firms adjust their expected demand in a heuristic way (DOSI et al., 2020), based on an adaptive expectation of their previous demand:

$$q_t^{e,j} = d_{t-1}^j \tag{3.8}$$

In this case, the expected capacity utilization is given by:

$$u_t^{e,j} = min\left[\frac{q_t^{e,j}}{\upsilon k_{t-1}^j},\ 1\right] \tag{3.9}$$

Labor demand[7] is:

$$l_t^j = \frac{q_t^{e,j}}{\iota} \tag{3.10}$$

As in Di Guilmi and Carvalho (2017), individual firm j production (eq. 3.11) depends on aggregate demand (D_t) distribution in terms of capital share (eq. 3.12), which is subject to a preferential attachment shock[8] (eq. 3.13):

$$q_t^j = min[\, d_t^j,\ \ \bar{q}_t^j \,] \tag{3.11}$$

$$d_t^j = \left[D_t \frac{k_t^j}{K_t} \right] [1 + s_t^j] \tag{3.12}$$

$$s_t^j = \tilde{s}_t^j \left[1 - \frac{k_t^j}{K_t} \right] \tag{3.13}$$

The demand shock (s_t^j) depends on the firm j relative size. Bigger firms receive more demand and are less prone to be affected by shocks, which can be interpreted in light of the Steindlian argument of monopolization (STEINDL, 1976). Firms set prices by applying an individual gross mark-up μ over unit production costs[9]:

$$p = (1 + \mu) \left(\frac{w}{\iota} \right) \tag{3.14}$$

Finally, firms exit the market if their market share is below a certain threshold τ. The number of firms is fixed, so whenever a firm exit the model, it is immediately substituted by a new entrant.[10]

3.2 Households

Labor supply is infinitely elastic. Households' total income in each period ($Y_{W,t}$) is the sum of the wage bill ($W_t = w \sum_j l_t^j$) and aggregate nominal distributed dividends ($\Theta_t = \sum_j \theta_t^j$). Households spend a fraction c_W from the nominal wage bill and and a

7 Labor supply is infinitely elastic, so labor demand determines employment.

8 $\tilde{s}_t^j \sim Normal(0, \sigma_s)$

9 Note that price is homogeneous and constant, therefore we only deal with real variables.

10 The debt of exiting firms is written off and their capital stock is distributed equally to the entrants. Entrant firms also obtain a loan to finance their capital stock to reach the market average. This is important because if they do not catch up with the average capital stock, they will keep being expelled from the model for being too small. Remember, we define the capital share determines the *ex-ante* market share of firms and aggregate demand distribution.

fraction c_Θ from aggregate nominal distributed dividends. They do not accumulate debt. Their nominal budget constraint is:

$$C_t + e_t M^*_{W,t} = c_W W_t + c_\Theta \Theta_t \leq Y_{W,t} \tag{3.15}$$

Equation (3.16) describes the households' import demand behavioral equation based on Dutt (2002). This specification is compatible with a large variety of assumptions of price and income elasticities of the demand for imports. Specifically, m_1 is the income elasticity, which means a 1% increase in the households' total income increase imports demand by m_1%. Similarly, m_2 is the price elasticity (the inverse of the exchange rate is the price of imported goods), which means a 1% devaluation of the exchange rate reduces imports demand by m_2%. The negative sign reflects that a devaluation (i.e. increase in the exchange rate) reduces the value of the domestic currency, which can now buy fewer foreign goods. m_0 is a positive parameter.

$$M^*_{W,t} = m_0 (Y_{W,t})^{m_1} (e_{t-1})^{-m_2} \tag{3.16}$$

Consumption of domestically produced goods is set as a residual of disposable income after saving, determined by their propensities to consume (c_W and c_Θ) and importing:[11]

$$C_t = c_W W_t + c_\Theta \Theta_t - e_t M^*_{W,t} \tag{3.17}$$

3.3 Foreign Bank

The financial sector is modeled as a monopolistic Foreign Bank that offers one period foreign-currency denominated loans to firms finance their investment decisions. Money is created endogenously through loans. We adopt Dosi et al. (2013) to model quantity rationing:[12] the maximum credit supply for each firm is limited by its past revenue (q^j_{t-1}) according to a loan-to-value ratio $0 \leq \phi \leq \infty$[13]:

$$b^{j*}_t = \min\left\{ b^{d,j*}_t, \phi \frac{q^j_{t-1}}{e_{t-1}} \right\} \tag{3.18}$$

Note that the real economy consequences of the balance sheet effect emerge in our model as a decrease in credit supply, limiting the capacity of firms to finance their

[11] Effective domestic consumption might also be constrained by any individual firm potential production, as explained in Section 3.7.

[12] Firms are never credit constrained to roll over negative retained profits.

[13] $\phi = \infty$ means credit is infinity elastic at the current interest rate.

desired investment decisions. Other papers (DI GUILMI; CARVALHO, 2017; KOHLER, 2017) model the balance sheet effect directly through the investment function, where an increase in firm's leverage decrease its desired investment. However, these papers don't explicitly model the financial sector nor any type of credit rationing, which limits them to a demand interpretation of the balance sheet effect. Additionally, there is no consensus in the literature regarding the importance of financial variables to investment decisions (PEDROSA; LANG, 2021). For that reason, the model's specification of the desired investment is conservative and only relies on the flexible accelerator and we introduce the balance sheet effect as a supply side mechanism.

We also introduce price differentiation based in Raberto, Teglio and Cincotti (2012). Given the probability of default measured by ρ_t^j, the effective supply interest rate for a firm j is r_t^{j*}:

$$\rho_t^j = 1 - exp^{-\left(\frac{e_{t-1} b_{t-1}^{j*}}{k_{t-1}^j}\right)} \tag{3.19}$$

$$r_t^{j*} = r^* + \beta \rho_t^j \tag{3.20}$$

where r^* is the foreign interest rate and β is a positive parameter. Allowing firms only to access credit abroad to finance their investment decisions is a simplifying hypothesis to shed light on our research question.

3.4 Foreign Trade Sector

The Foreign Trade Sector has an export demand function that informs how much domestic goods the rest of the world wants to consume. We adopt again Dutt (2002), where x_1 is the income elasticity of exports, which means a 1% increase in the world's income increases domestic exports' demand by x_1%. Similarly, x_2 is the price elasticity (the real exchange rate is the price of exported goods to foreigners), which means a 1% depreciation of the real exchange rate increases exports' demand by m2%. x_0 is a positive parameter. Exports demand function reflects that a depreciation makes domestic firms more competitive, enhancing the traditional exchange rate trade channel discussed in Chapter 1.

$$X_t = x_0 (Q_t^{*f})^{x_1} (e_{t-1})^{x_2} \tag{3.21}$$

The real foreign output (Q_t^{*f}) is exogenous due to our focus on a small open economy and grows at an exogenous constant rate g^f. Note that this is the only source of autonomous demand which makes our model fully export-led, as discussed in Chapter 4.

$$Q_t^{f*} = (1 + g^f)Q_{t-1}^{f*}$$

3.5 Goods Market

Output (Q_t) is determined by aggregate effective demand (D_t):[14] the sum of investment (I_t), consumption (C_t), and exports (X_t) minus imports ($M_t^* = M_{W,t}^* + \sum_j m_t^{j*}$). We abstract from government fiscal policy.

$$D_t = I_t + C_t + X_t - e_t M_t^* \tag{3.22}$$

3.6 Foreign exchange rate determination

The Balance of Payments (BoP) is:

$$X_t - e_t M_t^* - \sum_{j=1}^{n} e_t r_{t-1}^{j*} b_{t-1}^{j*} + \sum_{j=1}^{n} e_t \Delta b_t^{j*} = e_t \Delta R_t^* \tag{3.23}$$

We assume managed floating exchange rates. Modelling specification adapts Dosi, Roventini and Russo (2019) and Rolim, Lima and Baltar (2022), where BoP disequilibrium is met by changes in international reserves ($= e_t \Delta R_t^*$) and lead to gradual changes in the exchange rate (e_t). Also, we add a stochastic term ϵ_t[15] to mimic foreign exogenous conditions. In this context, the exchange rate[16] is determined by:

$$e_{t+1} = e_t \left[1 - \lambda_1 \frac{X_t - e_t M_t^* - \sum_{j=1}^{n} e_t r_{t-1}^{j*} b_{t-1}^{j*} + \sum_{j=1}^{n} e_t \Delta b_t^{j*}}{Q_t} + \lambda_2 \epsilon_{t+1} \right] \tag{3.24}$$

where λ_1 and λ_2 are positive parameters representing the exchange rate sensitivity to balance of payments disequilibrium and foreign exogenous conditions, respectively. We set $\lambda_2 > \lambda_1$ to follow the empirical evidence that emerging markets' exchange rates are mostly determined by external financial conditions (KALTENBRUNNER, 2018; BARBOSA; JR; MISSIO, 2018) - considered exogenous to our model.

[14] Individual firm demand might be higher than its supply at the maximum level of capacity utilization. In this scenario, supply is biding, and consumption would be the adjustment component. This process is detailed in 3.7.

[15] $\epsilon_t \sim Normal(0, \epsilon_{df})$

[16] For a detailed account of exchange rate determination in an ABM, see Bassi, Ramos and Lang (2023).

3.7 Sequence of events

1. Firms set their expected demand ($q_t^{e,j}$), their desired capacity utilization rate ($u_t^{d,j}$), their desired level of investment ($i_t^{d,j}$), their desired imports ($m_t^{d,j*}$), and their demand for labor (l_t^j);

2. Firms set their demand for credit ($b_t^{d,j*}$) - or distributed dividends (θ_t^j), if they have more resources than required;

3. The Foreign Bank sets the level of credit supply (b_t^{j*});

4. Realized aggregate investment (I_t), desired consumption (C_t^d), and imports (M_t^*) are computed;

5. Exports are (exogenously) determined (X_t^*);

6. Aggregate demand (D_t) is distributed to the firms (q_t^j), output (Q_t) and realized consumption are determined (C_t);

7. Profits are computed ($\pi_t^{g,j}, \pi_t^{r,j}$);

8. Foreign exchange market opens and both reserves (ΔR_t^*) and the nominal exchange rate (e_t) are determined;

9. Firms exit and entry the market.

Two sequence of events are worth being explained in detail: (i) the realization of investment; and (i) the production process. First, every period, each firm project its expected demand, and consequently, its desired level of capacity utilization. Using its investment function, firms decide how much they want to invest. Because of technological dependence, firms add to this an extra imported share of investment. They can finance this decision with internal resources (positive retained profits) or foreign debt. If they can finance it internally, all desired investment is realized. If they need to seek for credit, the foreign bank will supply accordingly to its specification and realized investment is the maximum level that the credit supply allowed. Note that the real economy consequences of the balance sheet effect emerge in this process by increasing credit rationing. The limited funding to desired investment decisions can limit aggregate demand and output.

Second, the production process depends on all realized demand because of our demand-led closure. Investment is realized in the above mentioned process, exports are autonomous and exogenous. Consumption is based on household's income, that in turn depends on firms' demand expectation and employment. With their income, households set their imports demand and desired level of consumption. After this, we can distribute aggregate demand through the individual firms. In the beginning of the period, firm's have hired both capital and labor but only produce when there is realized demand (in other words, firms produce on demand and do no accumulate inventories). Because of the preferential attachment shock, firms might receive more demand than their production at maximum capacity utilization. In this case, at the micro level, there might be supply constraints. After everything is produced, real output is determined by the sum of firms' individual production. Realized consumption is only determined in the end of the period when production is realized. We consider the model to be demand-led because, albeit supply being binding at the micro level, there is excess capacity at the macro level. This means that any increase in aggregate demand can be (partially) met by higher production. In particular, domestic growth is driven by exports growth which is an autonomous component of demand. This is equivalent to how most aggregate demand-led models work (see Blecker and Setterfield (2019) for an overview).

4 Results

4.1 Model validation

Matching simulated and real-world stylized facts is the most common validation practice in the ABM literature (FAGIOLO et al., 2019). Regarding our research question, we focus on real-financial nexus data. Specifically, we see whether the model reproduces main macroeconomic regularities and stylized debt dynamics. Additionally, we validate theoretically our model based on the Financial Instability Hypothesis main features. The model is simulated for 500 periods with 150 warm-up steps disregarded from the analysis. This section reports the median[1] results for the 50 Monte Carlo simulations for the baseline scenario.

First, Figure 2 shows that the model can generate sustained growth[2] with fluctuations for the main aggregate variables (output, consumption, and investment). Investment is more volatile than output and consumption (CARLIN; SOSKICE, 2014). Still, consumption is more volatile than output[3] as observed in some emerging economies (JACOBO; MARENGO, 2020).

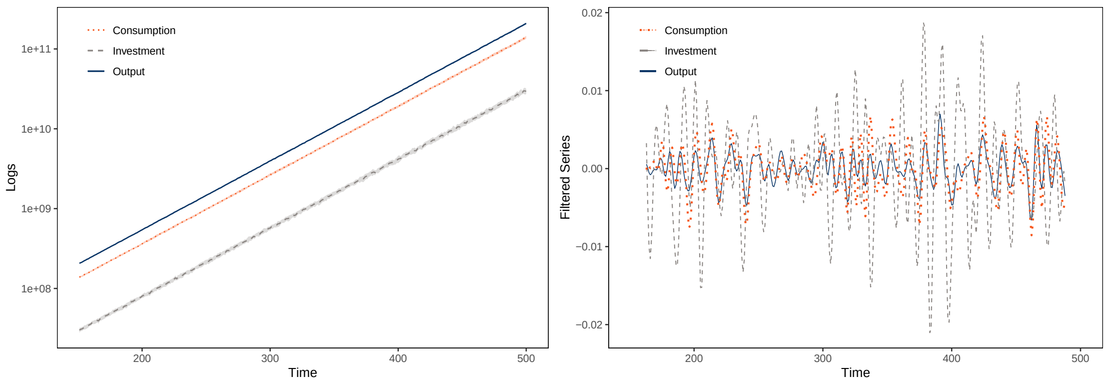


Figure 2 – Output, consumption, and investment: trend and cycles

Note: results from the median of 50 Monte Carlo runs. Cycles obtained through bandpass-filter (6,32,12). All series are taken in logarithms. Confidence interval of 95%. Source: authors' own elaboration based on simulation results.

1 We use median values (instead of averages) because we cannot assume normal distribution of the variables in the Monte Carlo experiment.

2 Economic growth is possible without productivity growth because of exports demand growth.

3 This result emerges in the model because consumption is the adjustment component of demand whenever supply is bidding. Note this can only happen at the micro level, where firms might receive more demand than expected at the beginning of the period because of demand shocks. Remember, labor is hired to fulfill the initial anticipated level of demand. In this case, higher than expected realized demand will be constrained. The economy is still led by demand at the macro level, and there is excess capacity.

Figure 3 shows the cross-correlations between the cyclical components of output and other demand components obtained through the bandpass filter. The sign of the correlation at time t indicates whether the variable is countercyclical (if negative) or procyclical (if positive). The peak position indicates whether the variable is lagged, coincident, or leading output. Results show that consumption and investment are procyclical (CARLIN; SOSKICE, 2014; STOCK; WATSON, 1999). Investment leads output,[4] in line with other ABM models (e.g., Rolim, Baltar and Lima (2023)), while consumption is coincident with it. Both exports and imports are procyclical (AIOLFI; CATÃO; TIMMERMANN, 2011).

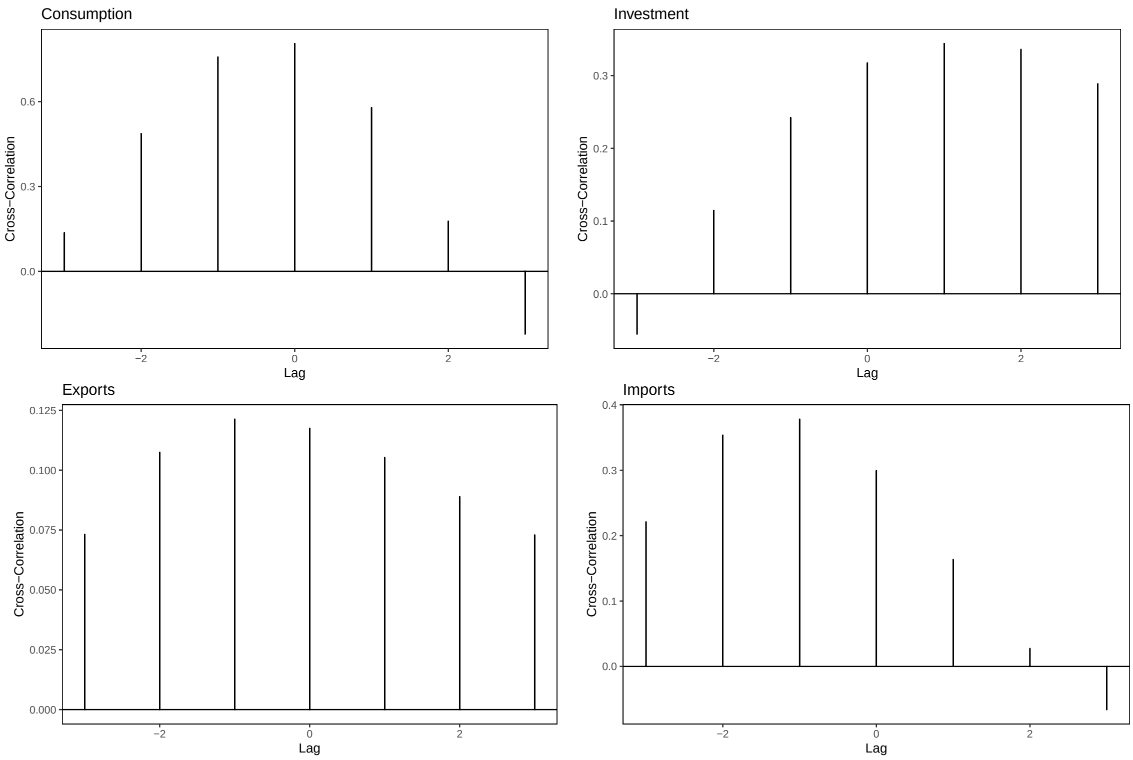


Figure 3 – Cross-correlations structure for output with demand components

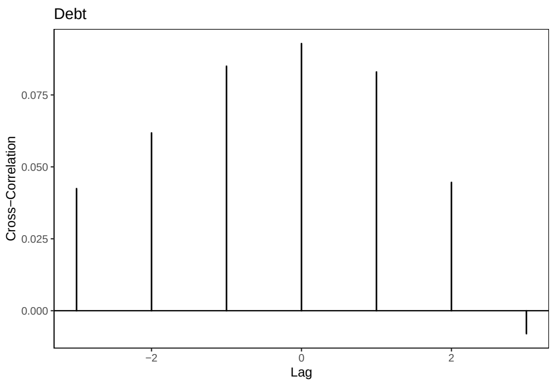
Note: results from the median of 50 Monte Carlo runs. Cycles obtained through bandpass-filter (6,32,12). All series are taken in logarithms. Source: authors' own elaboration based on simulation results.

The model also reproduces stylized facts about credit dynamics and the Financial Instability Hypothesis. Figure 4a shows the model produces procyclical aggregate debt dynamics (CLAESSENS; KOSE; TERRONES, 2009) in line with Minskyan debt regimes.[5]

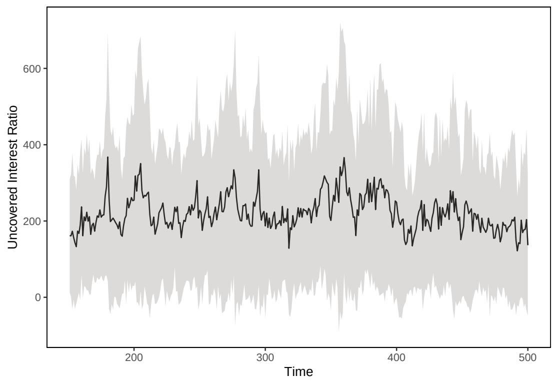
[4] Even though investment is completely induced in the model, the debt cycle dynamics make investment lead output in the short run. For instance, if credit supply begin to shrink, desired investment could not be completely financed and lead to a decrease in aggregate effective demand and output in the next couple of periods. Note that exports growth is deterministic. As seen in Chapter 5, this does not change the result that export growth determines average long-term growth rates in the domestic economy. In other words, cycles emerge in this interaction of investment and debt while growth trend is set by exports growth.

[5] The Minskyan debt regime is characterized by increasing debt with increasing investment and output. It opposes the Steindl debt regime when leverage decreases after an increase in investment and output due to the Kaleckian profit equation (LAVOIE; SECCARECCIA, 2001).

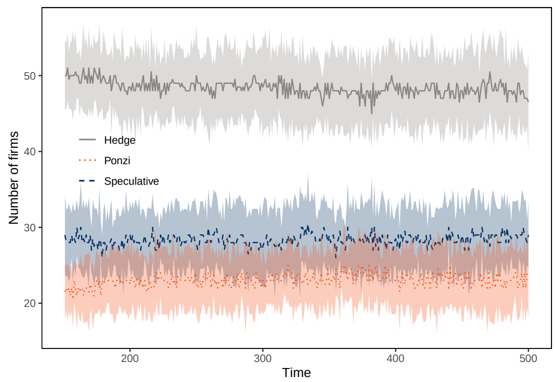
We also calculate a continuous measure of financial fragility inspired by Davis, Souza and Hernandez (2019), the uncovered interest ratio (UIR). The UIR is defined as interest payments less gross profits, normalised by the capital stock. The higher the UIR, the more financially unstable the economy is. Median results for the UIR are presented in Figure 4a. The model displays both short-term business cycle fluctuations and longer waves of financial fragility (see Ryoo (2010) for a discussion). Lastly, we can observe that, although all firms start equally, endogenous heterogeneity emerges in firm distribution between Hedge, Speculative, and Ponzi schemes. This is aspect is key for our research question and justifies our methodological choice. Figure 4c shows that, on average, 49 firms are Hedge, 28 are Speculative, and 23 are Ponzi. This is similar to results for Brazilian corporations (ROLIM; CATTAN; ANTONIOLI, 2021) and other Minskyan inspired agent-based models (PEDROSA; LANG, 2021).



(a) Cross correlation Output-Debt



(b) Uncovered Interest Ratio (UIR)



(c) Minskyan classification of firms

Figure 4 – Selected financial variables: debt-output cross-correlation, UIR, and Minskyan firms distribution

Note: results from the median of 50 Monte Carlo runs. Cycles obtained through bandpass-filter (6,32,12). Confidence interval of 95%. Source: authors' own elaboration based on simulation results.

4.2 Exchange rate devaluation

Our research question relies on the impact of exchange rate movements and their balance sheet effects in the presence of foreign indebted firms. To do so, we simulate a devaluation shock to the exchange rate. Specifically, we decrease the exchange rate e_t by 30% at period $t = 250$. The sizing is similar to what happened to emerging economies like Brazil during the Covid-19 pandemic (BRAGA; TONETO; CARVALHO, 2021). The shock is presented in Figure 5. The exchange rate suffers from a devaluation but stabilizes at a new higher level, characterising a level shift.

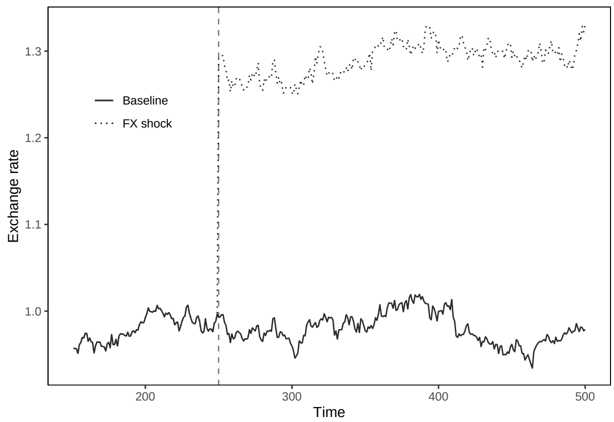


Figure 5 – Exchange rate devaluation (FX shock)

Note: Vertical line indicates the time of the shock. Black lines represent the baseline and dashed lines after the shock. Series represent the median of 50 Monte Carlo runs for each scenario. Source: authors' own elaboration based on simulation results.

We define the balance sheet effect as a revaluation of foreign liabilities with negative consequences to domestic financial stability and potential negative impacts on economic activity. The first and most straightforward effect is the direct revaluation of existing foreign debt at the macro level. Figure 6a shows an increase in the value of foreign debt as a share of output.[6] At the micro level, an exchange rate devaluation increases the cost of foreign debt in domestic currency for indebted firms, which reduces their profitability. Figure 6b shows a reduced aggregate retained profits after the shock. Note that gross profits remain stable, around 18%, even after the shock. The stability of gross profits share after the shock is explained by the fact that labor productivity, labor costs and mark-ups remain constant (remember, prices and wages are constant, and the model doesn't account for technological growth), which makes the domestic profit share constant. In this case, we abstract from the secondary effects of a devaluation on the functional income distribution between wages and profits.[7] The decrease in firms' profitability and financial costs also

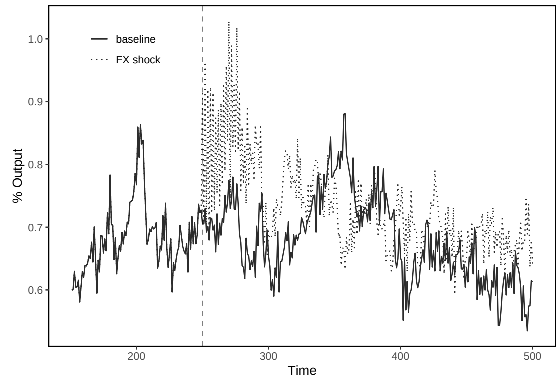
[6] All results presented are statistically significant for median results. For detailed analysis, see Appendix C.

[7] Many post-Keynesian open macroeconomic models try to understand the effects of exchange rate movements on the functional income distribution. For instance, an exchange rate devaluation is usually

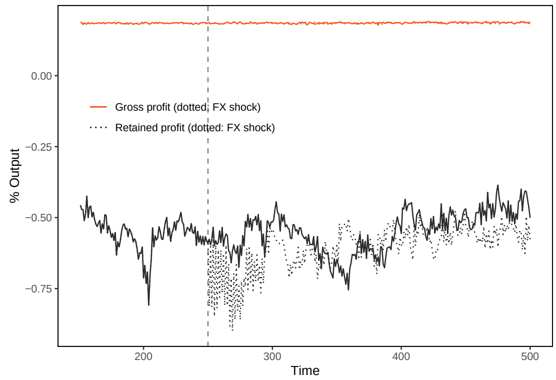
pushes more firms into financial distress, with a reduction of the number of Hedge firms to the detriment of Ponzi and Speculative ones (Figure 6c). However, it is worth noting that even though the value of debt in domestic currency increases, we observe a reduction in the volume of debt supplied. Figure 6d shows the ratio between the debt volume series before and after the shock. The ratio is calculated as the shocked series over the baseline series. A ratio lower than 1 means a reduction after the shock. In this case, we observe a decrease in cross-border banking loans after a devaluation (KADIRGAN, 2023). Also, the share of rationed credit increases by 10% on average (Figure 6e). It happens because the maximum credit supply for each firm is limited by its past revenue. After a devaluation, firms' (domestic) revenue value less in foreign currency. With lower funding resources, real realized investment might be constrained. This is the mechanism through which the balance sheet affect can impact aggregate demand.

Turning to the effects on real economic activity, Figure 7 shows the ratio of output and each of the demand components before and after the shock. We observe a reduction (i.e., a ratio lower than 1) of output after the shock (Figure 7a), which indicates a devaluation has a contractionary effect. This happens because the balance sheet effects have secondary consequences to economic activity. Investment decisions in the model are financed either with retained profits or foreign debt. After the shock, retained profits decrease and credit rationing increases. With fewer resources to finance investment decisions, aggregate investment decreases (Figure 7b). This is the real economy consequence of the balance sheet effect and the revaluation of foreign liabilities. Consumption is completely induced in the model, so it also decreases after the shock (Figure 7c). In addition, exports increase after a devaluation (Figure 7d). This is the consequence of a positive price elasticity: an increase in the exchange rate (i.e., a devaluation) is accompanied by an increase in export demand by the rest of the world. On the other hand, domestic demand for imported goods decreases after a devaluation since it is a function of both investment demand, households' wages and imports prices (i.e. the exchange rate) (Figure 7e). Note that these are all level effects affected in the short run by financial dynamics. Figure 7f shows the ratio for output growth, which remains at the baseline level (the ratio is not consistently below or above 1).

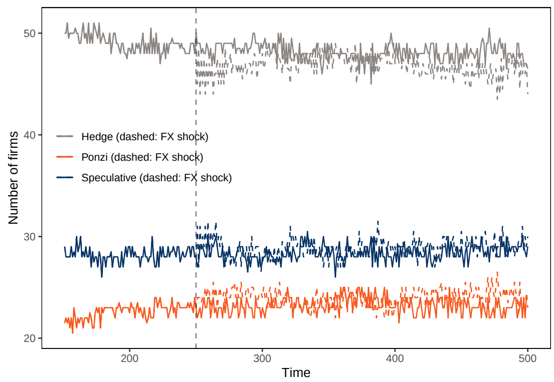
associated with an increase in prices and the profit share through an increase in the mark-up factor (BLECKER, 1989). This would play in the same direction as our results for output level presented below since higher prices lead to lower wage shares, lower real wages, lower consumption, and lower aggregate demand (KRUGMAN; TAYLOR, 1978).



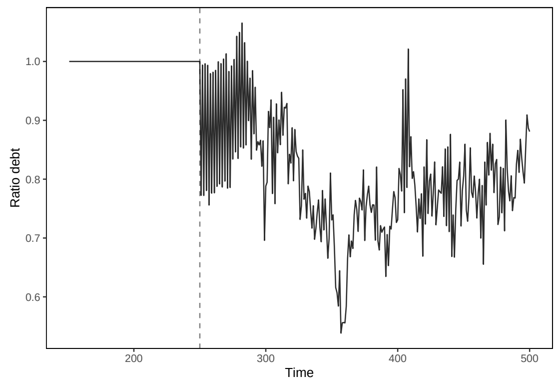
(a) Debt as a share of output



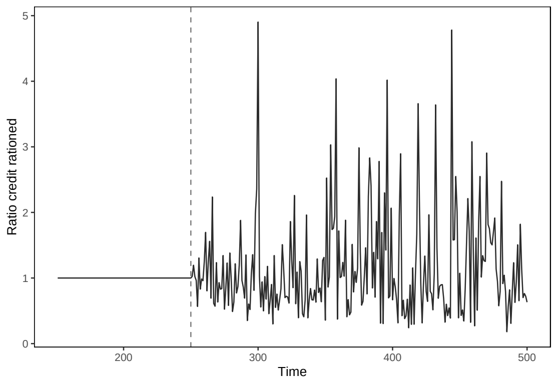
(b) Profits as a share of output



(c) Minskyan classification of firms



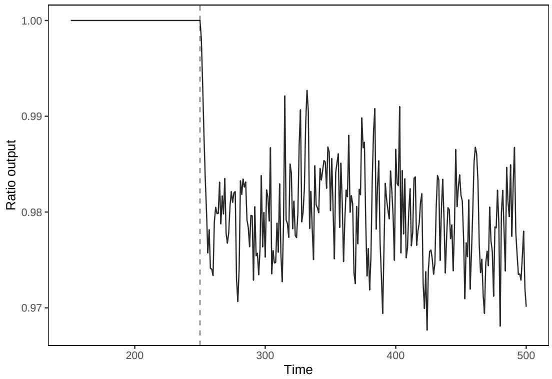
(d) Debt volume ratio in relation to baseline



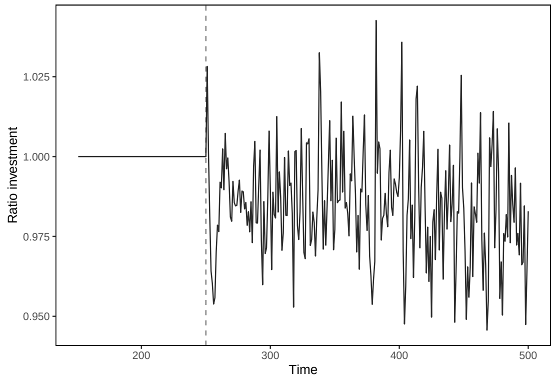
(e) Debt rationed ratio in relation to baseline

Figure 6 – Selected financial variables before and after FX shock

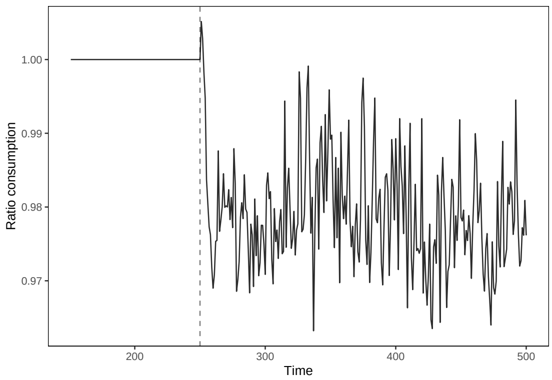
Note: Vertical line indicates the time of the shock. Black lines represent the baseline and dashed lines after the shock. Series represent the median of 50 Monte Carlo runs for each scenario. Source: authors' own elaboration based on simulation results.



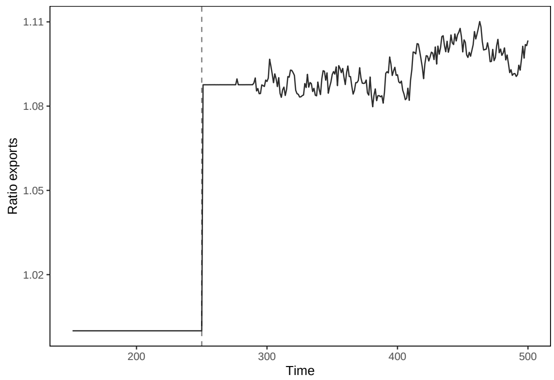
(a) Output ratio in relation to baseline



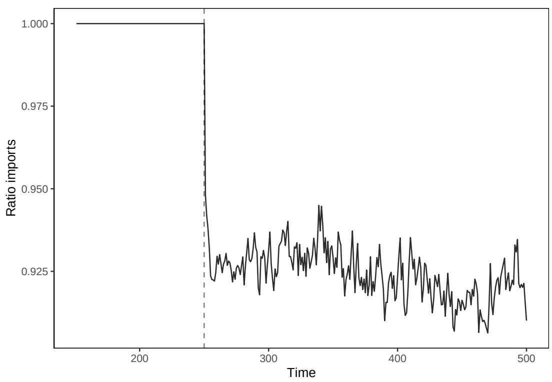
(b) Investment ratio in relation to baseline



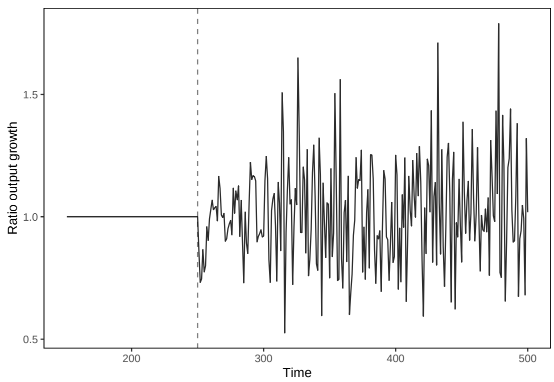
(c) Consumption ratio in relation to baseline



(d) Exports ratio in relation to baseline



(e) Imports ratio in relation to baseline



(f) Output growth ratio in relation to baseline

Figure 7 – Ratio of demand components before and after the FX shock

Note: Vertical line indicates the time of the shock. Series represent the median of 50 Monte Carlo runs for each scenario. Source: authors' own elaboration based on simulation results.

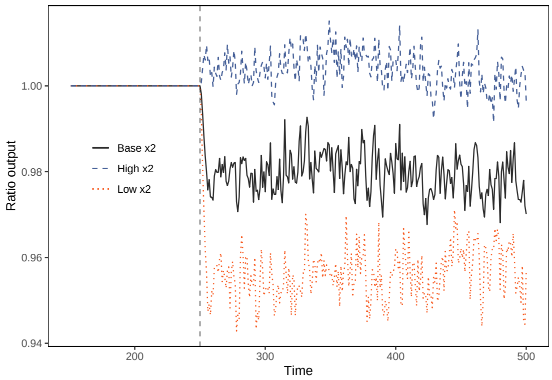
4.3 The role of trade elasticities

It is worth noting that foreign trade dynamics are crucial for our analysis of an exchange rate shock. Our research question relies exactly on the relative strength of the financial channel compared to the trade channel. Remember, a devaluation has an expansionary effect on the trade balance (through the trade channel) but a contractionary impact on investment (through the financial channel and balance sheet effects). Our specification for export and import demand is standard in the literature but requires both income and price elasticity calibration. We use empirical estimates from Bussière, Gaulier and Steingress (2020) to calibrate these elasticities to minimize any bias.

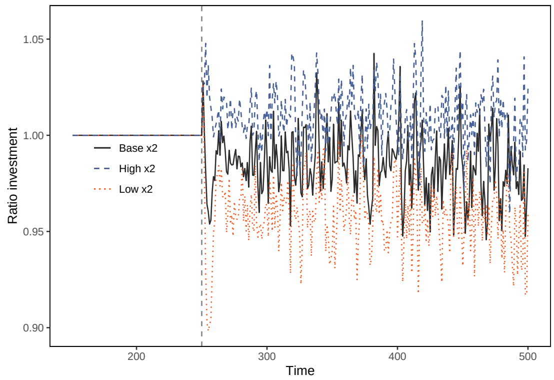
To further understand this idea, we vary the response of trade (via export sensitivity) to exchange rate movements. We aim to answer the question of the importance of trade responsiveness to exchange rate movements in the presence of the financial channel. To do so, we perform the same shock as in Section 4.2, but we simultaneously change the x_2 parameter. Specifically, we perform a high $x_2 = 0.42$ and a low $x_2 = 0.22$ scenario. The baseline value $x_2 = 0.32$ is obtained from the empirical literature for emerging economies (BUSSIÈRE; GAULIER; STEINGRESS, 2020).

Figure 8 shows the results for the ratio of output and each of the demand components before and after the shock with different values for x_2. First, as a sanity check, Figure 8d confirms that the higher the x_2 value, the higher the response of exports to a devaluation. Note that the blue line, which represents the scenario with high x_2, is the one where exports increase the most after the devaluation. As a consequence of this strengthening of the trade channel, we see that in all demand components, the blue line is always the higher one. In particular, Figure 8a shows that when x_2 is high enough, we can observe an expansionary exchange rate devaluation (i.e., the ratio is higher than 1). This expands the results presented in the previous section by confirming that the final impact of an exchange rate movement will depend on whether it is able to stimulate demand, even in the presence and operation of balance sheet effects. This result is equivalent to Kohler (2017)'s findings for an aggregate model. The result for other demand components follows the same logic as explained in the previous section but differs only for the strength of the trade channel imposed by changes in x_2. Finally, output growth rates do not vary in the long run as in the baseline scenario (Figure 8f).

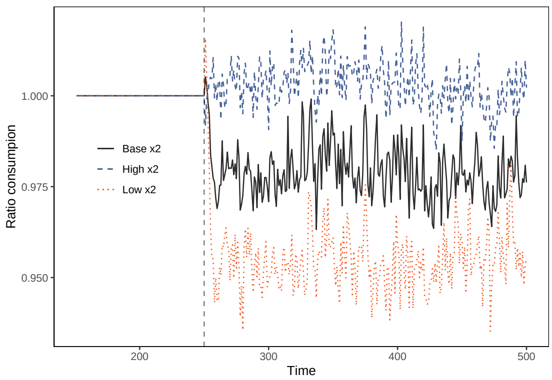
Despite the different effects on the real economy, Figure 9 shows no significant differences when we analyze the exchange rate devaluation impact on financial fragility. The balance sheet effect still operates in reevaluating foreign liabilities and increasing the value of debt after the shock (Figure 9a). We observe a ratio over 1 for all scenarios, despite variations in x_2. This means that the currency mismatch in domestic agents' balance sheets is always affected by a devaluation, no matter what is the short-term impact on economic



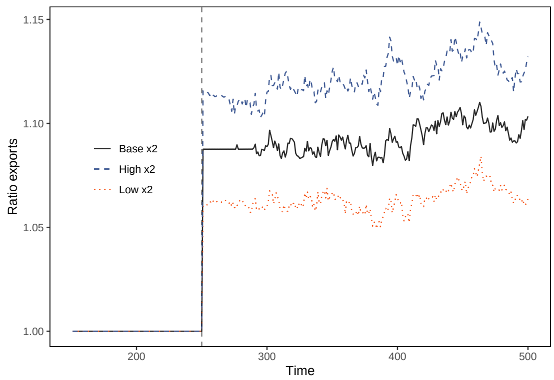
(a) Output ratio in relation to baseline



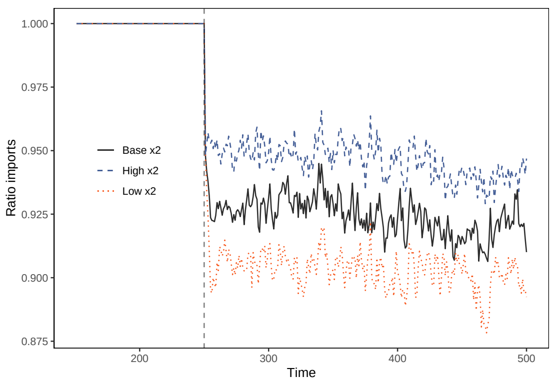
(b) Investment ratio in relation to baseline



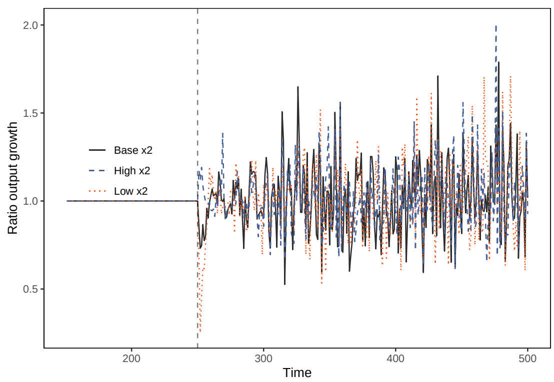
(c) Consumption ratio in relation to baseline



(d) Exports ratio in relation to baseline



(e) Imports ratio in relation to baseline

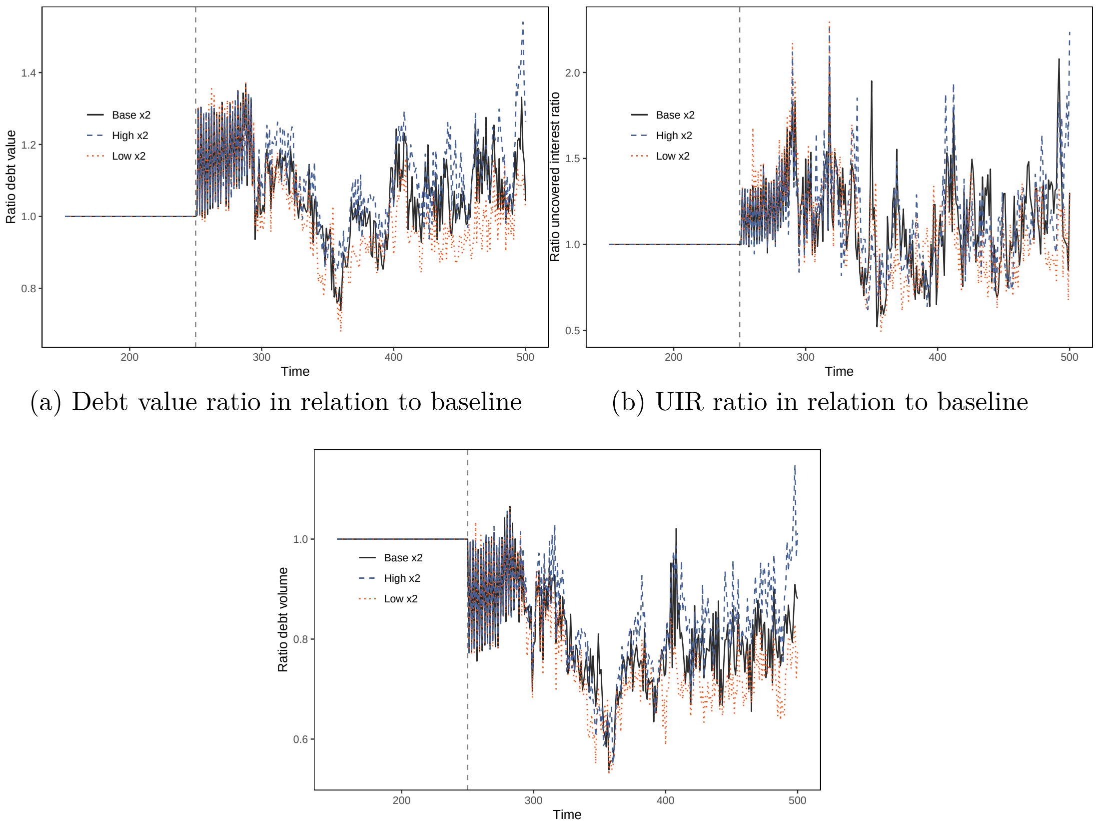


(f) Output growth ratio in relation to baseline

Figure 8 – Ratio of demand components before and after the FX shock with different values for x_2

Note: Vertical line indicates the time of the shock. Series represent the median of 50 Monte Carlo runs for each scenario. Source: authors' own elaboration based on simulation results.

activity. Figure 9b shows an increase in our continuous measure of financial instability, the uncovered interest ratio (UIR). Remember, the UIR is defined as interest payments less gross profits, normalized by the capital stock. The higher the UIR, the more financially unstable the economy is. On average, we observe a higher UIR than before the shock for all x_2 values. Lastly, debt volume also decreases for all scenarios (Figure 9c). This dual result is similar to Nalin and Yajima (2024)'s conclusions.



(a) Debt value ratio in relation to baseline

(b) UIR ratio in relation to baseline

(c) Debt volume ratio in relation to baseline

Figure 9 – Selected financial variables before and after FX shock with different values for x_2

Note: Vertical line indicates the time of the shock. Series represent the median of 50 Monte Carlo runs for each scenario. Source: authors' own elaboration based on simulation results.

5 Sensitivity analysis

To further understand the model's behaviour and ensure the robustness of our results, we perform a global sensitivity analysis exploring joint variations of key parameters. We follow the methodology proposed by Salle and Yıldızoğlu (2014), in which a meta-model is estimated with a parsimonious sampling of the possible parameters combinations in the selected parameters domain. This method uses the Nearly Orthogonal Latin Hypercube (NOLH) sampling (CIOPPA; LUCAS, 2007) as design of experiment (DoE). We use 17 DoE samples and 8 external samples[1] to construct the Sobol (2001) decomposition and estimate the meta-model, which relate the parameters and the variables of interest. The parameters we perform the analysis are listed in Table 1. We include financial and investment related parameters, given their relevance to our research question. Our variables of interest are: i) the output growth rate; and ii) the uncovered interest ratio (UIR).

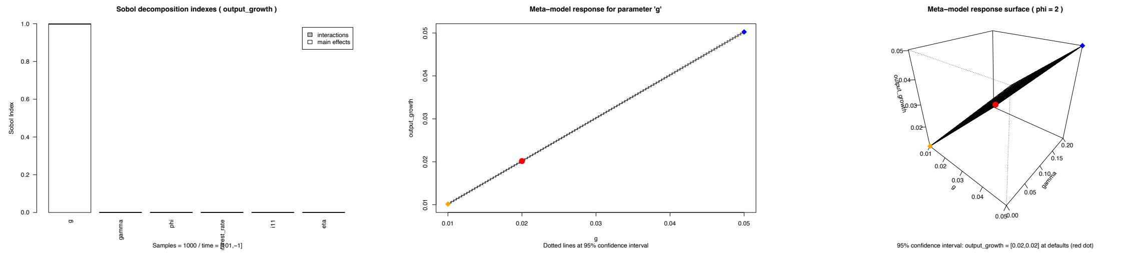
Table 1 – Sobol decomposition: direct effects and interactions

		Output growth		UIR	
	Parameter range	Direct	Indirect	Direct	Indirect
i_1	[0.75, 1]	0.000	0.000	0.004	0.002
η	[0.05, 0.2]	0.000	0.000	0.002	0.002
g^*	[0.01, 0.05]	0.998	0.002	0.014	0.002
ϕ	[1, 10]	0.000	0.000	0.033	0.002
r^*	[0.01, 0.09]	0.000	0.000	0.257	0.003
γ	[0, 0.2]	0.000	0.000	0.686	0.003

Note: results consider 50 Monte Carlo runs for each scenario in DoE. Source: own elaboration based on simulation results.

First, we find that domestic output growth rate is determined exclusively by the foreign output rate, g^* (Figure 10a). Remember that exports depend on the foreign output, which increases at an exogenous and constant rate. This result is similar to aggregate Supermultiplier models (FREITAS; SERRANO, 2015; SERRANO; SUMMA; FREITAS, 2023), where the existence of autonomous demand that does not generate capacity drives growth. This dynamic is a novelty in the post-Keynesian inspired agent-based literature, which either relies on cycle analysis (DI GUILMI; CARVALHO, 2017; REISSL, 2020; CAIANI et al., 2016; CAFFERATA; DÁVILA-FERNÁNDEZ; SORDI, 2021) or explicitly introduce some type of supply-side productivity growth (PEDROSA; LANG, 2021; CARVALHO; GUILMI, 2020; DOSI et al., 2013; ROLIM; BALTAR; LIMA, 2023;

[1] The sample size is obtained from Salle and Yıldızoğlu (2014).



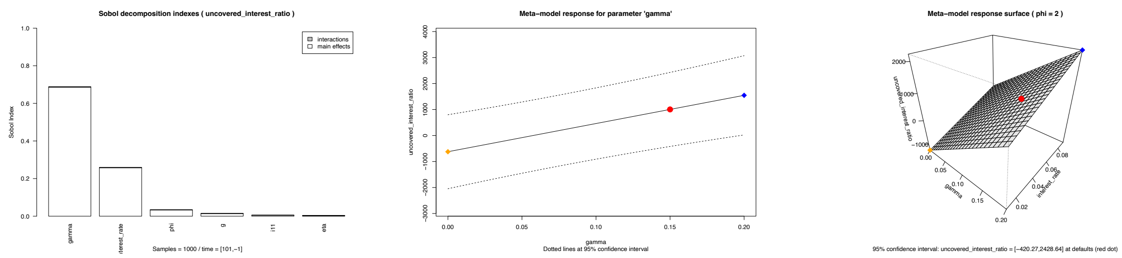
(a) Sobol decomposition (b) Main parameter effect (c) Response surface

Figure 10 – Sensitivity analysis results: output growth

Note: Sobol decomposition, conditional effects of main parameter and meta-model response surface for two main parameters. Source: own elaboration based on simulation results.

BASSI; LANG, 2016; FANTI, 2021).[2] Our model enriches the post-Keynesian tradition because it reproduces both endogenous financial fragility à la Minsky and demand-led growth.

Finally, analysing the results for the uncovered interest ratio (UIR), the two parameters with most influence are the interest rate sensibility to the firm probability of default, γ, and the foreign interest rate, r^*, respectively (Figure 11a). Remember that the UIR is our continuous measure of financial soundness, where higher ratios correspond to higher levels of financial fragility. The results are as expected. The interest rate sensibility to the firm probability of default puts that, the more leveraged a firm is, higher it is their probability of default. In this context, more leverage a firm is, more interest it pays on its debt. The foreign interest rate affect the UIR though this same increasing in foreign debt servicing cost. However, the impact is less prominent because of the linearity of r^* compared to γ.



(a) Sobol decomposition (b) Main parameter effect (c) Response surface

Figure 11 – Sensitivity analysis results: uncovered interest ratio

Note: Sobol decomposition, conditional effects of main parameter and meta-model response surface for two main parameters. Source: own elaboration based on simulation results.

[2] This result is possible because of our infinitely elastic labour supply, but it could also be achieved through an employment growth rate higher than the foreign output growth rate.

6 Conclusion

Recently, emerging economies have observed a surge of foreign liabilities in many non-financial corporate balance sheets. In this context, firms are more vulnerable to external shocks and exchange rate movements. Any strong enough devaluation could impose extra financial costs that would push them into financial distress. To better understand this, we develop a novel agent-based model (ABM) with heterogeneous firms that depend on foreign debt to finance their investment decisions. We aim to study the impact of exchange rate balance sheet effects in a small export-led open economy. We interpret the results in light of Minsky's Financial Instability Hypothesis (FIH). The model endogenously generate financial cycles and firm differentiation between Hedge, Speculative and Ponzi schemes. In general, we contribute to the post-Keynesian and agent-based literatures by combing the FIH in a novel open economy export-led growth model with heterogeneous firms.

In particular, our model is useful to understand how exchange rate movements can impact a small open economy with foreign debt. To do so, we simulate an exchange rate devaluation shock. We find that the impact of an exchange rate devaluation on economic activity will depend of the relative strength of the financial and trade channels. Our baseline result shows that, in the presence of foreign debt, the financial channel can compensate the expansionary effect of a devaluation on trade and have a contractionary effect on the economy. If we increase the responsiveness of exports to the exchange rate, we can observe an expansionary devaluation. Still, we always observe the negative financial impacts of the balance sheet effect. After a devaluation, debt is reevaluated in domestic currency and we observe an increase in financial instability no matter the short term consequence on demand. This result poses the question that, besides the argued positive effects of devaluated currency for growth, the presence of foreign liabilities can impose extra challenges to this strategy, specially for emerging markets with increasing foreign-currency denominated liabilities.

However, the present work does no intend to exhaust this problem. There are many future avenues for research and complements to this framework. First, we have a rather stylized financial system with a monopolistic foreign banks. The introduction of a domestic bank and the possibility of asset trading could enrich the analysis of aspects such as carry trade (LEE; LEE; COLDIRON, 2019). Second, we have a single good economy. We know that a close relation between trade elasticities, balance of payments constrained growth and structural changes exists (ARAUJO; LIMA, 2007, and GOUVEA; LIMA, 2010 for empirical evidence). Third, we did not account for distributive effects of the exchange rate (BLECKER, 2011), as the functional distribution of income was considered exogenous in our model. Lastly, we do not account for policy constraints the domestic economy could face. Monetary sovereignty and policy space are usually constrained by global financial cycles (PRATES, 2020; BONIZZI; KALTENBRUNNER; MICHELL, 2019; REY, 2015). Future research can tackle these issues.

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Appendix

APPENDIX A – Stock-flow consistency

Transaction flow matrix

		Firms			
	Workers	Current	Capital	Central Bank	Foreign Economy
Consumption	$-C_t$	$+C_t$			
Investment		$+I_t$	$-I_t$		
Wages	$+W_t$	$-W_t$			
Net profits		$-\Pi_t^n$	$+\Pi_t^n$		
Imports	$-e_t^{-1}M_{W,t}^*$	$-e_t^{-1}M_{F,t}^*$			$+e_t^{-1}M_t^*$
Exports		$+e_t^{-1}X_t^*$			$-e_t^{-1}X_t^*$
Interest on loans		$-e_t r_{t-1} B_{t-1}^*$			$+e_t r_{t-1} B_{t-1}^*$
Dividends	$+\Theta_t$		$-\Theta_t$		
Δ Foreign debt			$+e_t^{-1}\Delta B_t^*$		$-e_t^{-1}\Delta B_t^*$
Δ Wealth	$-\Delta\Omega_{w,t}$		$-\Delta\Pi_t^r$	$+\Delta\Omega_{w,t} + \Delta\Pi_t^r$	
Δ Reserves				$-e_t^{-1}\Delta R_t^*$	$+e_t^{-1}\Delta R_t^*$

Stock-flow consistent (SFC) models gained relevance in the post-Keynesian literature in recent years,[1] This approach employs specific social accounting matrices to ensure that every flow of payments comes from somewhere and goes somewhere. Every financial stock is recorded as a liability for someone and an asset for someone else, so there are no leakages. It provides a fundamental check of the model's consistency with the structure of national accounts (GODLEY; LAVOIE, 2016). Caiani et al. (2016) provide a methodological recommendation to combine agent-based modeling (micro adherent) with stock-flow consistency (macro appropriate). For them, combining ABM and SFC models solve weaknesses in both approaches because "accounting consistency is implemented at the very bottom level in order to give an account of structural interrelatedness of agents' balance sheet" (CAIANI et al., 2016, p. 377-378).

Note that our model is SFC for all agents but the Central Bank, which accumulates

[1] For a survey of seminal work, see Caverzasi and Godin (2015).

profits or losses throughout the simulations. As mentioned in Section 3, initial stock of reserves are set so they remain positive in every Monte Carlo run. However, this does not imply that Central Bank's balance sheet is SFC. This happens because reserve trade in the foreign exchange market is not met by other item in the Central Bank's balance sheet. In this case, Central Bank's net worth adjust to any increase or decrease of reserves. In other SFC models, this problem is met by the inclusion of a fiscal authority (i.e., the government) that absorbs this flows from the Central Bank. Since our interest is not in balance of payments crisis, but rather domestic financial crisis driven by foreign conditions, we abstract from this mechanism. However, this is a natural extension of the model and could be investigated in future work.

APPENDIX B – Model parameters

Parameter	Description	Value
ι	labor technical coefficient	7
υ	capital technical coefficient	1
γ	flexible accelerator parameter	0.15
u^n	normal level of capacity utilization	0.8
η	share of imported investment	0.1
δ	depreciation rate	0.10
ω	wage	5
p	price level	1
μ	mark-up	0.4
c_W	workers' propensity to consume out of wages	1
c_Θ	workers' propensity to consume out of dividends	0.5
m_0	workers' imports level coefficient	0.2
m_1	workers' imports elasticity to wage income	1
m_2	workers' imports elasticity to exchange rate	0.22
r^*	interest rate on foreign loans	0.05
ϕ	credit supply rationing parameter	2
β	interest rate sensitivity to firms probability of default	0.15
g^f	foreign output growth	0.02
x_0	exports level coefficient	0.05
x_1	exports elasticity to foreign income	1
x_2	exports elasticity to exchange rate	0.32
λ_1	exchange rate sensitivity to BoP disequilibrium	0.0001

λ_2	exchange rate sensitivity to foreign shock	0.01
s_σ	normal standard deviation of demand shock	0.2
e_σ	normal standard deviation of exchange rate shock	1
τ	minimum market share threshold	0.0001

APPENDIX C – Significante test of results

To check for the significance of the results, we performed the Mann-Whitney-Wilcoxon U-test on the series before and after the shock.[1] Table 3 shows the average of the series in the baseline scenario and after the shock, the ratio between them, and the U-test. Ratios below 1 represent reductions after the FX shock. If the p-value of the U-test is below 0.05, we can reject the null hypothesis and say the series before and after the shock are statistically different. All variables present statistically different results after the shock but for exports. Even the ratio column showing that exports increase by 10% after the shock, the test accepts the null hypothesis. This can be due to the exogeneity of foreign output that sets most export behavior. In this case, there is a change in level but not a change in the series behavior after the shock.

	Baseline Average	Post-shock Average	Ratio	U-test p-value
Retained profits over output	-0.49	-0.56	0.87	0.04
Number of Minskyan units	51.95	53.56	1.03	0.00
Debt over output	0.63	0.69	1.10	0.04
Debt volume	5.9e+10	4.7e+10	0.80	0.00
Output	9.1e+10	8.9e+10	0.98	0.00
Investment	1.3e+10	1.3e+10	0.98	0.00
Consumption	6.1e+10	5.9e+10	0.98	0.00
Exports	3.2e+10	3.5e+10	1.10	0.89
Imports	1.6e+10	1.4e+10	0.92	0.00
Output growth	0.02	0.02	1.01	0.00
Net exports over output	0.18	0.18	0.99	0.02
Balance of payments over output	0.12	0.11	0.95	0.01

Table 3 – Significance tests before and after FX shock

Note: Average of the median series of 50 Monte Carlo runs for each scenario. Source: authors' own elaboration based on simulation results.

[1] We use the Mann-Whitney-Wilcoxon U-test (instead of a regular t-test) because we cannot assume the normal distribution of the variables in the Monte Carlo experiment. P-values of the U-test are read the same way as in the case of a regular t-test.