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The agents of industrial policy and the North-South convergence: State-owned enterprises in an international-trade macroeconomic ABM[*]

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Abstract

How to conceive industrial policies as development instruments distinct from trade or fiscal-deduction interventions? How can we model and study the role of state-owned enterprises (SOEs) as *agents of industrial policy*? How can we model their main attributes and architectures? Drawing on the labour-augmented K+S agent-based model (ABM) in a two-country configuration, we propose an ABM aimed at analysing how SOEs may affect technological and industrial development, fostering economic growth and international competitiveness, in the context of a North-South, leader-laggard type of dynamics. Our objective is not simply to study the ex post outcomes of industrial policies, but rather to model SOEs as explicit economic agents potentially capable to drive industrial dynamics, institutional build-up, and, ultimately, growth. The results indicate that SOEs are a relevant policymaking instrument for these purposes.

JEL classification: C63, J3 , E24, O1

Keywords: Industrial Policy; State-Owned Enterprises; Technology Gap; Agent-Based Model

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1 Introduction

Are industrial policies an effective instrument to foster economic convergence of a developing country? The question is particularly compelling in a period of deep technological and industrial transformation, as the current stage of capitalism is being characterized by a fast-moving technological frontier and emergence of previously unknown industries and markets, such as those enabled by the diffusion of sustainable-energy technologies. In such landscape of deep transformation, less-developed countries progressively risk being excluded from the associated benefits if adequate strategic industrial policies are missing. The case of China is a representative example of the capacity of policies to reorient the country's development trajectory (Yu et al., 2015). Similarly, the US oriented their "America First" strategy to rebuild internal industrial capacity (Mazzucato and Rodrik, 2023). More recently, even the European Union is considering the importance of coordinated investment plans, as demonstrated by the Green New Deal and the clean hydrogen strategy (Wolf et al., 2021). Particularly, in a phase of rapid transformations, industrial policies supporting the transition from GHG-emitting technologies (Rodrik, 2014) might represent an important instrument for developing countries to catch-up with developed ones.

While a growing role for industrial policies seemed to emerge in recent years, particularly after the Great Recession (Wade, 2015; Cherif and Hasanov, 2019), and the pandemic crisis (Cherif and Hasanov, 2021), it is less clear the identification of which agents and authorities should be responsible for their implementation. Such gap is specifically due to the weak understanding and traditional definition of industrial policies as "any type of selective government intervention or policy that attempts to alter the structure of production in favor of sectors that are expected to offer better prospects for economic growth in a way that would not occur in the absence of such intervention in the market equilibrium." (Pack and Saggi, 2006, p. 267-268). In fact, a recent IMF report (Evenett et al., 2024) includes subsidies (in developed countries), and tariffs or quotas (in developing one) among the main forms of industrial policy. However, this definition clearly de-emphasizes one of the most important aspects of industrial policies, that is, *agency*. One of the major differences between industrial policy and trade regulation or tax-incentive schemes is indeed the role of direct state agency, usually in the form of state-owned firms directly involved with technological and industrial development.

On this ground, state-owned enterprises (SOEs) have long played a significant role in the economic landscape of many developing countries, as key actors for targeted industrial policy programs. The literature has extensively documented their role in the case of Asian Tigers (Di Maio, 2009) and China (Cimoli et al., 2020). In general, state-ownership/support to firms has been acknowledged to be effective for economic development when targeting high-level innovative programs in large firms but under conditionality of stringent forms of competition, pushing for the participation in export markets and international competition (Roberts, 2020). In terms of agency form and scope of action, SOEs directly or indirectly managed by the government have been drawing a renewed interest in both public and academic debate. This is true not only for national development purposes but also to enhance countries' trade and international competitive performances

(Kowalski et al., 2013; OECD, 2011). As a matter of fact, one of the most relevant reasons behind the recent stimulus to industrial policymaking has been the achievement of strategic international advantage (Evenett et al., 2024), although in the majority of cases using traditional political-economy instruments.

SOEs have deep historical roots in the construction of the socio-economic fabric of many countries, particularly in their development phase. Here we just mention the Hamilton (1791) "Report on the Subject of Manufacturers" proposing the infant industry argument in order to support the creation of a national production capacity in the U.S. Similarly, List (1856), in his book *National System of Political Economy*, identifies in the protection and development of internal industrial structure one of the key elements for England economic success (Oqubay, 2020). SOEs frequently emerged as the *primus* instrument for developing and implementing industrial policies, in particular the ones targeted at convergence of development trajectories in the Global South regions and countries. Their presence is often associated with strategic sectors for development such as infrastructure, energy, telecommunications, and heavy industry. There, direct state involvement is usually deemed as essential to promote national security, economic stability, and long-term catching-up with the North (IMF, 2020).

In this context, which industrial policy instruments one could envision beyond trade or taxation interventions? How can we model and study the *real agents* of such industrial policies, like SOEs? How can we model their main attributes and architectures? Drawing on the labour-augmented Schumpeter Meeting Keynes (K+S) agent-based model (ABM) (Dosi et al., 2017), and in particular its two-country, North-South version (Fanti et al., 2024), we propose here a new macroeconomic ABM. It is aimed at analysing how SOEs may affect technological and industrial development, fostering economic growth and international competitiveness in the context of a North-South, leader-laggard type of dynamics. Our objective is not simply to study the ex post outcomes of industrial policies, but rather to model SOEs as explicit economic agents potentially capable to drive industrial dynamics, institutional build-up, and, ultimately, growth.

Because the model setting in Fanti et al. (2024) allowed only for capital-goods trade between private firms under fixed exchange rates and no currency constraints, a North-South gap emerged and remained constant. It was not possible to identify clear policies capable to revert the emerging leader-laggard structure and reach convergence. In this paper, however, we experiment with the presence of SOEs under a more comprehensive international trade setting, aiming at the identification of (potentially) more effective industrial policies. Considering the North-South nature of the model, and the relevance of goods-exchange and currency-constraint mechanisms particularly for developing countries, we explicitly add a comprehensive trade set-up to the baseline K+S model. It now includes consumption-goods exports, floating exchange rates, and foreign-currency deficit control. In the new setting, firms and consumers have access to the worldwide capital- and consumption-goods markets, and national currencies depreciate (appreciate) on persistent trade balance deficits (surpluses). Additionally, workers from the South can migrate to escape unemployment and search for better wages.

In our new model, SOEs endogenously emerge in the South country, both at the capital-and the consumption-goods sectors. The aim of SOE introduction is to perform industrial policies. They are modelled as a combination of innovation and investment schemes that are not performed by private firms but have potential to accelerate technological dynamics, and to improve sectoral stability in the long run. In this respect, the mission of SOEs is not only technological, by spurring the upgrade of productive capital, but also social, in terms of indirect outcomes for workers, like more and better jobs, and higher wages. In order to implement innovation policies, SOEs are more "patient" in financial terms, and less sensitive to market volatility, being able to attract and retain more qualified workers. Notably, SOEs compete on both domestic and foreign markets. Also, other than endogenously entering, they may exit the market, leading to an endogenous competitive dynamics between public and private firms, proxying the alternating phases of industrial policymaking throughout history. It must be noticed that the modelled SOEs are far from (the stigmatized view of) bureaucratic and inefficient public firms, rather representing organizations with different means and objectives, created in a process that do not offer the rentier opportunities often associated with firm statization, as they are subject to stringent forms of domestic and international *dynamic competition*, as a discipline device rather than as a growth strategy per se (Amsden and Singh, 1994).

Additionally, as in Fanti et al. (2024), the North and South countries are further differentiated only in terms of the national education system achievements, favouring the North. As in the cited work, just this distinction is sufficient to orient the two countries towards non-converging development paths. Nevertheless, our new model set-up shows that SOEs may represent crucial actors for development policies, being capable of fostering both economic growth and industrial progress in the South. In this respect, SOEs robustly confirm their capability to help the convergence between North and South.

The paper is structured as follows. Section 2 proposes a brief literature review on the role of SOEs as crucial agents for industrial policymaking. Section 3 presents the building blocks of our model. In Section 4 we discuss the main simulation results, including two scenarios with possible industrial policy strategies to ensure convergence. In the last Section we discuss the main conclusions of our contribution.

2 State-owned enterprises and industrial policies

In this section we show that the state-owned enterprise (SOE) is a peculiar form of business organization that has been acknowledged as a pivotal actor for different economic processes, such as innovation dynamics, industrial development, and economic growth. In particular, this form of organization may crucially impact on industrial policy programs aimed at stimulating the macroeconomic performance of developing regions and countries (IMF, 2020).

The debate on the effectiveness of industrial policies is pretty much polarized in the economic literature (Cherif and Hasanov, 2019). Many analysts have traditionally considered SOEs as less innovative and efficient, as compared to their private counterparts, due to bureaucratic inefficiencies, because of higher transaction costs, or to the lack of profit-driven management, due to inadequate incentives or knowledge competences (Pack and

Saggi, 2006). However, a variety of contributions, both theoretical and empirical, have challenged this conventional wisdom (Kowalski et al., 2013; OECD, 2011). Indeed, under conditions such as strong governance structures or appropriate managerial incentives, SOEs can actually become crucial drivers for technological progress (Belloc, 2014). This perspective is supported by empirical evidence showing that a SOE can leverage on its unique configuration to do long-term investment in high-risk (and opportunity) innovations that private firms might avoid (Mazzucato, 2013). Moreover, the capability of SOEs to align strategies with national development goals and policies further underscores their role as catalyst agents for technological catching-up (Del Carmen Sánchez-Carreira et al., 2020; Tonurist and Karo, 2016).

A textbook example for the role of SOEs in fostering economic upgrading are Chinese firms embedding this strategic role in affecting the overall macroeconomic performance, including labour markets, in an economy undergoing rapid industrialization and structural transformation. This impact has been extensively explored particularly for the manufacturing sector. On this ground, Yu et al. (2015) discuss the relationship between institutional changes and productivity dynamics in China, by emphasizing the role of knowledge accumulation and "creative restructuring". In particular, the authors show micro-level evidence on SOEs productivity path, and put forward the case for SOEs as carriers of growth via continuous institutional adaptation and investment in techno-economic capabilities. Dosi et al. (2020) further extend this analysis by exploring the wage-productivity nexus in this world-factory economy, looking at the distinctive wage-setting strategies and productivity pass-through mechanisms vis-à-vis the institutional and ownership structure. The micro-level data on wage-productivity pass-through shows a neat evidence on the special role that SOEs have played both in patterns of value generation and distribution.

Back to the past, economic historians largely acknowledge the role of targeted policies to sustain long-term technological and industrial development of developing regions and countries (Gerschenkron, 1962; Allen, 2011). Italy is an exemplary case study to this point, inasmuch specific public-procurements programs, ensuring regular orders to state-owned producers (e.g., the steam locomotive industry between 1850-1913 (Ciccarelli and Nuvolari, 2015)), and the more qualified composition of the workforce (e.g., the case of engineers in ENI, an energy SOE), were pre-conditions to technological advancements and catching-up for some capital-intensive industries. This went up to the point of Italy reaching the technological frontier of the top Western European competitor countries, by the beginning of the twentieth century (Fenoaltea, 1983).

The stream of literature on SOEs emphasizes the relationship over time between technological progress, policy intervention and industrial development. For instance, it provides valuable historical and institutional context to understand their pivotal role for the long-term trajectories of European economies (Cardinale, 2020). In particular, with respect to the Italian development path, Gasperin (2022) proposes an historical overview on a specific state-owned agent, the Istituto per la Ricostruzione Industriale (IRI) during the 1930s. It offers a compelling historical reconstruction on how the state intervention supported the industrial restructuring and rejuvenation, and spurred the country performance. Indeed, in the period after the WWII, the long-lasting divergence between the North and South regions in Italy significantly contracted as the result of specific SOE investment programs undertaken to accelerate Southern industrial development, in particular the ones financed by the (public) Cassa del Mezzogiorno and the IRI (Saraceno, 1955; Bianchi, 1987). The literature on Italian regional divide highlights the importance of SOEs in stabilizing industries, promoting industrial policy objectives, and fostering economic development. The IRI example shows how strategic State ownership and management may actually lead to significant structural changes and economic modernization, offering lessons for contemporary SOE management and policy frameworks (Gasperin et al., 2021).

Also in developing countries, like Brazil, SOEs had (and still have) an important contribution to increase industrial complexity and reduce the gap to the developed North, being considered critical for the almost 40 years of fast economic growth following the WWII. SOEs as the Banco Nacional de Desenvolvimento Econômico e Social (BNDES), Petrobrás, and Companhia Siderúrgica Nacional (CSN), were essential players in this process, as has been repeatedly identified by the literature on the subject (Suzigan, 1996; Trebat, 1983). A more comprehensive and detailed analysis on the role of industrial policies for economic development both in developed and developing countries can be found in Sections IV and V in Oqubay et al. (2020), respectively.

In recent years, a growing number of contributions within the ABM literature[1] has been devoted to open-economy and multi-country analysis of growth and industrial development, especially to address convergence issues among countries or regions within the European Monetary Union (EMU). On this ground, Caiani et al. (2018, 2019) present a multi-country ABM aimed at studying the effect of different fiscal targets and wage regimes on the divergent performance among the EMU members, with a focus on austerity policies' impact on core-periphery dynamics. Similarly, Dawid et al. (2013) and Dawid et al. (2018) propose a multi-region ABM framework to analyse the effects of different labour-market and social-cohesion policies on regional macroeconomic convergence. Moreover, Petrović et al. (2020) present an open-economy ABM to discuss under which conditions it is beneficial for interacting advanced economies to belong to a monetary union such as the EMU.

Nevertheless, the agent-based literature so far has only indirectly addressed SOEs as agents of industrial policies, by *not* explicitly modelling them. For example, Dosi et al. (2021) proposed a multi-country ABM to show how targeted public policies, implemented by parametric changes, can support firms operating in a laggard country to overcome market barriers to innovation, and to drive successful economic convergence. Fanti et al. (2023) proposed an ABM endogenously reproducing the divergence between two macro-regions differentiated only in terms of labour-market organization, looking at the role of industrial policies supporting machine replacement and capital upgrading to foster the convergence process of the laggard region. Dosi et al. (2023) have added public research laboratories to the original Keynes Meeting Schumpeter (K+S) model (Dosi et al., 2010) meant to foster R&D activity and mimicking an entrepreneurial state.

Therefore, the ABM literature, although advancing on the general macroeconomic ef-

[1] For a detailed discussion on computational ABM macroeconomics and the associated methodologies see Dawid and Gatti (2018).

fect of industrial policies and issues of convergence, is still missing a model capable to more deeply study the role of SOEs as agents of industrial policies, competing in the market with private firms but characterized by a different organizational architecture to such an extent to potentially influence the macroeconomic performance. Notably, in our proposed model setting, we will allow the endogenous emergence of SOEs resulting from a policy of rescuing selected, high-opportunity failing firms. The role of these firms is studied from a focused research question, that is, the possibility of spurring North-South convergence. To better encompass the complexity involved in multilateral commerce, we propose a fully-fledged, international-trade, macroeconomic model, accounting for trading patterns of both capital- and consumption-goods. So far, there are very few examples of full multi-country macro ABMs of international trade (e.g., Dosi et al., 2019; Fanti et al., 2024), in particular integrating both inter-industry and final goods flows.

3 The model

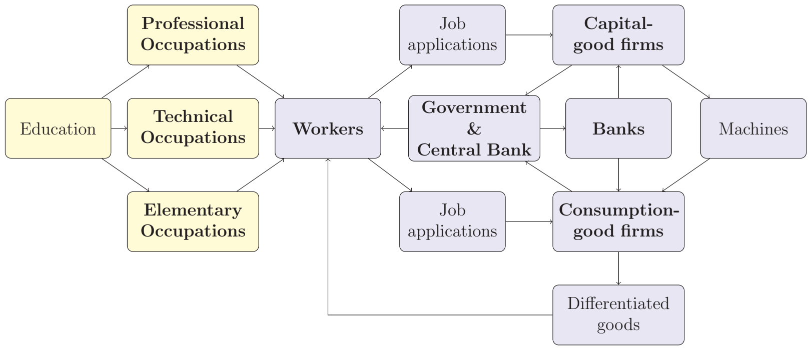
In this paper we propose an extension to the North-South agent-based model (ABM) presented in Fanti et al. (2024). The proposed improvements go along three main dimensions: (i) directly modelling stated-owned enterprise (SOE) agents, (ii) international trade of both capital and consumption goods, and (iii) endogenously floating exchange rate driven by long-run trade imbalances. The functioning of the new North-South set-up is depicted in Figure 1.

The two-sector national economy in the K+S model is composed by four populations of heterogeneous agents, that is L_t^S workers/consumers, F_t^1 capital-good firms, F_t^2 consumption-good firms, and B banks, plus the central bank and the government.[2] Agents are organized within one or more countries, which present a similar overall internal structure.[3]

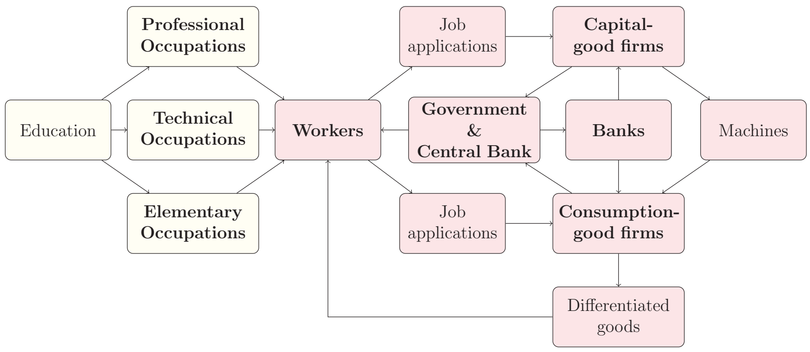
Capital-good firms invest in R&D and produce heterogeneous machine-tools whose stochastic productivity endogenously evolves over time using labour only. Consumption-good firms combine machines, bought from capital-good firms, and labour in order to produce quality-differentiated, perfect-substitute goods for final consumers. The banking sector is represented by a fixed number of banks collecting deposits and providing interest-paying loans in order to finance firms' production and investment plans. Workers search for jobs and firms hire them according to their individual demand expectations. The central bank manages the monetary policy, imposes regulatory reserves to the banks, and bails out the failing ones. The government levies taxes on firms' or banks' profits,

[2] Subscript t stands for (discrete) time $t = 1, 2, ..., T$. Agent-specific variables are denoted by subscript i, for capital-good firms, j, for consumption-good firms, k, for banks, and ℓ, for workers. Countries are tagged by y only when required.

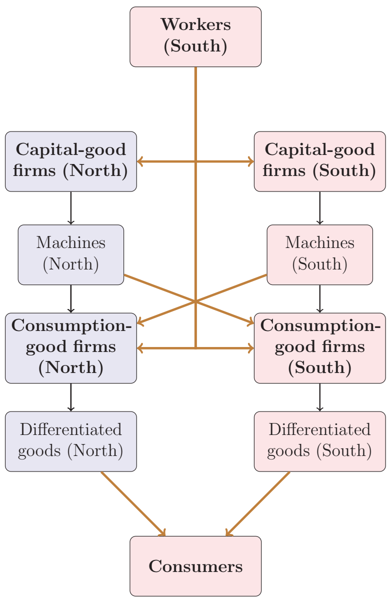
[3] Subscripts and superscripts are used in combination with parameter and variable names to provide context to similar variables of different countries, sectors, goods, trade-flow direction, etc. In what follows, the 0 subscript indicates an initial condition, y/w, an specific country, and t, the simulation time. The superscripts have the following meaning: $'$ standardized value; τ technological generation of a machine; $1/2$ a specific capital-/consumption-good industry/sector; k/c relative to capital-/consumption-goods; m/x relative to imports/exports; e relative to exchange rate; d desired amount; max absolute maximum value.



(a) North country (leader)



(b) South country (laggard)



(c) North-South trade and worker migration

Figure 1: Model description. (a) North country (blue) with high level of education (dark yellow); (b) South country (red) with low level of education (light yellow). The yellow nodes indicate the education and segmented labour markets blocks. (c) North-South machines and consumption-good trade and workers migration from the South (trade flows in brown). Model agents indicated in bold typeface. Source: Fanti et al. (2024) with authors' additions.

workers income and imports, it pays unemployment benefits, provides education, possibly rescues and owns firms (SOEs), imposes a minimum wage, absorbs excess profits and losses from the central bank and SOEs, and keeps a non-explosive public debt trajectory in the long run.

Countries trade both capital and consumption goods. Machine producers send brochures to potential clients worldwide, and consumption-good firms choose suppliers from the received brochures. Countries also compete on the consumption-good international market, and the export shares (imperfectly) evolve based on a replicator dynamics: the more countries are competitive in terms of price and quality the more they export, and conversely. International prices are affected by (relative) nominal exchange rates which evolve according to countries' trade balances. Currencies are fully convertible and excess supplies are hold by central banks. Exports may incur in transaction costs/taxes. The only international financial flows are eventual (unlimited) liquidity swap lines arranged by the central banks.

The government charges tax on profits, income, and imports, provides education, pays unemployment benefits, and may rescue/take ownership of leading bankrupt firms. Education system expenses and unemployment benefits are represented as transfers to workers. The government still enforces a minimum wage indexed (partly or fully) to the aggregate productivity of the country.

The model is fully stock-flow consistent, at the macro (world and country), micro (sector), and individual (firm and worker) levels, at any time step. Entrant firm's capital is derived from bank debt (private companies) or government expense (SOEs).

In each simulated period in our ABM the following events take place:

1. Educated workers enter the market, retire, and update their skills;
2. Machines ordered in the previous period (if any) are delivered;
3. Central and commercial banks set interest rate structure and credit supply;
4. Capital-good firms perform R&D and signal machines to consumption-good firms;
5. Consumption-good firms determine desired production, investment and workforce;
6. Firms allocate cash-flows and (if needed) borrow from banks to operate and invest;
7. Firms send/receive machine-tool orders for the next period (if applicable);
8. Job-seeking workers send applications to firms;
9. Wages are set (indexation or bargaining) and job vacancies are partly or totally filled;
10. Firms pay wages/bonuses and government pays unemployment benefits;
11. Workers decide desired consumption;
12. Market shares are allocated according to relative competitiveness;
13. Firms and banks compute their profits, pay taxes, and repay (part of) their debt;
14. Exit takes place, near-zero share and bankrupt firms leave the market;
15. Prospective entrant firms decide to enter according to market conditions;
16. Government decides on acquiring and rescuing bankrupt exiting firms;
17. Aggregate variables are computed.

3.1 State-owned enterprises

Under usual conditions, firms in both capital- and consumption-good sectors are private, as detailed in Appendix A. However, under country-specific policy settings, the government may intervene when capital firms producing advanced machinery, or large consumption ones, are exiting the market because of financial trouble (bankruptcy). The intervention may be applied only to firms that satisfy, respectively for capital- and consumption-good firms:

$$A^{\tau}_{i,t} > \gamma^1_g \bar{A}^{\tau}_t, \tag{1}$$

$$L_{j,t} > \gamma^2_g \bar{L}^2_t, \tag{2}$$

being $(\gamma^1_g, \gamma^2_g) \in \mathbb{R}^2_+$ two threshold parameters, $\bar{A}^{\tau}_t$, the average productivity of machines currently offered by the capital-good sector in the country[4], and $\bar{L}^2_t$, the average number of workers employed by firms in the domestic consumption-good sector. In this case, the government rescues only the best eligible firm in sector (larger $A^{\tau}_{i,t}$ or $L_{j,t}$), each period the policy is applied.

When a firm is rescued, all private equity is transferred to the state (full statization), without any compensation to private shareholders as the firm has negative net worth. Additionally, all outstanding firm debt $Deb_{i|j,t}$ is repaid by the government, and new money is also provided to ensure positive net worth:

$$NW_{i|j,t} = NW^z_0 \frac{PPI_t}{p^k_0}, \quad z = 1, 2, \tag{3}$$

where $(NW^1_0, NW^2_0) \in \mathbb{R}^2_+$ are parameters defining initial firm cash at $t = 1$ for capital- and consumption-good firms, respectively, PPI_t is the producer price index at time t, and p^k_0 is the initial price of machines, a parameter (equivalent to PPI_0).[5] So, the total new equity injected by the government in rescued firms is equal to $Deb_{i|j,t} + NW_{i|j,t}$.

Immediately after statization, capital-good SOEs are yet endowed with a new technological set (A^{τ}_i, B^{τ}_i) for the production of machines, defined by:

$$A^{\tau}_i = (1 - x_6) \max_{z \in \Gamma} A^{\tau}_z, \tag{4}$$

$$B^{\tau}_i = (1 - x_6) \max_{z \in \Gamma} B^{\tau}_z. \tag{5}$$

$x_6 \in [0, 1]$ is a parameter defining the firm initial distance from the technological frontier represented by the maximum productivities A^{τ}_z and B^{τ}_z of any existing firm z in the set Γ of ones operating in the country.

Public firms have bank loans guaranteed by the government, which allows for larger leverage on debt. This is implemented by a differentiated value to the parameter Λ which defines the prudential limit banks impose on loans over the ratio $Deb_{i|j,t} / \max\left(NW_{i|j,t}, OM_{i|j,t}\right)$. The operating margin $OM_{i|j,t}$ is defined as the difference between sales $S_{i|j,t}$ and wage costs $W_{i|j,t}$. See Appendix A for details.

[4]The labour productivity of the machine when producing consumption goods, see Appendix A.

[5]This equation simply adjusts the initial values to the producer inflation.

In addition, to leverage on the initial technology boost and the loan guarantee, SOEs may behave differently from private firms with regards to (i) increased propensity to R&D (as defined by parameter ν), (ii) more "patience" to recover investment, allowing for accelerated replacement of capital (parameter b), (iii) additional slack when investing in new capital (parameter ι), (iv) differentiated demand of labour education (parameters θ_2 and θ_3), (v) higher education-wage premiums (parameters ϕ_2 and ϕ_3), and (vi) alternative hiring/firing strategies (priority to worker skills vs. wage levels).

Other than that, the behavioural rules applicable to SOEs are the same presented in Appendix A for private ones, being the above behaviours and parameter values the only (potential) differences. Notably, SOEs leave the market similarly to private ones, because of bankruptcy ($NW_{i|j,t} < 0$) or irrelevant market share $f_{i|j,t}$ (see Appendix A for details). The sole difference is the government loan guarantee, as already stated, which ensures banks recover any outstanding debt on the exit of such firms.

3.2 International trade

The extended K+S model can be configured with multiple countries, under the same structure but different parametrizations. Countries have their own currency and may trade machines and consumption goods. Machine trade follows the same process presented in Fanti et al. (2024), and is summarized in Appendix A.

The exchange rates $e_{y,t}$ and $e_{w,t}$, between countries y and w, determine the domestic prices of imported goods, and conversely (see details below). So, the gross price paid by firm j or consumer ℓ in country y for buying a machine or consumption good imported from capital-good firm i or consumption-good firm j at country w, inclusive of duties and transaction costs, is:

$$p^m_{j|\ell,t} = \frac{e_{y,t}\, p_{i|j,t}}{e_{w,t}\left(1 - tr_y^{mk|mc}\right)\left(1 - tr_w^{x1|x2}\right)}, \tag{6}$$

being $tr_y^{mk}, tr_y^{mc} \in [0,1[$ country-specific parameters representing duties imposed by country y on gross final prices of imported machines (superscript mk) or consumer products (mc). $tr_w^{x1}, tr_w^{x2} \in [0,1[$ are parameters modeling transaction costs and other duties on capital- ($x1$) and consumption-good ($x2$) sector exports due in country w. Firms get the same price $p_{i|j,t}$, in home currency, for goods sold domestically or abroad. Duties and costs are collected by the respective government of the exporting (w) and the importing (y) countries.

Competition among countries for consumption-good exports takes place worldwide, and is modelled at the country level. The competitiveness $E^c_{y,t}$ of country y in consumption goods is defined by a weighted combination of the standardized[6] reference export price $p'_{y,t-1}$ and quality $q'_{y,t}$:

$$E^c_{y,t} = \delta_1 \left(1 - p'_{y,t-1}\right) + \delta_2\, q'_{y,t-1}, \tag{7}$$

where $(\delta_1, \delta_2) \in \mathbb{R}^2_+$ are parameters. Reference export price $p_{y,t} = e_{y,t}\, \bar{p}_{y,t} \,/\, \left(1 - tr_y^{xc}\right)$ is computed considering the nominal exchange rate $e_{y,t}$, the weighted-average domestic

[6] Prices and qualities are standardized to the interval $[0.1, 0.9]$ using a log-linear transformation.

price of consumption good $\bar{p}_{y,t}$, and the export barriers tr_y^{xc}. $q_{y,t}$ is the weighted-average domestic quality of consumption goods.

Countries compete to supply the worldwide demand for consumption-good imports. The export share of country y is directed by a replicator dynamics driven by the *relative* competitiveness:

$$f_{y,t}^{cx} = \max\left(f_{y,t-1}^{cx} \left[1 + \chi_x \frac{E_{y,t}^c - \bar{E}_t^c}{\bar{E}_t^c} \right], \; f_0 \right), \qquad \bar{E}_t^c = \sum_y f_{y,t-1}^{cx} \, E_{y,t}. \tag{8}$$

$\bar{E}_t^c$ is the worldwide weighted-average competitiveness, $\chi_x \in \mathbb{R}_+$ is the replication parameter, and $f_0 \in \,]0,1[$ is a market-share fixed baseline. The corresponding desired exports value of country y in domestic currency is:

$$X_{y,t}^{c,d} = f_{y,t}^{cx} \sum_{w \in \Omega} \frac{e_{y,t}}{e_{w,t}} M_{w,t}^{c,d}, \tag{9}$$

where Ω is the set of all countries in the world, and $M_{w,t}^{c,d}$ is the desired imports of each country w.

Similarly, the share of consumption-good imports in country y's domestic market is also driven by the competitiveness $E_{y,t}^c$ of its industry, modelled by a second bounded quasi-replicator equation:

$$f_{y,t}^{cm} = \min\left(\max\left(f_{y,t-1}^{cm} \left[1 + \chi_m \frac{\left(1 - tr_y^{mc}\right) \bar{E}_t^c - E_{y,t}^c}{E_{y,t}^c} \right], \; f_0 \right), \; f_y^{max} \right), \qquad f_y^{max} > f_0. \tag{10}$$

$\chi_m \in \mathbb{R}_+$ is the replicator parameter, and $f_y^{max} \in \,]0,1[$ is a maximum import share parameter. Consequently, the desired imports value in domestic currency is:

$$M_{y,t}^{c,d} = f_{y,t}^{cm} \, C_{y,t}^d, \tag{11}$$

where $C_{y,t}^d$ is the desired aggregate consumption, considering workers demand for consumption-goods.

Therefore, the effective imports $M_{y,t}^c$ and exports $X_{y,t}^c$ depend on the supply and demand conditions of countries and are obtained by allocating the entire worldwide demand *or* supply, iteratively, but *likely* not both. The process avoids *simultaneous* worldwide excess demand and supply. There is no market clearing at the international level: excess demand leads to additional (forced) savings of workers, *or* oversupply becomes inventories at firms. If country y desired supply of consumption-goods is insufficient to match the net desired demand $C_{y,t}^d - M_{y,t}^{c,d} + X_{y,t}^{c,d}$, domestic market has precedence (up to $C_{y,t}^d - M_{y,t}^{c,d}$) and, potentially, $M_{y,t}^c > M_{y,t}^{c,d}$ if there is excess supply abroad, and conversely, if domestic supply is in excess of net desired demand, but there is excess demand worldwide, $X_{y,t}^c > X_{y,t}^{c,d}$. Import shortages are split proportionally among countries. Exports are allocated to consumption-good firms according to the same dynamics used in the exporter country domestic market (see Appendix A).[7]

[7] This arrangement is schematically equivalent to the international trade of goods being managed solely by trading companies, which procure goods in the domestic markets and resell them directly to consumers abroad.

3.3 Exchange rate and trade balance

For convenience, the domestic currency exchange rate $e_{y,t}$ of each country is expressed in relation to a (notional) stable currency.[8] Therefore, the nominal exchange rate between countries y and w, the number of units of y's currency to buy one unit of w's money, is defined as $e_{y,t}/e_{w,t}$. In other words, $e_{y,t}$ is the domestic price of the notional foreign currency.

The nominal exchange rate evolves according to the current account conditions:

$$e_{y,t} = e_{y,t-1}\left(1 - \gamma_y^e \frac{TB_{y,t-1}}{e_{y,t-1}\,Y_{t-1}}\right), \qquad Y_t = \sum_w \frac{Y_{w,t}}{e_{w,t}}, \tag{12}$$

being $\gamma_e \in \mathbb{R}$ a parameter, and Y_t, the world product in international monetary-standard terms, $Y_{y,t}$ is the GDP in domestic currency. $TB_{y,t}$ is the balance of trade or net exports of country y in domestic currency:

$$TB_{y,t} = X_{y,t} - M_{y,t}, \tag{13}$$

where $X_{y,t} = X^k_{y,t} + X^c_{y,t}$ are the effective exports of capital and consumption goods of country y, respectively, and $M_{y,t} = M^k_{y,t} + M^c_{y,t}$, the effective imports of such goods. Intuitively, if country y has $TB_{y,t} > 0$, $e_{y,t}$ decreases, and a smaller amount of domestic currency is required to buy one unit of a country w with stable exchange rate ($TB_{w,t} = 0$). That is, the currency of country y *appreciates* when $TB_{y,t} > 0$, and conversely.

Countries' currencies are assumed to be fully convertible. Domestic agents only keep reserves in the national currency. Central banks offer unlimited supply of domestic and foreign money for the required exchange transactions. Consequently, the central bank can carry foreign currency reserves indefinitely, and has access to other central banks to convert its own currency as needed.[9] In summary, there is no foreign currency constraint for countries with a (even permanent) deficit on the balance of trade ($TB_{y,t} < 0$).

In Appendix A, we briefly present the remaining behavioural rules characterizing agents. For in-depth presentations, see Dosi et al., 2010, 2015, 2017; Fanti et al., 2023, 2024. The model's stock-flow matrices are presented in Appendix B.

4 Model simulation results

We start this section by presenting an overview on the macroeconomic numerical results obtained from the model computer simulation. The presented model was coded and simulated using the LSD framework (Valente and Pereira, 2023), and the produced simulation results were analysed using the R platform (R Core Team, 2024).[10] The figures

[8]Such stable currency is notional, as it refers to a non-modelled country which would be large enough so trade would not affect the international prices of its goods. Alternatively, we can understand it as a reference (weight-balanced) basket of the modelled countries' currencies.

[9]Alternatively, one may assume the central banks regularly clear the excess reserves to control liquidity, by means of swap line arrangements, for instance. Such details are not explicitly modelled, as the proposed exchange rate mechanism prevents explosive accumulation of reserves in practice.

[10]Other than these, several auxiliary third-party open-source libraries were used under the respective licence terms. Please refer to `https://github.com/SantannaKS/LSD` for code and licensing details.

presented below are the outcomes of a Monte Carlo (MC) experiment, to properly consider across-run stochastic effects, comprising 100 realizations of 500 discrete time periods ($t = 1, ..., 500$) each.[11] The model is parametrized so that one time period roughly corresponds to one quarter. The employed values for the model parameters and initial conditions are shown in Appendix B. An extensive analysis of the model sensitivity to the chosen parameters and initial conditions is offered in Appendix C, and concludes that the results presented below are robust to significant parametric changes.

In the following, we present the MC time series excluding a "warm-up" period. Therefore, all time plots refer to relative $\hat{t} = 1, ..., 400$, corresponding to absolute simulated $t = 101, ..., 500$ after the warm-up. Calibration of initial conditions are kept to a minimum: all firms in each sector, and workers start equal at $t = 1$, departing from balanced supply and demand, under full utilization, in all markets of each (then similar) country.[12] During the warm-up period there is no state-owned enterprise (SOE) and countries do not trade, but the different educational systems are effective from $t = 1$. All other parameters and initial conditions are equal among countries.

To better evaluate the relative distance between the two country trajectories, we construct a gap measure computed for each country as the relative difference between a variable of interest X in the North (X_N) and in the South (X_S), using the North as reference. Therefore, $\tilde{X}_N = (X_N - X_S)/X_N$ is the gap from the North country perspective and, conversely, $\tilde{X}_S = -\tilde{X}_N$ is the South's take. Hence, an increasing trend of the absolute gap $\tilde{X} = |\tilde{X}_N| = |\tilde{X}_S|$ indicates a growing divergence.

4.1 Trade flows and specialization patterns

To establish a baseline scenario for our analysis, we compare a North country, under a higher level of education expenditure and attainment, to a South one, with lower levels of education expenditure and attainment. Countries interact through international trade of both capital and consumption goods, and by migration of workers from the South. However, there are no SOEs, all firms are private and government does not acquire any firm. It is a similar setup to the one employed by Fanti et al. (2024) with the addition of consumption-goods trade and floating exchange rates.

Figure 2(a) presents the macroeconomic performance (real GDP) and the components of aggregate demand (real consumption and investment) of both countries. We notice that an endogenous leader-laggard gap had already emerged during the pre-trade period $\hat{t} < 0$ (or $t < 100$), and shows an accelerating dynamics thereafter ($\hat{t} > 0$). Also, in Figure 2(b) we present the GDP gap measure, clearly showing this trend. Additionally, Figure 2(a) hints at a divergence that is even stronger for the internal demand components. Looking at the external demand component (net exports), the international trade balance sets into

[11]Such MC design of experiment was validated to capture the behaviour of most model variables under a significance level of at least 5%, and more typically at 1%.

[12]The objective of this *light-touch* approach is to let the model structure, which induces significant heterogeneity among agents, to find the K+S "steady state"-like regime, usually achieved during the first 100 time periods of simulation. Therefore, results are analysed from $t = 101$ (or $\hat{t} = 1$) without requiring significant initial condition assumptions, all chosen values are indeed purely notional.

a stable asymmetry, as expected, with the North (black line) presenting a net exporter position vis-à-vis the South (Figure 2(c)). Notably, the relative volatility of the two time series is different – because of the dissimilar references, the respective country GDP – with the impact of trade in the South reaching negative peak values of more than 10% of the GDP, therefore leading to larger relative shocks due to negative trade balance positions.

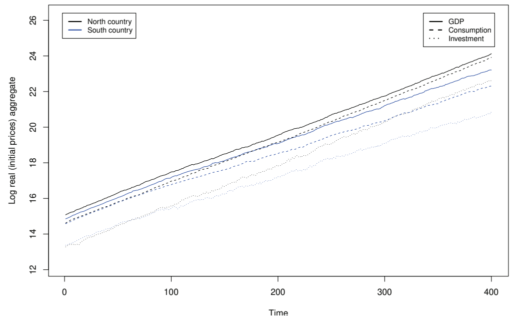
The diverging net exports also reflects in the behaviour of the nominal exchange rate, as shown in Figure 2(d). Recalling that exchange rates are defined as the domestic price of a notional stable reference foreign currency, the positive trade balance of the North decreases the domestic price of the notional foreign currency, that is, it appreciates vis-à-vis the reference. Conversely, the negative net exports in the South leads to a depreciation of its currency, therefore leading to a negative feedback shock in terms of the cost of imported goods.

Which are the specialization patterns of the two countries in terms of exported goods, if any? Panels (e) and (f) in Figure 2 show the flows of import and export for each type of good. Notably, the North presents a positive trade balance for consumption goods while the South is a net exporter of capital goods. A specialization pattern starts to emerge around $\hat{t} = 200$, and clearly dominates the trade scenario after a while.

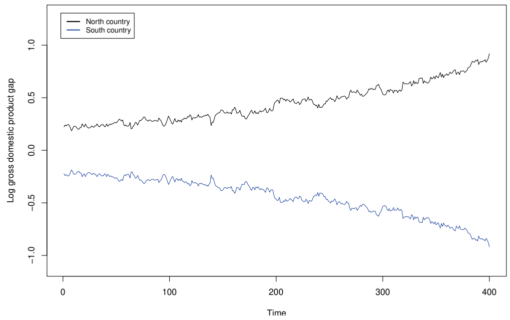
However, of special interest is the reversion in the specialization profiles usually observed around the period $\hat{t} \in [150, 250]$ for machines, and about $\hat{t} \in [50, 350]$ for consumption goods. The North starts the simulation as a net exporter of capital goods while the South, of final goods, but there is a non-synchronized switch in this specialization pattern over time. The mechanisms leading to the emergence of such dynamics are not trivial to grasp but, fortunately, they can be fully identified and analysed in the ABM framework. The higher education level in the North indeed turns into a larger share of highly-educated professional workers (more productive labour), and higher opportunities of innovation (more effective R&D). This leads the North to an initial specialization in capital goods for a rather long period – about 50 "years" in simulated time. However, over time, the South reaps the benefit of machine imitation from the North and starts to export capital goods. Then, as the South progressively acquires the capacity to build competitive machines and to satisfy the worldwide demand, the larger revenues – from which a fixed share is applied in R&D – produce a mix of high R&D expenditures and low wages that finally overcome the initial advantages of the North.

Nevertheless, the North still maintains a dominant position in terms of leader-laggard dynamics, with higher growth rate and lower debt-to-GDP ratio, therefore being more efficient in the use and allocation of resources at the global macro level (see Figure 2, panels (g) and (h)). This is possible, even in the long run, exactly because of the (slow) domination of the (much larger) global consumption-goods market. With cheaper machines offered by the South, the North country can leverage on its larger domestic consumption market and more skilled labour force to produce final goods that can overcome the (low-wage) South competition in terms of *both* price and quality, slowly locking-in the largest share of the world demand.

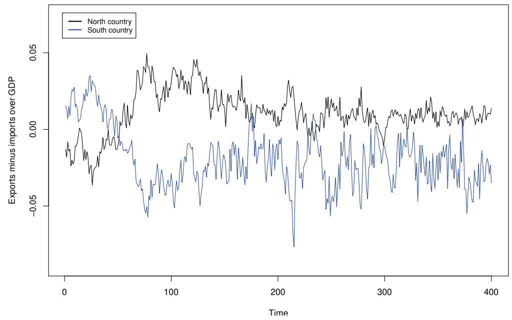
Table 1 compares the relative performance of some key macro variables for the two countries, and evaluates the statistical significance of the differences found. As plots above



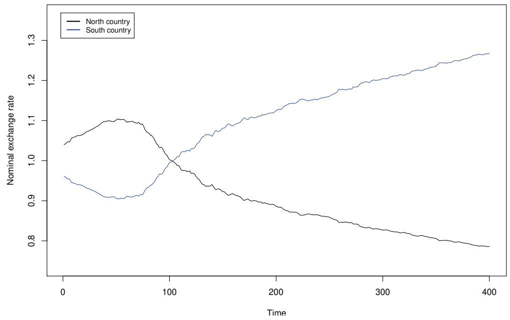
(a) Real GDP, investment and consumption



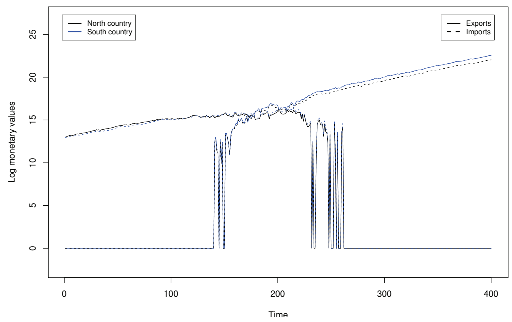
(b) GDP gap



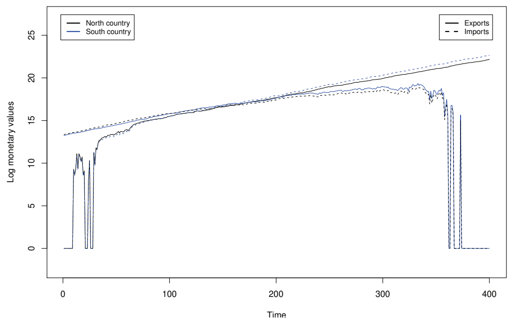
(c) Balance of trade on GDP



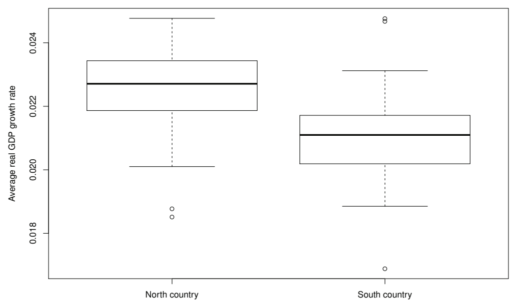
(d) Nominal exchange rate



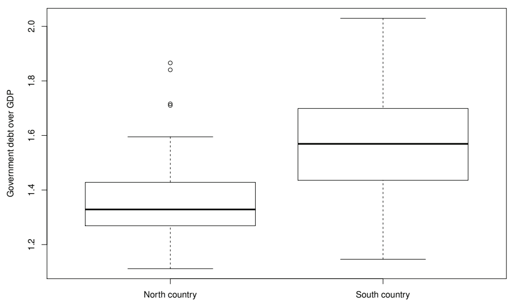
(e) International machine trade



(f) International consumption-good trade



(g) GDP growth distribution



(h) Government debt distribution

Figure 2: Selected temporal and distributional results comparing North (black) and South (blue) countries. Baseline scenario MC median results for 100 runs in period $\hat{t} \in [1, 400]$. Source: authors' analysis.

have already hinted, all gaps are substantial and significant at any relevant confidence level. GDP growth is systematically lower in the South, 7% in average, leading to significantly lower GDP level in the entire period. Productivity is also lower in the South, but to a smaller extent, due to the impulse provided by the capital-good sector. Balance of trade for the entire $\hat{t} \in [1, 400]$ is almost neutral for the North country (+0.8% of the GDP), while more significantly negative to the South (-1.8% of the GDP), meaning that the dominance of the machine market is not enough to reverse the continuous drain of the domestic demand for final goods. On the government side, the South country also presents a larger public debt in average, due to more crises and higher unemployment, of about 18 p.p. of the GDP.

	NORTH	SOUTH	
	Baseline	*Ratio*	*p-value*
GDP growth	0.023	0.929	0.000
GDP growth volatility	0.040	1.105	0.000
GDP gap	0.147	2.654	0.000
productivity gap	0.363	1.272	0.000
Balance of trade	0.008	-2.248	0.000
Government debt	1.364	1.181	0.000

Table 1: Relative performance comparison between North and South countries. Ratios for baseline and alternative scenario MC average results for 100 runs in period $\hat{t} \in [1, 400]$. p-values for a two-means t-test among countries, H_0: no difference between countries. Source: authors' analysis.

Finally, comparing our results with those obtained by Fanti et al. (2024), we can underline how international trade in both sectors, under a floating exchange rate regime, opens up the possibility to get less divergent and closer outcomes between the two countries. In our baseline configuration, presented above, this happens mainly because of the specialization patterns that slowly emerge over the long run.

4.2 Agents of industrial policies

The present section discusses the consequences of the introduction of SOEs in the South country, and it is aimed at detecting if and to what extent they affect the macroeconomic dynamics. For that purpose, we introduce an alternative model configuration which allows for the statization, only in the South, of financially troubled firms but with significant policy opportunities, as described in Section 3. Therefore, we compare the baseline scenario introduced above, where only private firms operate in both countries, with a new alternative scenario with SOEs operating in the South. Notably, the number, size, and lifetime of SOEs are completely endogenous, that is, driven by the current market structure, and by the profile of prospect exiting firms. Moreover, the emergence of new SOEs is based on specific criteria for each industrial sector, therefore leading to multiple possible outcomes – SOEs in both, one, or no sector – at any given time.

Starting with the participation of SOEs in consumption-good market, data immediately shows that SOEs have a very small penetration there, with a median market share just above 0.04%, and in the 0.03-0.07% range for about 50% of the simulation runs (2nd and 3rd quartiles), peaking just under 0.12% in a few cases. At those reduced levels, the overall influence of those firms is certainly negligible. Analysing data for the reasons of this apparent policy failure, the main causes can be enumerated: (i) the final-product market in the K+S model shows very little concentration – a median Herfindahl-Hirschman index of only 0.01 (vs. 0.45 for the machine market) – where large firms hardly emerge, (ii) a yet smaller number of *large* failing firms which could be candidates for state takeover, (iii) a very competitive consumption market in which firms defend shares fiercely – the median Hymer-Pashigian index shows only 5% of the market shares changing hands each period (vs. 45% in the machine market) – turn growth opportunities very limited for the rare SOE that emerge. In summary, this market is structurally challenging for the policymaker action.[13]

Figure 3(a) represents the overall market share distribution of SOEs participation in the capital-goods sector. Under the proposed configuration, the median penetration of machine-producer SOEs is about 6%, with significant variations across MC runs. In half of the cases, the market share lies between the 4-8% range for the entire period $\hat{t} \in [1, 400]$, reaching more than 10% in some runs. Figure 3(b) brings light to the dynamics of market share along this period. Notably, the government creates SOEs mostly following the trade-start shock ($\hat{t} = 0$), more precisely around $\hat{t} \in [10, 180]$, after which they tend to disappear in most runs.[14] The usual market share they hold is about 10% during this period, or almost twice the entire-simulation median.

Remarkably, when SOEs are more active in the market, they are quite effective in spurring the sectoral innovative capacity and in triggering macroeconomic feedback effects. Starting with the pattern of international specialization in machine trade, SOEs objectively anticipate this trend by about 40 periods, as per Figure 3(c), or 10 simulated years. Yet, and despite the dismal penetration of consumption-goods SOEs, the improvement in the domestic supply of (better) machines also indirectly affects the performance of the entire final-product market, even if more modestly, as shown in Figure 3(d). In this case, specialization accelerates, finishing about 30 periods (7.5 years) earlier.

Beyond international trade effects, SOE presence also enhances the macroeconomic performance of the South (Figure 3(e)) in terms of GDP, consumption and investment. When looking at the (log) gap between scenarios, one notices a very significant gradual improvement. Investigating what drives this improved performance, and coherently with their role of agents of the modelled industrial policy, SOEs drive the increase of the productivity in both sectors, directly for the machine sector and indirectly for the final-goods

[13] Changing this scenario would require deeper changes to the base K+S model at its very core, and would make any comparison with previous results, one of the objectives of this paper, significantly more difficult. This seems to be an interesting future research path, to allow a better understanding of the possible role of consumption-goods SOEs as agents of policymaking. Therefore, we opted to focus the analysis here on thederesults obtained with the capital-goods SOEs, as presented next.

[14] Please notice that a Monte Carlo (MC) median equal to zero for a certain variable does not mean that *all* runs in the experiment also present a zero value, even for non-negative variables. For instance, a MC median of zero SOEs is perfectly possible even if in many runs a few public firms do exist.

one, as shown in Figure 3(f). The causal chain is very explicit in the model: increased innovation dynamics accelerates labour productivity on both building new machines, at the same time the new machines get more productive when used to produce consumption products, affecting the macro productivity in tandem as new technologies diffuse *first* in the South country. This not only improves the absolute macro conditions of the country, but also creates a source of dynamic competitive advantage in the world markets.

Additionally, as a consequence of the (partial) pass-through from firms' productivity gains to workers, the overall real wage dynamics replicates the trajectories observed for the GDP. The significant (log) gap observed in Figure 3(g) is even more relevant if we consider the slightly reduced devaluation path of the South country exchange rate (not shown). That is, the real wages measured in the notional stable currency increased substantially, representing an effective increase of the standards of living in the South.

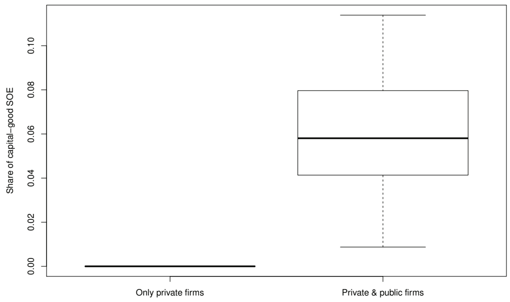
Finally, the alternative scenario allows us to evaluate a common critique to SOE-based policies: the negative effect on the primary deficit results and, consequently, on public debt. Notably, Figure 3(h) shows that government debt, as a fraction of GDP, is significantly reduced *exactly* during the period of more active state intervention. One may ask how, as the government has to disburse funds to rescue statized firms, as well to provide additional operating capital and guarantee new debt. The answer is relatively straightforward, and can be compounded out of three components: (i) evidently, as SOEs spur GDP Y, the comparison base increases, and reduces the ratio Deb/Y, (ii) other than costs, SOEs represent sources of *new incomes* to the government as retained profits at some moment will be transferred to the public budget, and (iii) as the main government expenditure are unemployment benefits, improved macroeconomic environment implies less unemployed workers and so a lower primary deficit. As the model consistently shows, these three components consistently outweigh the costs associated with the SOE policy.

Table 2 presents a comparison of the relative South country performance for some key variables for the two scenarios. Overall, the proposed model seems to produce results that are in line with many stylized facts – or empirical regularities – usually identified in the literature. Table 3 presents the most relevant ones.

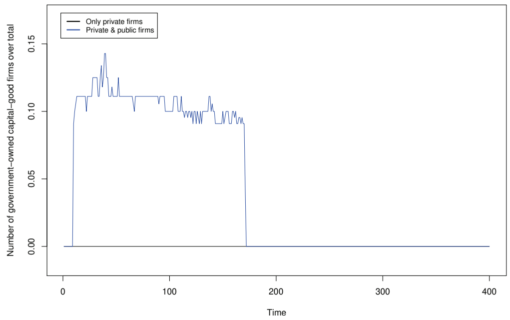
	W/O SOEs	WITH SOEs	
	Baseline	*Ratio*	*p-value*
GDP growth	0.021	1.167	0.000
GDP growth volatility	0.043	1.139	0.000
Productivity growth	0.022	1.162	0.000
Real wage	9.027	1.354	0.000
Government debt	1.595	0.878	0.000

Table 2: Relative performance comparison between alternative SOE configurations in South country. Ratios for baseline and alternative scenario MC average results for 100 runs in period $\hat{t} \in [1, 400]$. p-values for a two-means t-test among countries, H_0: no difference between countries. Source: authors' analysis.

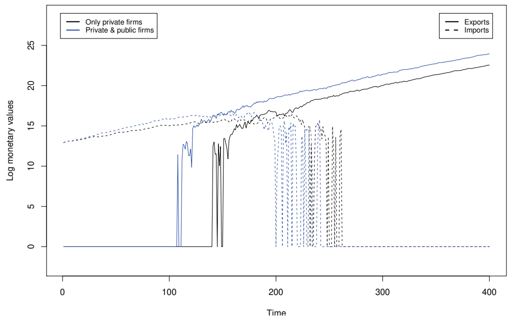
As previously discussed, SOE behaviours can be tuned in the model by means of some



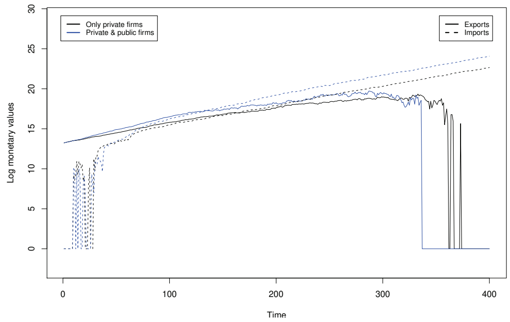
(a) Capital-good SOE share distribution



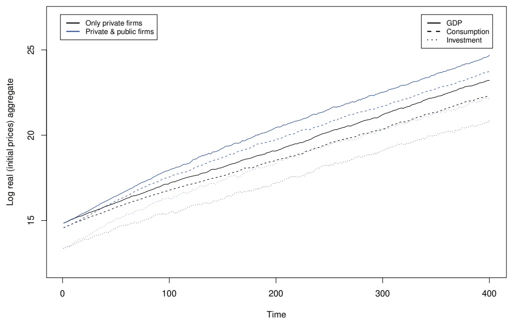
(b) Market share of capital-good SOEs



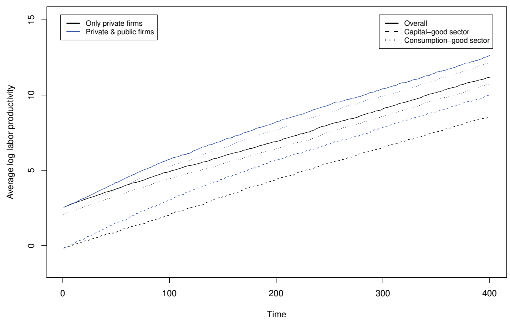
(c) International machine trade



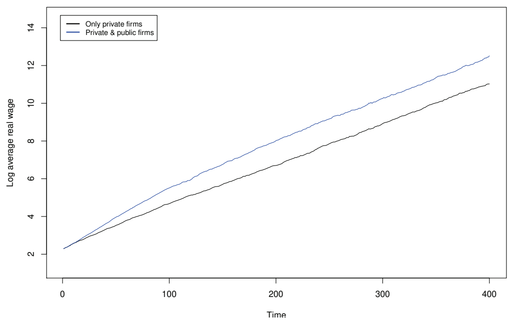
(d) International consumption-good trade



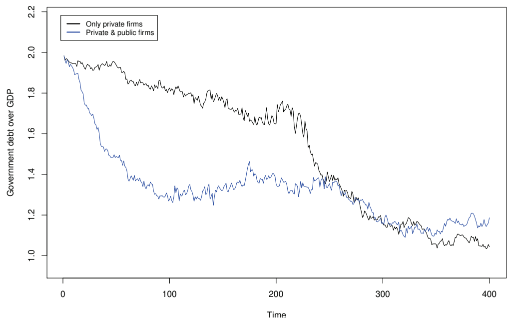
(e) Real GDP, investment and consumption



(f) Aggregate and sectoral productivity



(g) Real wage



(h) Government debt

Figure 3: Selected distributional and temporal results comparing South country with (blue) and without (black) state-owned enterprises. Baseline and alternative scenario MC median results for 100 runs in period $\hat{t} \in [1, 400]$. Source: authors' analysis.

Model properties	Empirical evidence
Higher GDP and productivity growth rates in the long run	Yu et al. (2015)
Accelerated innovation dynamics	Belloc (2014)
Improved competitiveness of international machine trade	Kowalski et al. (2013); OECD (2011)
Positive real wage dynamics	Dosi et al. (2020)

Table 3: Attributes of modeled SOE matching the empirical evidence

crucial parameters. In the following, we experiment with some of these parameters in order to study how they affect the convergence patterns of the South country, therefore representing potential levers for policymaking.

We start with two scenarios where the SOE's initial distance from the technological frontier is increased, that is, the parameter x_6 in equations (12) and (13) is higher ($x_6 = 0.10$ and $x_6 = 0.15$) than in the scenario designed for the previous subsection ($x_6 = 0.00$). This parameter tells us about the initial SOE technological endowment. A smaller distance from the frontier represents an increased capability to develop more innovative (productive) machines, and conversely.

On the one hand, by modifying x_6 the overall market share of SOEs grows but the period of their more intense activity within the economy only changes slightly, as shown in Figure 4(a). On the other hand, however, in both scenarios the acceleration in the specialization of the South country in both sectors is mostly lost, as per Figure 4(b). This is a clearly non-linear effect, hinting at the importance for the policymaker of selecting SOEs with high absorptive capabilities.

As expected, the reduced endowments have a direct negative, relatively proportional (linear) effect on the macro performance, as evident in Figure 4(c). A similar result can be observed (Figure 4(d)) on the benefits for the public accounts, as a result of the weakening of the three causation components described above. Table 4 presents a comparison of the relative results for some key variables.

	$x_6 = 0.00$	$x_6 = 0.10$		$x_6 = 0.15$	
	Baseline	*Ratio*	*p-value*	*Ratio*	*p-value*
GDP growth	0.025	0.896	0.000	0.863	0.000
GDP growth volatility	0.051	0.927	0.000	0.888	0.000
Government debt	1.422	1.088	0.000	1.136	0.000
Share capital-good SOEs	0.062	1.352	0.001	1.228	0.007

Table 4: Relative performance comparison between alternative configurations for parameter x_6 in South country. Ratios for alternative scenario MC average results for 100 runs in period $\hat{t} \in [1, 400]$. p-values for a two-means t-test among countries, H_0: no difference between countries. Source: authors' analysis.

Finally, we experiment with different trigger levels for the statization rule, controlled by parameters γ_1^g and γ_2^g in equations (9) and (10), and comparing the results with the previous subsection scenario ($\gamma_1^g = \gamma_2^g = 1.0$). Two alternative configurations are proposed, the first one reducing the selectivity of the rescued firms ($\gamma_1^g = \gamma_2^g = 0.5$), and the second, increasing it ($\gamma_1^g = \gamma_2^g = 1.2$).

Figure 4(e) presents the dynamics of capital-goods SOE market-shares. The low-selectivity scenario significantly increases the participation of SOEs, almost doubling it, but for a shorter period. On the contrary, their share is reduced when selectivity increases, and the peak participation period gets delayed and narrower. Again, Figure 4(f) hints at a non-linear effect on the specialization timing: the low value for γ_1^g induces a significant acceleration of the process (20 periods or 5 years), while the high one has no relevant effect.

This time, macroeconomic (positive) effects of the alternative scenarios where much smaller, not significantly different, as suggested by Figure 4(g). Also, differently from previous experiment, there was no significant effect on public deficit and debt (Figure 4(h)). Overall, the experiments seem to indicate that SOE policies may marginally benefit from a less stringent criterion for statization targets, but there is a clear decreasing returns mechanism in action. The additional SOEs bring less technological capabilities to the capital-good sector, and so have a more limited impact on the South country economy. Table 5 summarizes the relative results for key variables.

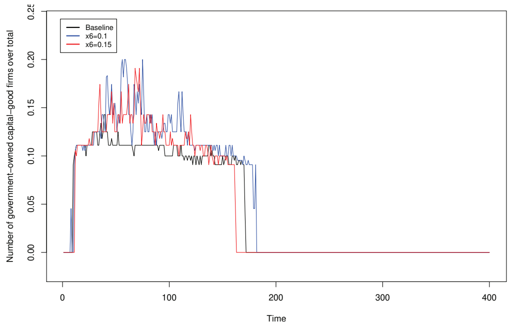
	$\gamma_1^g = \gamma_2^g = 1.0$	$\gamma_1^g = \gamma_2^g = 0.5$		$\gamma_1^g = \gamma_2^g = 1.2$	
	Baseline	*Ratio*	*p-value*	*Ratio*	*p-value*
GDP growth	0.025	1.016	0.134	0.9465	0.000
GDP growth volatility	0.051	1.081	0.006	0.9801	0.133
Government debt	1.422	0.991	0.577	1.017	0.092
Share capital-good SOEs	0.062	1.359	0.000	0.661	0.000

Table 5: Relative performance comparison between alternative configurations for parameters γ_1^g and γ_2^g in South country. Ratios for alternative scenario MC average results for 100 runs in period $\hat{t} \in [1, 400]$. p-values for a two-means t-test among countries, H_0: no difference between countries. Source: authors' analysis.

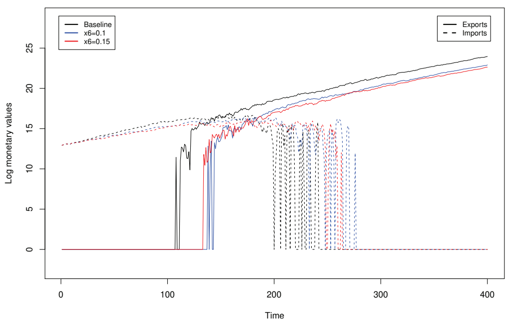
5 Conclusions

In this paper, we try to answer crucial questions related to the effectiveness of industrial policies that are based on state-owned enterprises (SOEs) to foster the economic convergence of less-developed countries with advanced ones. In a theoretical agent-based model (ABM), we evaluate the effect of explicitly modelling SOEs which are responsible for operating as instruments for industrial policymaking. To this purpose, we propose a novel North-South, international-trade, macroeconomic ABM where SOEs are agents of industrial policy.

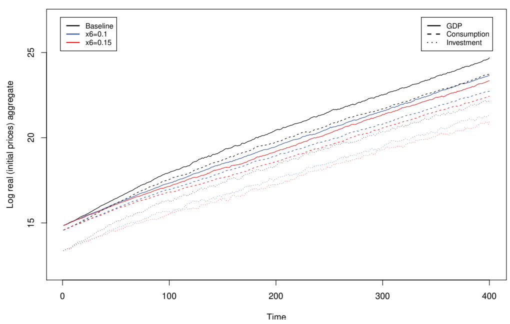
We model the SOE emergence by means of the ownership transfer to the state of large or technologically-capable but failing firms – therefore secondarily acting also as a countercyclical policy. The proposed set-up allows SOEs to advance towards the technological frontier, to dispose of enough operating capital, and to have guarantees to access the re-



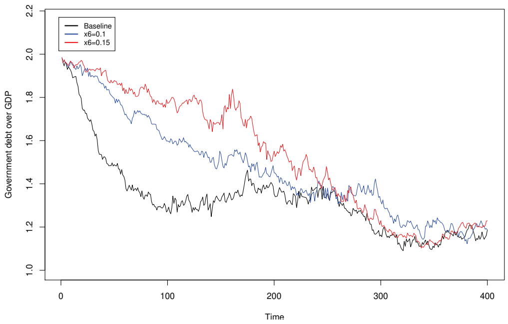
(a) Market share of capital-good SOEs (x_6)



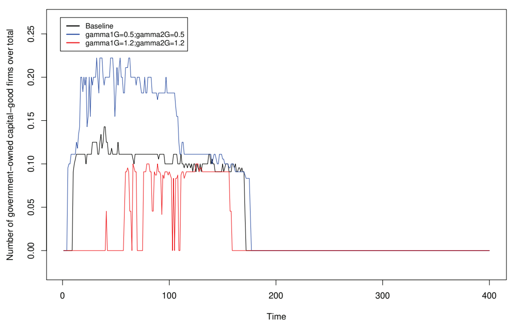
(b) International machine trade (x_6)



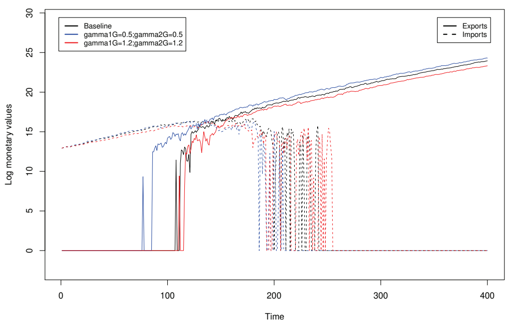
(c) Real GDP, investment and consumption (x_6)



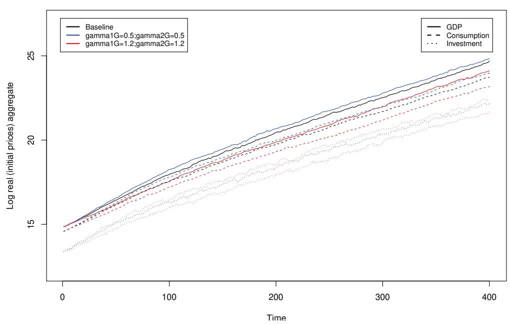
(d) Government debt (x_6)



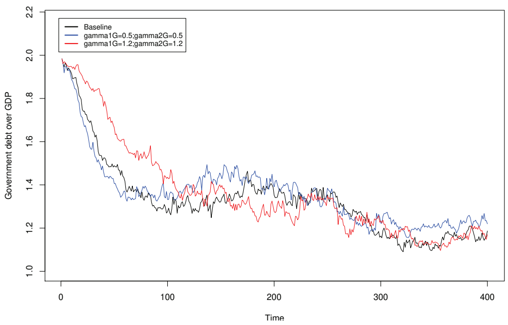
(e) Market share of capital-good SOEs (γ_g^1/γ_g^2)



(f) International machine trade (γ_g^1/γ_g^2)



(g) Real GDP, investment and consumption (γ_g^1/γ_g^2)



(h) Government debt (γ_g^1/γ_g^2)

Figure 4: Selected temporal results comparing South country with alternative configurations for parameters x_6 and γ_g^1/γ_g^2. Alternative scenario MC median results for 100 runs in period $\hat{t} \in [1, 400]$. Source: authors' analysis.

quired private credit. Yet, based on the empirical evidence, our modelling strategy endows SOEs with specific behavioural traits, enabling the endogenous activation of different policy mixes. Hence, our contribution offers an ABM in which it is possible to objectively identify the relevant effects of the policy choices and the feedback mechanisms propagating them in the domestic and international economic environments.

The model results clearly support that SOE-based policies can be indeed effective in fostering the proposed convergence objectives, by stimulating productivity advancement and sectoral specialization. Such results seem in line with the historical evidence on the policy role played by SOEs for countries undergoing industrial development, as in the case of IRI for Italy, Petrobrás in Brazil, or the many SOEs in China.

The Economic History literature had already pointed out several cases in which SOE-based industrial policies were particularly effective at reverting the long-run divergence path of developing in South-type countries and regions. However, in the current research agenda, economists seem to consider only indirect instruments, such as fiscal (e.g., tax and R&D subsidies) or trade policies (e.g., tariff and import substitution), as going under the heading of industrial policies. Our contribution provides robust evidence for the inclusion of the direct intervention of the state, by means of SOEs, to the list of available policymaking instruments.

Future lines of research include the potential to experiment with larger and more effective policy-driven consumption-good SOEs, and the implementation of more specific SOE behaviours explicitly targeting, for instance, inequality reduction or technological transition. More broadly, extensions of the present work may go in the direction of modelling the rise and decline of institutional arrangements, based on agent-level behavioural rules, rather than being limited to simpler parametric analysis. Finally, the study of multi-country settings, and the ensuing trade relationships, represents a further avenue of research in order to explore into the patterns of centre-periphery organization, economic catching-up, and general development processes. History-oriented analyses, applied to specific country-period case studies are also a natural way forward for the general model setting proposed here.

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Appendices

Appendix A: behavioral rules

Education

Workers may receive heterogeneous (free) education before entering the labour market, and have a fixed working lifetime $T_r \in \mathbb{N}$ before retiring (retired workers are replaced by new ones). Individual years of schooling $ed_\ell \in [0, 16]$ is attributed to each worker ℓ, producing three general levels of education: (1) primary ($ed_\ell \leq 8$), (2) secondary ($8 < ed_\ell \leq 12$), and (3) tertiary ($ed_\ell > 12$). The government expends G_t^{ed} to provide education:

$$G_t^{ed} = \epsilon_{ed} Y_{t-1}, \tag{14}$$

$\epsilon_{ed} \in [0, 1]$ is a parameter, and Y_t, the nominal GDP. To obtain an advanced-country educational profile, the expenditure must be $\epsilon_{ed} = \epsilon_{ad}$, $\epsilon_{ad} \in [0, 1]$ is a parameter. The education level is draw from a beta distribution with the support adjusted to the expenditure:

$$ed_\ell \sim 16 \text{ beta}\left(g\,\alpha_{ed}, \beta_{ed}/g\right), \qquad g = \left(\frac{\epsilon_{ed}}{\epsilon_{ad}}\right)^{\vartheta_{ed}}, \tag{15}$$

where $(\alpha_{ed}, \beta_{ed}) \in \mathbb{R}_+^2$ are parameters defining the beta PDF that proxy the educational attainment distribution of an advanced country ($g = 1$), mapped to the $[0, 16]$ support. $\vartheta_{ed} \in \mathbb{R}_+$, a parameter, is the sensitivity of the distribution shape when $\epsilon_{ed} \neq \epsilon_{ad}$.

Technical change

The technology of capital-good firm i is defined by (A_i^τ, B_i^τ). A_i^τ is the notional labour productivity of the machine-tool manufactured by firm i for the consumption-good sector, while B_i^τ is the labour productivity to produce the machine. Superscript τ denotes the technology vintage being produced/used. Given the monetary average wage $w_{i,t}$ paid by firm i, its unit cost of production is:

$$c_{i,t} = \frac{w_{i,t}}{m_1 B_i^\tau}, \tag{16}$$

$m_1 \in \mathbb{R}_+$ is the fixed capital productivity.

Under a fixed mark-up $\mu_1 \in \mathbb{R}_+$ pricing rule, price $p_{i,t}$ of firm i is defined as:

$$p_{i,t} = (1 + \mu_1) c_{i,t}. \tag{17}$$

Firms in the capital-good industry adaptively strive to increase market shares and profits by improving technology via innovation and imitation. Firms invest in R&D a fraction $\nu \in [0, 1]$ of their past sales $S_{i,t-1}$:

$$RD_{i,t} = \nu S_{i,t-1}. \tag{18}$$

R&D activity is performed by workers devoted to this activity, whose demand is:

$$L_{i,t}^{R\&D} = \frac{RD_{i,t}}{w_{i,t}} \tag{19}$$

Firms split their R&D workers $L_{i,t}^{RD}$ between innovation ($IN_{i,t}$) and imitation ($IM_{i,t}$) activities according to the parameter $\xi \in [0,1]$:

$$IN_{i,t} = \xi L_{i,t}^{RD}, \tag{20}$$

$$IM_{i,t} = (1-\xi) L_{i,t}^{RD}. \tag{21}$$

In-firm, incremental innovation and imitation are two-step processes. The first step determines whether a firm obtains or not access to an innovation or imitation — irrespectively of whether it will ultimately be a success or a failure — through a draw from a Bernoulli distribution with mean $\theta_{i,t}^{in}$ or $\theta_{i,t}^{im}$. R&D allocation $IN_{i,t}/IM_{i,t}$ and education distribution g affect the probability of obtaining access to innovation and imitation respectively:

$$\theta_{i,t}^{in} = 1 - e^{-\zeta_1 \, g \, IN'_{i,t}}, \tag{22}$$

$$\theta_{i,t}^{im} = 1 - e^{-\zeta_2 \, g \, IM'_{i,t}}. \tag{23}$$

$(\zeta_1, \zeta_2) \in \mathbb{R}_+^2$ are parameters, and $(IN'_{i,t}, IM'_{i,t})$ are the standardized share of workers allocated to innovative and imitative R&D activities, respectively.

If a firm innovates, it may draw a new machine-embodying technology $(A_{i,t}^{in}, B_{i,t}^{in})$ according to:

$$A_{i,t}^{in} = A_{i,t}\left(1 + x_{i,t}^{A}\right), \tag{24}$$

$$B_{i,t}^{in} = B_{i,t}\left(1 + x_{i,t}^{B}\right), \tag{25}$$

where $x_{i,t}^{A}$ and $x_{i,t}^{B}$ are two independent draws from a $\text{beta}(\alpha_1, \beta_1)$ distribution, $(\alpha_1, \beta_1) \in \mathbb{R}_+^2$ over the fixed support $[\underline{x}_1, \bar{x}_1] \subset \mathbb{R}$.

Imitation also follows a two-step procedure. As before, the access to imitation comes from sampling a Bernoulli with mean $\theta_{i,t}^{im}$. If successful, firms try to imitate machines developed by other worldwide firms, domestically or (potentially) abroad. The imitation success probability is inversely proportional to the technological gap $\mathcal{D}_t^{m,n}$ between imitating and imitated firms. The gap depends on the technological coordinates (A_i^τ, B_i^τ) defining the operating unit cost $c_{i,t}^2$ and price $p_{i,t}^1$ to machine buyers. The gap is measured as the Euclidean distance – in the (c^2, p^1) normalized space – of the imitator's m current machines and the imitated firm n:

$$\mathcal{D}_t^{m,n} = \sqrt{\left(\frac{c_{n,t}^2 - c_{m,t}^2}{\bar{c}_t^{2w}}\right)^2 + \left(\frac{p_{n,t}^1 - p_{m,t}^1}{\bar{p}_t^{1w}}\right)^2}, \tag{26}$$

where $c_{i,t}^2$ is the unit cost of a client firm when using the machine, and $p_{i,t}^1$ is its price. $\bar{c}_t^{2w}$ and $\bar{p}_t^{1w}$ are the respective (world) average values. They are calculated as:

$$c_{i,t}^2 = \frac{e_{y,t}\,\bar{w}_t^{2w}}{A_i^\tau}, \tag{27}$$

$$p_{i,t}^1 = \frac{(1+\mu_1)\,\bar{w}_{i,t}^1}{m_1 B_i^\tau}. \tag{28}$$

A_i^τ is the machine labour productivity when producing consumption-goods, and B_i^τ is the labour productivity of firm i when building the machine. τ represents the best technology known by firm i. $\bar{w}_t^{2w}$ is the (world) average wage at the consumption sector, and $\bar{w}_{i,t}^1$ is the average wage at firm i. $\mu_1 \in \mathbb{R}_+$ is the mark-up, and $m_1 \in \mathbb{R}_+$, the capital productivity, both parameters. When imitating a foreign firm, all monetary values are converted to the domestic currency of the imitator firm using the exchange rate $e_{m,t}/e_{n,t}$ between countries, $e_{y,t}$ being country y exchange rate to the international reference currency (see below).

Once firm i succeeds on imitating firm v, the different education expenditures between the host countries, if any, imply in distinct absorptive capacities:

$$A_{i,t}^{im} = \frac{g_i}{g_h} A_{v,t-1}, \tag{29}$$

$$B_{i,t}^{im} = \frac{g_i}{g_h} B_{v,t-1}. \tag{30}$$

$(A_{i,t}^{im}, B_{i,t}^{im})$ are the productivities achieved by firm i when imitating firm v machines defined by $(A_{v,t-1}, B_{v,t-1})$. (g_i, g_h) are the adjusted relative government expenditures g of the countries where firms i and v are established.

Firms accessing the second stage of the innovation or imitation process select the machine to produce using the rule:

$$\min\left(p_{i,t}^m + bc_{A_{i,t}^m}^m\right), \quad m = \tau, in, im, \tag{31}$$

where $b \in \mathbb{R}_+$ is a payback parameter used by firms' clients (see below).

Labour productivity

Worker education level drives individual labour productivity at consumption-good firms:

$$A_{\ell,t} = \frac{s_{\ell,t}}{\bar{s}_t} A_i^\tau \left(\frac{ed_\ell}{\overline{ed}_{ad}}\right)^{\tau_{ed}}, \tag{32}$$

being $\bar{s}_t$ is the average overall skill level (see below), and A_i^τ, the standard notional productivity of the specific machinery vintage in whose operation the worker is involved. $\tau_{ed} \in \mathbb{R}_+$ a scaling parameter defining the effect intensity of a deviation from the expected education level of an advanced country $\overline{ed}_{ad} = 16\,\alpha_{ed}/\left(\alpha_{ed} + \beta_{ed}\right)$. Capital-good sector productivity is affected by education as well:

$$B_{i,t} = B_i^\tau \left(\frac{ed_{t-1}^1}{\overline{ed}_{ad}}\right)^{\tau_{ed}}, \tag{33}$$

where $B_{i,t}$ is the effective labour productivity of firm i to produce machines at time t, B_i^τ is the notional labour productivity to produce the current machine vintage, and ed_t^1, the average education level of workers in capital-good sector.

The skill level $s_{\ell,t} \in \mathbb{R}_+$ of worker ℓ evolves in time t as a multiplicative process:

$$s_{\ell,t} = \begin{cases} (1+\tau_T) s_{\ell,t-1} & \text{if employed in } t-1 \\ \dfrac{1}{1+\tau_U} s_{\ell,t-1} & \text{if unemployed in } t-1, \end{cases} \tag{34}$$

where $(\tau_T, \tau_U) \in \mathbb{R}_+^2$ are parameters governing the learning rate while the worker is employed or unemployed, respectively. When hired, worker acquires the minimum skill level present in the firm, if above her present level. Worker has a fixed working life, retires after a number of periods T_r, and is replaced by a new one with skills equal to the minimum among employed workers.

Firms in consumption-good sector do not conduct R&D. Instead, they access new technologies incorporating machines to their existing capital stock $\Xi_{j,t}$. The firm effective, machine-level labour productivity $A_{j,t}$ results from both machine (single-stage) notional productivity A_i^τ, and worker skills $s_{\ell,t}$ and education ed_ℓ, as described previously, and is computed as:

$$A_{j,t} = \frac{1}{L_{j,t}} \sum_{\ell \in \{L_{j,t}\}} A_{\ell,t}, \tag{35}$$

where, $L_{j,t}$ is the number of workers at firm j, and $\{L_{j,t}\}$ is the set of these workers. $A_{\ell,t}$ is worker ℓ productivity (Eq. 32). $A_{j,t}$ and $A_{\ell,t}$ are machine-level labour productivities. So, if the mean wage paid by j is $w_{j,t}$, the average unit cost is given by:

$$c_{j,t} = \frac{w_{j,t}}{m_2 A_{j,t}}. \tag{36}$$

$m_2 \in \mathbb{R}_+$ is the fixed notional capital productivity, measured as the potential output per period for a single machine.

Investment

Consumption-good firm j invests according to expected demand $D^e_{j,t}$ (monetary terms), computed by an adaptive rule:

$$D^e_{j,t} = \mathrm{g}\left(D_{j,t-1}, D_{j,t-2}, D_{j,t-n}\right), \quad 0 < n < t, \tag{37}$$

where $D_{j,t-n}$ is the actual demand faced by firm at time $t-n$. $n \in \mathbb{N}$ is a parameter and $\mathrm{g} : \mathbb{R}^n \to \mathbb{R}_+$ is the expectation function, usually an unweighed moving average over a fixed number of periods. The corresponding desired level of production $Q^d_{j,t}$, considering the actual inventories $N_{j,t}$ from previous period, is:

$$Q^d_{j,t} = (1+\iota)\frac{D^e_{j,t}}{p_{j,t-1}} - N_{j,t-1}, \tag{38}$$

being $\iota \in \mathbb{R}_+$ a parameter, $p_{j,t}$ the price of firm j in t (see below), and $N^d_{j,t} = \iota D^e_{j,t}$ the desired inventories.

If the desired capital stock K^d_j, computed as the number of machines required for the desired level of production $Q^d_{j,t}$, is higher than the current $K_{j,t}$, firm invests in $EI^d_{j,t}$ new machines to expand capacity:

$$EI^d_{j,t} = K^d_{j,t} - K_{j,t-1}. \tag{39}$$

As each machine has $m_2 \in \mathbb{R}_+$ fixed capital productivity:

$$K^d_{j,t} = \frac{Q^d_{j,t}}{m_2}, \tag{40}$$

Replacement investment $SI^d_{j,t}$, to substitute a set $RS_{j,t}$ of existing machines by more productive ones, is decided according to a fixed payback period $b \in \mathbb{R}_+$. Machines $A_i^\tau \in$

$\Xi_{j,t}$ are evaluated by the ratio between the price of new machines and the corresponding (labour) cost savings:

$$SI^d_{j,t} = \#RS_{j,t},$$

$$RS_{j,t} = \left\{ A_i^\tau \in \Xi_{j,t} : \frac{p^*_{i,t}}{w_{j,t-1}\left(\frac{1}{A_i^\tau} - \frac{1}{A^*_{i,t}}\right)} \leq b \quad \vee \quad t - \tau > \eta \right\}, \tag{41}$$

where $p^*_{i,t}$ and $A^*_{i,t}$ are the price and the notional labour productivity upon the selected new machine from supplier i, among the ones known to firm j. $w_{j,t}$ is the average wage paid by this firm. Supplier i is selected by comparing the received brochures from competing capital-good firms using the same total cost of ownership criterion. For a foreign supplier in country w sending machines to country y, price $p^*_{i,t} = p_{i,t}\, e_{y,t}/e_{w,t} \left(1 + tr^{xk}_w\right)\left(1 + tr^{mk}_y\right)$ considers price at origin country $p_{i,t}$, the exchange rate between countries $e_{y,t}/e_{w,t}$, and countries' respective export and import costs $(tr^{xk}_w, tr^{mk}_y) \in \mathbb{R}^2_+$, two parameters. Machines over expected technical life $\eta \in \mathbb{N}$, a parameter, are also included for scrapping.

Segmented labour markets and migration

Labour demand of firm j in the consumption-good sector $L^d_{j,t}$ is determined by the desired output $Q^d_{j,t}$, the capital productivity m_2 and the expected average labour productivity $A_{j,t}$:

$$L^d_{j,t} = \frac{Q^d_{j,t}}{m_2 A_{j,t}}. \tag{42}$$

Capital-good firms, instead, compute $L^d_{i,t}$ considering orders $Q_{i,t}$ and final labour productivity $m_1 B_{i,t}$, being $B_{i,t}$ the notional productivity of labour when building the current machine generation produced by firm i, and m_1, a scale parameter (see above). Labour demand is segmented in three education categories $c = 1, 2, 3$:

$$L^{d,1}_{i|j,t} = (1 - \theta_2 - \theta_3)\, L^d_{i|j,t}, \qquad L^{d,2}_{i|j,t} = \theta_2 L^d_{i|j,t}, \qquad L^{d,3}_{i|j,t} = \theta_3 L^d_{i|j,t}, \tag{43}$$

being $\theta_2, \theta_3 \in [0, 1]$, $\theta_2 + \theta_3 \leq 1$, parameters, $L^{d,c}_{i|j,t}$, $c = 1, 2, 3$, the labour demand of firm i or j for the respective level workers. R&D labour demand consists of tertiary-level ($c = 3$) workers only.

Firms decide to hire or fire workers according to expected production $Q_{i,t}/Q^d_{j,t}$: if increasing, $\Delta L^{d,c}_{i|j,t} > 0$, $c = 1, 2, 3$, new workers on each category are (tentatively) hired in addition to the existing number $L^c_{i|j,t-1}$ in each category. Firm j (expectedly) gets in the candidates queue $\{\ell^s_{j,t}\}$ a fraction of the total applicant workers, proportional to firm market share $f_{j,t-1}$:

$$\mathrm{E}(L^s_{j,t}) = [\omega\,(1 - U_{t-1}) + \omega_u U_{t-1}]\, L^S f_{j,t-1}, \tag{44}$$

where $L^S \in \mathbb{N}$ is the total labour supply, U_t, the unemployment rate, and $(\omega, \omega_u) \in \mathbb{R}^2_+$ are parameters defining the number of applications each job seeker sends if employed or unemployed, respectively. Firms organize the candidate queue into three sub-queues, according to the worker category c. Considering the set of workers in the sub-queues $\{\ell^{s,c}_{i|j,t}\}$, each firm select the subsets of desired workers $\{\ell^{d,c}_{i|j,t}\}$ to make a job (wage) offer:

$$\{\ell^{d,c}_{i|j,t}\} = \{\ell_{i|j,t} \in \{\ell^{s,c}_{i|j,t}\} : w^r_{\ell,t} \leq w^{o,c}_{i|j,t}\}, \quad c = 1, 2, 3. \tag{45}$$

Firms in consumption-good sector target workers that would accept the wage offer $w^{o,c}_{j,t}$ (see below), considering the wage $w^r_{\ell,t}$ requested by workers, if any. In the capital-good sector, firms top the wages offered by the consumer-good sector ($w^{o,c}_{i,t} = \max_j w^{o,c}_{j,t}$).

The process for hiring goes from higher to lower education levels. Remaining open positions in level $c+1$ are transferred to the labour demand $L^{d,c}_{i|j,t}$ of the level c immediately below, if any. Firm i or j hires up to the total demand $L^{d,c}_{i|j,t}$ for each category or up to all workers in each sub-queue, whichever is lower. The total number of workers $L_{i|j,t} = \sum_{c=1}^{3} L^c_{i|j,t}$, given the current workforce $L_{i|j,t-1}$, is bound by:

$$0 \leq L^c_{i|j,t} \leq L^{d,c}_{i|j,t} \leq L^{s,c}_{i|j,t}, \qquad L^{z,c}_{i|j,t} = L^c_{i|j,t-1} + \#\{\ell^{z,c}_{i|j,t}\}, \qquad z = d, s, \quad c = 1, 2, 3. \tag{46}$$

The search, wage determination and firing processes differ according to the configuration. When there is no bargaining, firm j offers the wages:

$$w^{o,1}_{j,t} = \min\left([1 + WP_{j,t}]\, w^{o,1}_{j,t-1}, \quad p_{j,t-1}A_{j,t-1}\right), \tag{47}$$

$$w^{o,c}_{j,t} = \max\left([1 + WP_{j,t}]\, w^{o,c}_{j,t-1}, \quad [1 + \phi_c]\, w^{o,c-1}_{j,t}\right), \qquad c = 2, 3, \tag{48}$$

that are accepted by the worker if she has no better offer. The upper bound for category 1 wages is the break-even wage defined by firm price $p_{j,l}$, and the labour notional (single-stage) average productivity $A_{j,t}$. $(\phi_2, \phi_3) \in \mathbb{R}^2_+$ are parameters defining a lower bound to the wage-category structure. The wage premium is defined as:

$$WP_{j,t} = \psi_2 \frac{\Delta A_t}{A_{t-1}} + \psi_4 \frac{\Delta A_{j,t}}{A_{j,t-1}}, \qquad \psi_2 + \psi_4 \leq 1, \tag{49}$$

being A_t the aggregate labour notional productivity, Δ the time difference operator, and $(\psi_2, \psi_4) \in \mathbb{R}^2_+$ parameters. $w^{o,c}_{j,t}$ may be also applied to existing workers of category c, according to the institutional set-up.

When one-round bargaining exists, workers have reservation wages equal to the unemployment benefit, if any, and request a wage $w^r_{\ell,t}$ in the job application:

$$w^r_{\ell,t} = \begin{cases} w_{\ell,t-1}(1 + \epsilon) & \text{if employed in } t-1 \\ w^s_{\ell,t} & \text{if unemployed in } t-1, \end{cases} \tag{50}$$

$w_{\ell,t}$ is the current wage for the employed workers and $\epsilon \in \mathbb{R}_+$, a parameter. Unemployed workers have a shrinking satisfying wage $w^s_{\ell,t}$, accounting for the wage history:

$$w^s_{\ell,t} = \max\left(w^u_t, \frac{1}{T_s}\sum_{n=1}^{T_s} w_{\ell,t-n}\right), \tag{51}$$

being $T_s \in \mathbb{N}$, the moving average time-span parameter.

An employed worker of category c accepts the best offer $w^{o,c}_{i|j,t}$, if any, she receives for this category, if higher than current wage $w_{\ell,t}$. An unemployed worker always accepts the best offer if at least equal to the unemployment benefit w^u_t and for a category c compatible with her education ed_ℓ. She may also consider offers for categories below her education with probability $1 - \Delta c / 2T^u_{\ell,t}$, where $\Delta c = 0, 1, 2$ is the category difference (actual vs. offered position), and $T^u_{\ell,t}$ is the number of periods the worker has been unemployed.

Government may impose a minimum wage w^{min}_t on firms, indexed on aggregate productivity A_t:

$$w^{min}_t = w^{min}_{t-1} \left(1 + \psi_2 \frac{\Delta A_t}{A_{t-1}} \right). \tag{52}$$

On top of the wage $w_{\ell,t}$ paid to worker ℓ, a firm with above-average profit may distribute bonus $Bon_{j,t}$, equally-divided among workers:

$$Bon_{j,t} = \psi_6 (1 - tr) \Pi_{j,t-1}, \tag{53}$$

being $\psi_6 \in [0, 1]$ a sharing parameter, $tr \in [0, 1]$ the tax rate parameter, and $\Pi_{j,t}$ the firm gross profit. Total income of worker ℓ working for firm j in period t is $w_{\ell,t} + Bon_{j,t}/L_{j,t}$.

Worker population may change at a constant rate, so that country y labour force evolves over time according to its $\delta_y \in [-1, 1]$ rate, a parameter:

$$L^S_{y,t} = (1 + \delta_y) \, L^S_{y,t-1}, \qquad y = 1, 2, ... \tag{54}$$

Migration may be implemented as a matched process where countries with negative δ_y send workers or (i) to the ones with positive δ_y, or (ii) distributed among the ones assigned as migration destinations.

Worker consumption and savings

Workers consume part of their income and do not take credit. Worker ℓ (gross) income in any period t is originated by monetary transfers from firms, banks, or the government:

$$In_{\ell,t} = w_{\ell,t} + Bon_{\ell,t-1} + Div_{\ell,t-1} + NW^{exit}_{\ell,t-1} + G^{trf}_{\ell,t} + emig^{trf}_{\ell,t} + r^D_{t-1} \, Sav^{acc}_{\ell,t-1}, \tag{55}$$

where $w_{\ell,t}$ is the wage paid by the employer firm, if employed, $Bon_{\ell,t}$ is worker ℓ bonus, if any, $Div_{\ell,t}$, the dividend accrued due to any firm ownership, $NW^{exit}_{\ell,t}$, liquidation net worth from private firms exiting market, $G^{trf}_{\ell,t}$ are the unemployment subsidy and other transfers from the government, if applicable, $emig^{trf}_{\ell,t}$ are transfers from other workers emigrating out of the country, if any, r^D_t is the interest rate on deposits, and $Sav^{acc}_{\ell,t}$, the worker accumulated savings.

Income tax is charged based on a flat rate $tr_{in} \in \mathbb{R}_+$, a parameter, over positive income:

$$Tax_{\ell,t} = \max \left(\left[1 - tr_{in} + s^{in}_t \right] In_{\ell,t}, \quad 0 \right) \tag{56}$$

$s^{in}_t \geq 0$ is a possible policy shock temporarily reducing the tax. The disposable (net nominal) income is $In_{\ell,t} - Tax_{\ell,t}$.

Consumer-workers real desired consumption $\hat{C}^d_{\ell,t}$ depends on the expected *real* disposable income $\hat{In}^{exp}_{\ell,t}$, and the recent-past real consumption reference $\hat{C}^{ref}_{\ell,t}$:

$$\hat{C}^d_{\ell,t} = \max\left(\alpha_c \, \hat{In}^{exp}_{\ell,t} + \beta_c \, \hat{C}^{ref}_{\ell,t}, \quad \gamma_c \, \hat{C}^{ref}_{\ell,t}\right), \qquad \alpha_c + \beta_c \leq 1, \qquad \beta_c < \gamma_c < 1, \tag{57}$$

$\alpha_c, \beta_c \in [0,1]$ are parameters, as well as $\gamma_c \in [0,1]$, defining the stickiness of consumers to reduce consumption. The expected real disposable income is:

$$\hat{In}^{exp}_{\ell,t} = \frac{In_{\ell,t} - Tax_{\ell,t}}{CPI^{exp}_t}, \qquad CPI^{exp}_t = \frac{1}{T_{exp}} \sum_{v=1}^{T_{exp}} CPI_{t-v}, \tag{58}$$

where $T_{exp} \in \mathbb{N}$ is the expectation time horizon parameter, and CPI^{exp}_t is the consumer price index expectation moving average. The real consumption (habit) reference is computed as a power-weighted mean over the same horizon:

$$\hat{C}^{ref}_{\ell,t} = \frac{\sum_{v=1}^{T_{exp}} (\omega_c)^{v-1} \, \hat{C}^d_{\ell,t-v}}{\sum_{v=1}^{T_{exp}} (\omega_c)^{v-1}}, \tag{59}$$

$\omega_c \in [0,1]$ is a parameter. The nominal desired consumption is bounded by the available liquidity:

$$C^d_{\ell,t} = \min\left(\frac{\hat{C}^d_{\ell,t}}{CPI^{exp}_t}, \quad In_{\ell,t} - Tax_{\ell,t} + Sav^{acc}_{\ell,t-1}\right). \tag{60}$$

Worker ℓ expects to save $In_{\ell,t} - C^d_{\ell,t}$ in period t, but effective current savings $Sav_{\ell,t}$ may be higher than expected, due to unfilled demand, or negative, if desired consumption $C^d_{\ell,t}$ is above disposable income $In_{\ell,t} - Tax_{\ell,t}$:

$$Sav_{\ell,t} = In_{\ell,t} - Tax_{\ell,t} - C_{\ell,t}, \tag{61}$$

and accumulated savings is updated as:

$$Sav^{acc}_{\ell,t} = Sav^{acc}_{\ell,t-1} - Eq^{entry}_{\ell,t-1} + Sav_{\ell,t}, \tag{62}$$

where $Eq^{entry}_{\ell,t}$ is the investment in new equity (entrant firms), if applicable.

Competition, prices, and quality

Capital-good suppliers send brochures to clients (potentially) in all countries to advertise machines. Every period, they contact existing $HC_{i,t}$ (historical) clients, and a number $\gamma HC_{i,t}$ of new prospects. $\gamma \in \mathbb{R}^*_+$ is a fixed parameter. Consumption-good firms can choose machines only from the suppliers they know, that is, the ones from which they had previously received brochures, domestic or foreign. There are no duties, additional costs or delays for imported machines.

In the consumer-good sector, firm j compete according to their relative competitiveness. Market share evolves following a replicator dynamics:

$$f_{j,t} = f_{j,t-1}\left(1 + \chi \frac{E_{j,t} - \bar{E}_t}{\bar{E}_t}\right), \qquad \bar{E}_t = \sum_j E_{j,t} f_{j,t-1}, \tag{63}$$

where $\chi \in \mathbb{R}_+$ is a parameter. Firm relative competitiveness $E_{j,t}$ is defined by the individual price $p'_{j,t}$, unfilled demand $l'_{j,t}$ and product quality $q'_{j,t}$:

$$E_{j,t} = \omega_1 \left(1 - p'_{j,t-1}\right) + \omega_2 \left(1 - l'_{j,t-1}\right) + \omega_3 q'_{j,t-1}, \tag{64}$$

being $(\omega_1, \omega_2, \omega_3) \in \mathbb{R}^3_+$ parameters. All competitiveness components are log-normalized at the industry level to the interval $[0.1, 0.9]$.

Consumption-good prices are set by firm j applying a variable mark-up $\mu_{j,t}$ on average unit cost $c_{j,t}$:

$$p_{j,t} = (1 + \mu_{j,t})\, c_{j,t}. \tag{65}$$

Firms have a heuristic mark-up rule driven by the evolution of individual market shares:

$$\mu_{j,t} = \begin{cases} \mu_{j,t-1} \left(1 + \upsilon \frac{f_{j,t-1} - f_{j,t-2}}{f_{j,t-2}}\right) & \text{if } f_{j,t-1} > f^2_{min} \\ \mu_{j,t-1} & \text{otherwise ,} \end{cases} \tag{66}$$

with parameters $\upsilon \in \mathbb{R}_+$ and $f^2_{min} \in \mathbb{R}_+$ (the minimum share to stay in market).

Unfilled demand $l_{j,t}$ is the difference between actual demand $D_{j,t}$ firm j gets and its effective production $Q_{j,t}$ plus existing inventories $N_{j,t}$ from past periods, if any:

$$l_{j,t} = \max\left(\frac{D_{j,t}}{p_{j,t}} - (Q_{j,t} + N_{j,t}), 0\right). \tag{67}$$

The quality of consumer-good produced by firm j is determined by its average (log) skill level, considering each worker ℓ skills $s_{\ell,t}$:

$$q_{j,t} = \frac{1}{L_{j,t-1}} \sum_{\ell \in \{L_{j,t-1}\}} \log\left(s_{\ell,t-1}\right), \tag{68}$$

being $\{L_{j,t}\}$ the set of workers employed by firm, and $L_{j,t}$ the number of workers in the set.

Banks, government, and consumption

There are B commercial banks (subscript k) which take deposits and provide credit to firms. Bank-firm pairs are set randomly and are stable along firms' lifetime. Bank profits come from interest received on loans $Loans_{k,t}$, reserves at the central bank $Res_{k,t}$, and sovereign bonds $Bonds^b_{k,t}$ deducted from interest paid on deposits $Depo_{k,t}$ and liquidity loans from central bank $Loans^{cb}_{k,t}$, and losses from defaulted loans $BadDeb_{k,t}$:

$$\Pi^b_{k,t} = i^b_{k,t} + r^{res}_{t-1} Res_{k,t-1} + r^{bonds}_{t-1} Bonds^b_{k,t-1} - r^D_{t-1} Depo_{k,t-1} - r_{t-1} Loans^{cb}_{k,t-1} - BadDeb_{k,t}, \tag{69}$$

being $i^b_{k,t}$ the income from loan interest, r^{res}_t, r^{bonds}_t, r^D_t, and r_t, the interest rates on bank reserves, sovereign bonds, deposits, and liquidity loans (prime rate), respectively. The interest rate structure is set so $r^D_t = (1 - \mu_D) r_t$, $r^{res}_t = (1 - \mu_{res}) r_t$, $r^{bonds}_t = (1 - \mu_{bonds}) r_t$, $r^{deb}_t = (1 + \mu_{deb}) r_t$, and $r^D_t \leq r^{res}_t \leq r^{bonds}_t \leq r_t \leq r^{deb}_t$. $(\mu_D, \mu_{res}, \mu_{bonds}, \mu_{deb}) \in \mathbb{R}^4_+$ are parameters.

Banks charge interest rates on loans according to the credit ranking of clients, grouped in four quartile classes $q = 1, 2, 3, 4$. So, effective interest rate of firm j in credit class $q_{j,t}$ is:

$$r_{j,t}^{deb} = [1 + (q_{j,t} - 1)\, k_{const}]\, r_t^{deb}, \tag{70}$$

$r_{j,t}^{deb}$ is the base interest rate on deposits, and $k_{const} \in \mathbb{R}_+$ is a scaling parameter. Total income from loan interest of bank k is computed as:

$$i_{k,t}^{b} = \sum_{j \in \Omega_{t-1}} r_{j,t-1}^{deb} Deb_{j,t-1}, \tag{71}$$

Ω_t is the set of customers of bank k, and $Deb_{j,t}$ is the debt from loans of firm j.

Bank net worth/capital $NW_{k,t}^{b}$ is the difference between assets and liabilities: loans $Loans_{k,t}$, plus required reserves at the central bank $Res_{k,t}$, plus excess reserves $ExRes_{k,t}$, plus sovereign bonds stock $Bonds_{k,t}$, less deposits $Depo_{k,t}$, and less liquidity loans from central bank $Loans_{k,t}^{cb}$:

$$NW_{k,t}^{b} = Loans_{k,t} + Res_{k,t} + ExRes_{k,t} + Bonds_{k,t}^{b} - Depo_{k,t} - Loans_{k,t}^{cb}. \tag{72}$$

Excess reserves (cash at vault) are updated according to the bank cash flow:

$$ExRes_{k,t} = ExRes_{k,t-1} + \Pi_{k,t}^{b} - Tax_{k,t}^{b} - \Delta Res_{k,t} - \Delta Bonds_{k,t}^{b}, \tag{73}$$

where $\Delta Res_{k,t}$ and $\Delta Bonds_{k,t}$ are the changes on the stocks of required reserves and sovereign bonds from previous period, and $Tax_{k,t}^{b}$ is the bank tax on profits, if any.

Government taxes firms and banks profits at a fixed rate $tr \in \mathbb{R}_+$:

$$Tax_t = tr\left(\Pi_t^1 + \Pi_t^2 + \Pi_t^b\right), \tag{74}$$

where Π_t^1, Π_t^2 and Π_t^b are the aggregate total profits of the capital-good, the consumer-good and the banking sectors, respectively. It pays to unemployed workers a benefit w_t^u which is a fraction of the current average wage $\bar{w}_t$:

$$w_t^u = \psi \bar{w}_{t-1}, \tag{75}$$

where $\psi \in [0, 1]$ is a parameter. The recurring total public expenditure G_t and the public total deficit (surplus) are:

$$G_t = w_t^u \left(L^S - L_t^D\right) + G_t^{ed}. \tag{76}$$

$$Def_t = G_t - Tax_t - \Pi_t^{cb} + G_{t-1}^{bail} + r_{t-1}^{bonds} Bonds_{t-1} - r_{t-1}^{res} Depo_{t-1}^{g}, \tag{77}$$

G_t^{ed} is the expenditure in education, G_t^{bail} is the net cost of rescuing (bail-out) the banking sector during financial crises, if any, $Bonds_{t-1}$ is the stock of outstanding sovereign bonds (at banks and central bank), and $Depo_t^g$ are the accumulated government surpluses kept at the central bank. The operational result (profits/losses) of the central bank is:

$$\Pi_t^{cb} = r_{t-1} Loans_{t-1}^{cb} + r_{t-1}^{bonds} Bonds_{t-1}^{cb} - r_{t-1}^{res}\left(Res_{t-1} + Depo_{t-1}^{g}\right), \tag{78}$$

$Loans_t^{cb}$ are the liquidity loans provided to banks, $Bonds_t^{cb}$, the government bonds hold by central bank, and Res_t, the banks' reserves kept at the central bank.

Government issues new sovereign bonds with average maturity $\sigma_{bonds} \in \mathbb{R}_+^*$ to finance the public deficit (if $Def_t > 0$), and to pay maturing bonds, if $Depo_{t-1}^g = 0$. Banks buy bonds when there is free cash after required reserves $Res_{k,t}$ are deposited at the central bank, or sell them, otherwise, trying to minimize excess reserves $ExRes_{k,t}$ (money at vault). The central bank always clears the sovereign bond market.

Finally, the consolidated public sector debt, if any, is updated:

$$Deb_t = Deb_{t-1} + Def_t. \tag{79}$$

Workers fully consume their income (when possible) and do not take credit. Accordingly, desired aggregate consumption C_t^d depends on the income of both employed and unemployed workers plus the accumulated savings Sav_t^{acc} from unsatisfied desired consumption from previous periods, if any:

$$C_t^d = Sav_{t-1}^{acc} + \sum_{\ell} \left(w_{\ell,t} + w_{\ell,t}^u + Bon_{\ell,t-1} \right). \tag{80}$$

The effective consumption C_t is bound by the current-price production $\widetilde{Q}_t^2$ of the consumption-good sector:

$$C_t = \min\left(C_t^d, \widetilde{Q}_t^2 \right), \qquad \widetilde{Q}_t^2 = \sum_j p_{j,t} Q_{j,t}. \tag{81}$$

Unfilled desired consumption, if any, is saved:

$$Sav_t^{acc} = C_t^d - C_t. \tag{82}$$

The model applies the standard national account identities by the aggregation of agents' stocks and flows. The GDP Y_t is equal to the aggregate value added by firms, that is, the sum of the aggregate production of capital- and consumption-goods, $\widetilde{Q}_t^1$ and $\widetilde{Q}_t^2$, respectively. There are no intermediate goods. Y_t is also equal to the sum of the effective consumption C_t, the total nominal investment $\widetilde{I}_t$, the change in firm's inventories at current prices $\Delta\widetilde{N}_t$, plus the net exports $X_t - M_t$, if any, in domestic currency terms:

$$\widetilde{Q}_t^1 + \widetilde{Q}_t^2 = Y_t = C_t + \widetilde{I}_t + \Delta\widetilde{N}_t + X_t - M_t. \tag{83}$$

Appendix B: parameters, initial conditions, and S-F consistency

All the model's parameters and initial conditions, their calibration values, as well as the key SA tests statistics (cf. Appendix C), are detailed in the following tables. The model stock-flow consistency matrices are presented next.

SYMBOL	DESCRIPTION	VALUE	MIN.	MAX.	μ^*	DIRECT	INTERACTION
Education							
ϵ_{ed}	Public education expenditure as share of GDP	0.050	0.010	0.100	4.35	0.010	0.001
ϵ_{ad}	Education expenditure of advanced country (%GDP)	0.050	0.040	0.100	2.84*	0.004	0.001
ϑ_{ed}	Sensitivity of education attainment to expenditure	0.500	0.000	2.000	6.40	0.001	0.001
τ_{ed}	Leverage of education on productivity	0.500	0.000	2.000	5.60*	0.003	0.001
$(\alpha_{ed}, \beta_{ed})$	Beta distribution parameters (education attainment)	(6.560,3.600)	(4.000,5.000)	(9.000,2.000)	(3.57*,4.26)	(0.005,0.007)	(0.001,0.001)
(θ_2, θ_3)	Labour demand share for secondary/tertiary education	(0.550,0.250)	(0.300,0.100)	(0.700,0.300)	(0.73,1.38*)	(0.007,0.002)	(0.001,0.001)
(ϕ_2, ϕ_3)	Wage premium from secondary/tertiary education	(0.250,0.200)	(0.000,0.000)	(1.000,1.000)	(1.91,1.43)	(0.000,0.002)	(0.001,0.001)
Labour market							
δ	Labour force growth rate (per country)	(0.001,-0.001)	(0.000,-0.002)	(0.002,0.000)	2.09*	0.000	0.001
ϵ	Minimum desired wage increase rate	0.020	0.005	0.200	0.82	0.000	0.001
τ_T	Skills accumulation rate on tenure	0.010	0.001	0.100	4.37*	0.002	0.001
τ_U	Skills deterioration rate on unemployment	0.010	0.001	0.100	0.88	0.008	0.001
T_r	Number of periods before retirement (work life)	120	60	240	2.11*	0.005	0.001
T_s	Number of wage memory periods	4	1	8	2.39	0.001	0.001
ω	Number of firms to send applications (employed)	5	1	20	3.38*	0.000	0.001
ω_u	Number of firms to send applications (unempl.)	10	1	20	5.05	0.000	0.001
ψ_2	Aggregate productivity pass-trough	1.000	0.950	1.050	0.85*	0.002	0.001
ψ_4	Firm-level productivity pass-trough	0.500	0.000	1.000	2.68*	0.012	0.001
ψ_6	Share of firm free cash flow paid as bonus	0.200	0.000	0.500	4.48*	0.002	0.001

(continue...)

SYMBOL	DESCRIPTION	VALUE	MIN.	MAX.	μ^*	DIRECT	INTERACTION
Technology							
η	Maximum machine-tools useful life	19	10	40	3.81	0.000	0.001
ν	R&D investment propensity over sales	0.040	0.010	0.200	1.23*	0.000	0.001
ξ	Share of R&D expenditure in imitation	0.500	0.200	0.800	3.91	0.000	0.001
b	Payback period for machine replacement	8	1	20	2.65*	0.002	0.001
m_1	Capital productivity in capital-good sector	1	0.1	10	2.59*	0.002	0.001
m_2	Capital productivity in consumer-good industries	10	1	100	2.57	0.001	0.001
(α_1, β_1)	Beta distribution parameters (innovation process)	(3,3)	(1,1)	(5,5)	(5.49**,6.07*)	(0.002,0.001)	(0.001,0.001)
(α_2, β_2)	Beta distribution parameters (entrant productivity)	(2,4)	(1,1)	(5,5)	(7.42**,10.05)	(0.095,0.224)	(0.001,0.001)
(ζ_1, ζ_2)	Search capabilities for innovation/imitation	(0.100,0.100)	(0.050,0.050)	(0.200,0.200)	(1.35*,2.13*)	(0.000,0.001)	(0.001,0.001)
$[\underline{x}_1, \bar{x}_1]$	Beta distribution support (innovation process)	[-0.150,0.150]	[-0.300,0.100]	[-0.100,0.300]	(3.65*,3.38)	(0.000,0.001)	(0.001,0.001)
Industrial dynamics							
γ	Share of new customers for capital-good firm	0.500	0.200	0.800	2.71*	0.004	0.001
ι	Desired inventories share	0.100	0.000	0.300	0.60	0.001	0.001
κ_{max}	Maximum threshold to capital expansion	0.500	0.100	1.000	6.33*	0.043	0.001
μ_1	Mark-up in capital-good sector	0.100	0.010	0.200	1.62*	0.001	0.001
ω_1	Firm competitiveness weight for price	1.000	0.200	5.000	4.12*	0.004	0.001
ω_2	Firm competitiveness weight for unfilled demand	1.000	0.200	5.000	0.80*	0.000	0.001
ω_3	Firm competitiveness weight for quality	1.000	0.200	5.000	5.67	0.002	0.001
χ	Replicator dynamics coefficient (inter-firm)	1.000	0.200	5.000	4.51*	0.001	0.001
υ	Mark-up adjustment coefficient	0.040	0.010	0.100	3.77	0.002	0.001
f^2_{min}	Min share to firm stay in consumption-good sector	10^{-5}	10^{-6}	10^{-3}	1.54*	0.003	0.001
u	Planned utilization by consumption-good entrant	0.750	0.500	1.000	1.02*	0.013	0.001
x_5	Max technical advantage of capital-good entrant	0.300	0.000	1.000	9.90*	0.341	0.001
$[\Phi_1, \Phi_2]$	Min/max capital ratio for consumer-good entrant	[0.100,0.900]	[0.000,0.500]	[0.500,1.000]	(3.95*,2.10)	(0.001,0.003)	(0.001,0.001)
$[\Phi_3, \Phi_4]$	Min/max net wealth ratio for capital-good entrant	[0.100,0.900]	[0.000,0.500]	[0.500,1.000]	(1.56,3.28)	(0.004,0.007)	(0.001,0.001)
$[\underline{x}_2, \bar{x}_2]$	Entry distribution support for entrant draw	[-0.150,0.150]	[-0.300,0.100]	[-0.100,0.300]	(1.17*,1.87)	(0.004,0.003)	(0.001,0.001)
$[F^1_{min}, F^1_{max}]$	Min/max number of capital-good firms	[1,100]	[1,20]	[20,400]	(2.76*,3.04)	(0.013,0.002)	(0.001,0.001)
$[F^2_{min}, F^2_{max}]$	Min/max number of consumer-good firms	[1,100]	[1,20]	[20,400]	(0.84*,3.35*)	(0.001,0.002)	(0.001,0.001)

(continue...)

Symbol	Description	Value	Min.	Max.	μ^*	Direct	Interaction
Financial market							
r_T	Target prime interest rate	0.010	0.005	0.050	2.53	0.000	0.001
μ_D	Mark-down of interest on deposits under prime rate	0.900	0.750	1.000	1.82*	0.000	0.001
μ_{bonds}	Mark-down of interest on bonds under prime rate	0.500	0.250	1.000	1.46	0.004	0.001
μ_{deb}	Mark-up of interest on debt over prime rate	0.300	0.100	0.500	2.82*	0.006	0.001
μ_{res}	Mark-down of interest on reserves to prime rate	0.600	0.500	1.000	3.37	0.000	0.001
Λ	Prudential limit on debt (sales multiple)	3	1	4	1.51	0.000	0.001
International trade							
γ_e	Sensitivity of exchange rate to trade unbalance	0.100	0.020	0.500	1.26*	0.006	0.001
χ_m	Replicator dynamics coefficient for import share	0.010	0.001	0.01	1.00*	0.006	0.001
χ_x	Replicator dynamics coefficient for export shares	0.010	0.001	0.01	0.68*	0.001	0.001
f_0	Replicator dynamics minimum import/export share	0.200	0.050	0.400	1.64*	0.000	0.001
f_{max}	Replicator dynamics maximum import share	0.500	0.000	0.800	2.99*	0.000	0.001
(tr_{mc}, tr_{mk})	Duty rate on imports of consumption/capital goods	(0.000,0.000)	(0.000,0.000)	(0.300,0.300)	(2.03*,4.83*)	(0.002,0.001)	(0.001,0.001)
(tr_{x1}, tr_{x2})	Duty rate on exports of capital/consumption sectors	(0.000,0.000)	(0.000,0.000)	(0.300,0.300)	(2.33*,1.35)	(0.006,0.000)	(0.001,0.001)
Policy							
tr	Tax rate on firm and bank profits	0.100	0.000	0.300	0.98*	0.000	0.001
x_6	Technical gap of statized capital-good firm	0.000	-0.300	0.300	1.42	0.000	0.001
Φ_b	Bank bail-out reference as share of incumbent wealth	0.500	0.000	1.000	1.25	0.001	0.001
(γ_g^1, γ_g^2)	Minimum productivity/size ratio to allow statization	1.000	0.500	2.000	(2.87*,0.94)	(0.001,0.003)	(0.001,0.001)
ϕ	Unemployment subsidy rate on average wage	0.400	0.000	1.000	2.19*	0.002	0.001

(continue...)

Symbol	Description	Value	Min.	Max.	μ^*	Direct	Interaction
Initial conditions							
μ_0^2	Initial mark-up in consumption-good industries	(0.2,0.3)	(0.1,0.1)	(0.5,1.0)	1.81*	0.000	0.001
w_0^{min}	Initial minimum wage and social benefit floor	0.500	0.100	1.000	2.90*	0.006	0.001
L_0^S	Number of workers	2.510^5	1.310^5	5.010^5	4.01*	0.005	0.001
Λ_0	Prudential limit on debt (initial fixed floor)	1000	500	2000	4.27*	0.001	0.001
B	Number of banks	10	5	15	1.99*	0.001	0.001
(F_0^1, F_0^2)	Initial number of capital/consumption-good firms	(10,50)	(5,20)	(20,200)	(1.66,2.72*)	(0.012,0.003)	(0.001,0.001)
(NW_0^1, NW_0^2)	Multiple on initial net wealth for capital/consumption	(1,2)	(0,0)	(10,10)	(2.74,2.34*)	(0.001,0.008)	(0.001,0.001)

Table 6: Model parameters and initial conditions, calibration values, minimum-maximum range for sensitivity analysis, elementary effects μ^* statistic ($n = 4850$ samples) and Sobol decomposition direct and interaction effects indexes ($n = 5120$ samples).
Baseline values. Sensitivity analysis statistics relative to $\hat{X}_{y,t}^k$ (the most sensitive variable). Statistics for other variables are available on request.
μ^* statistic estimated using factors rescaled to $[0, 1]$. μ^* significance: *** 0.1% | ** 1% | * 5% | (no asterisk) not significant at 5% level.

	Workers	Firms		Banks	Central bank	Government	Foreign firms	$\sum$
	(households)	*capital-good*	*consumption-good*					
Fixed capital			$+K_t^{nom}$					$+K_t^{nom}$
Equities	$+Eq_t^w$	$-Eq_t^1$	$-Eq_t^2$			$+Eq_t^g$		0
Deposits	$+Sav_t^{acc}$	$+NW_t^1$	$+NW_t^2$	$-Depo_t$				0
Loans		$-Deb_t^1$	$-Deb_t^2$	$+Loans_t$				0
Monetary base				$+MB_t$	$-MB_t$			0
Reserves (required)				$+Res_t$	$-Res_t$			0
Excess reserves				$+ExRes_t$	$-ExRes_t$			0
Liquidity facilities				$-Loans_t^{cb}$	$+Loans_t^{cb}$			0
Government bonds				$+Bonds_t^b$	$+Bonds_t^{cb}$	$-Deb_t$		0
Government deposits					$-Depo_t^g$	$+Depo_t^g$		0
International reserves					$-IntRes_t$		$+IntRes_t$	0
Balance	$-Bal_t$	$-Bal_t^1$	$-Bal_t^2$	$-Bal_t^b$	$-Bal_t^{cb}$	$-Bal_t^g$	$-Bal_t^w$	$-K_t^{nom}$
$\sum$	0	0	0	0	0	0	0	0

Table 7: Stock-flow consistency: balance-sheet matrix, single country view.

	Workers	Capital-good firms		Consumption-good firms		Banks		Central bank	Government	Foreign agents	$\sum$
	(households)	*current*	*capital*	*current*	*capital*	*current*	*capital*				
Transactions											
Consumption	$-C_t^{w,l}$			$+S_t^{2,l}$					$-G_t^c$		0
Investment		$+S_t^{1,l}$			$-I_t^{nom,l}$						0
Trade, imports	$-M_t^c$				$-M_t^k$					$+X_t^f$	0
Trade, exports		$+X_t^k$		$+X_t^c$						$-M_t^f$	0
Government transfers	$+G_t^{trf}$								$-G_t^{trf}$		0
Wages	$+W_t$	$-W_t^1$		$-W_t^2$							0
Taxes, local gov.	$-Tax_t^w$	$-Tax_t^1, -Tax_t^{x1}$		$-Tax_t^2, -Tax_t^{x2}$		$-Tax_t^b$			$+Tax_t$	$-Tax_t^m$	0
Taxes, foreign gov.		$-Tax_t^{m1,f}$		$-Tax_t^{m2,f}$						$+Tax_t^{m,f}$	0
Profits, firms and banks		$-\text{ net }\Pi_t^1$	$+\text{ net }\Pi_t^1$	$-\text{ net }\Pi_t^2$	$+\text{ net }\Pi_t^2$	$-\text{ net }\Pi_t^b$	$+\text{ net }\Pi_t^b$				0
Op. result, central bank								$-\Pi_t^{cb}$	$+\Pi_t^{cb}$		0
Bonuses	$+Bon_{t-1}$				$-Bon_{t-1}^2$						0
Dividends	$+Div_{t-1}^w$		$-Div_{t-1}^1$		$-Div_{t-1}^2$		$-Div_{t-1}^b$		$+Div_{t-1}^g$		0
New equity expense	$-Eq_{t-1}^{w,entry}$		$+Eq_{t-1}^{1,entry}$		$+Eq_{t-1}^{2,entry}$				$-Eq_{t-1}^{g,entry}$		0
Exit remaining net worth	$+NW_{t-1}^{w,exit}$		$-NW_{t-1}^{1,exit}$		$-NW_{t-1}^{2,exit}$				$+NW_{t-1}^{g,exit}$		0
Bad debt			$+BadDeb_{t-1}^1$		$+BadDeb_{t-1}^2$	$-BadDeb_{t-1}$			$-BadDeb_{t-1}^g$		0
Bail-out							$+G_t^{bail}$	$-G_t^{bail} + G_{t-1}^{bail}$	$-G_{t-1}^{bail}$		0
Interest, deposits	$+r_{t-1}^D Sav_{t-1}^{acc}$	$+r_{t-1}^D NW_{t-1}^1$		$+r_{t-1}^D NW_{t-1}^2$		$-r_{t-1}^D Depo_{t-1}$					0
Interest, loans		$-r_{t-1}^{deb} Deb_{t-1}^1$		$-r_{t-1}^{deb} Deb_{t-1}^2$		$+r_{t-1}^{deb} Loans_{t-1}$					0
Interest, reserves						$+r_{t-1}^{res} Res_{t-1}$		$-r_{t-1}^{res} Res_{t-1}$			0
Interest, liq. facilities						$-r_{t-1} Loans_{t-1}^{cb}$		$+r_{t-1} Loans_{t-1}^{cb}$			0
Interest, gov. bonds						$+r_{t-1}^{bonds} Bonds_{t-1}^b$		$+r_{t-1}^{bonds} Bonds_{t-1}^{cb}$	$-r_{t-1}^{bonds} Deb_{t-1}$		0
Interest, gov. deposits								$-r_{t-1}^{res} Depo_{t-1}^g$	$+r_{t-1}^{res} Depo_{t-1}^g$		0
Flow of funds											
Change, deposits	$-\Delta Sav_t^{acc}$		$-\Delta NW_t^1$		$-\Delta NW_t^2$		$+\Delta Depo_t$				0
Change, loans			$+\Delta Deb_t^1$		$+\Delta Deb_t^2$		$-\Delta Loans_t$				0
Change, monetary base							$+\Delta MB_t$	$-\Delta MB_t$			0
Change, reserves							$-\Delta Res_t$	$+\Delta Res_t$			0
Change, excess reserves							$-\Delta ExRes_t$	$+\Delta ExRes_t$			0
Change, liq. facilities							$+\Delta Loans_t^{cb}$	$-\Delta Loans_t^{cb}$			0
Change, gov. bonds							$-\Delta Bonds_t^b$	$-\Delta Bonds_t^{cb}$	$+\Delta Deb_t$		0
Change, gov. deposits								$+\Delta Depo_t^g$	$-\Delta Depo_t^g$		0
Change, int'l reserves								$-\Delta IntRes_t$		$+\Delta IntRes_t$	0
$\sum$	0	0	0	0	0	0	0	0	0	0	0

Table 8: Stock-flow consistency: transaction-flow matrix for a single country.
To ensure consistency for the world, if N is the number of countries, $\sum_{y=1}^{N} \Delta IntRes_{y,t} = 0$.
$\Delta X_t = X_t - X_{t-1}$, $\text{net }\Pi_t^z = \Pi_t^z - Tax_t^z, z = 1, 2, b$, $C_t^{w,l} = C_t^w - M_t^c$, $I_t^{nom,l} = I_t^{nom} - M_t^k$.

Appendix C: sensitivity analysis

Global sensitivity analysis (SA) is performed on the model for the period $t \in [100, 500]$ on a set of output variables (the "metrics") relevant to the current discussion, namely the net exports as a share of the GDP for the capital- (k) and consumption-goods (c) sectors of each country y:

$$\hat{X}^k_{y,t} = \frac{X^k_{y,t} - M^k_{y,t}}{Y_{y,t}}, \qquad \hat{X}^c_{y,t} = \frac{X^c_{y,t} - M^c_{y,t}}{Y_{y,t}}, \tag{84}$$

and for the critical times on the international specialization, also for the both sectors:[15]

$$t^k_X = \min_t \left(\left\{ t \in [101, 500] \mid \hat{X}^k_{1,t} = \hat{X}^k_{2,t} \right\} \right), \quad t^c_X = \min_t \left(\left\{ t \in [101, 500] \mid \hat{X}^c_{1,t} = \hat{X}^c_{2,t} \right\} \right), \tag{85}$$

being $y = 1$ the North country, and $y = 2$, the South one.

These metrics can be better understood using Figure 5. $\hat{X}^k_{y,t}$ is represented by the continuous lines, and $\hat{X}^c_{y,t}$, by the dashed ones. t^k_X is the time when the continuous (machine) lines of both countries (black and blue) cross. Similarly, t^c_X marks the crossing of the dashed (product) lines.

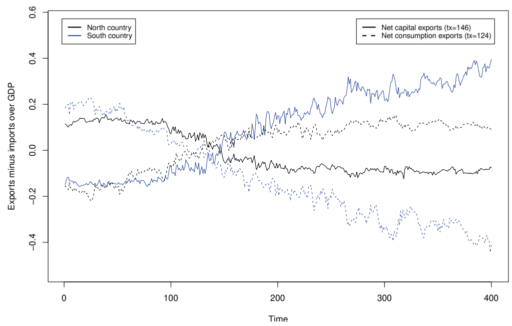

Figure 5: Sectoral balance of trade temporal results comparing North (black) and South (blue) countries. Baseline scenario MC median results for 32 runs in period $\hat{t} \in [1, 400]$. Source: authors' analysis.

SA is performed across the entire parametric space, inside the closed region defined by Table 6 (columns MIN. and MAX.) in Appendix B, and the synthetic results are reported (columns μ^*, DIRECT and INTERACTION) for the most sensitive among the tested output variables (results for the remaining variables can be requested to the authors). Two SA

[15]Other relevant metrics, like the macro aggregates' growth rates, the inequality measures, and the industrial performance indicators were already evaluated in previous papers based on the labour-augmented K+S model and are not be replicated here. The general results from these past analyses indicate a relatively small dependence of the model qualitative results on the chosen parametrization.

methodologies are employed, elementary effects (EE),[16] and Sobol variance decomposition based on a Kriging meta-model (SVD-KMM).[17,18]

EE analysis is summarized by the μ^* statistic in Table 6, which is a measure of the direct absolute effects of each factor (parameter or initial condition) on the chosen output variable, being the parametric space rescaled to the $[0, 1]$ interval on each dimension. The statistical significance of this statistic, the probability of not rejecting $H_0 : \mu_i^* = 0$ is also evaluated and indicated by the usual asterisk convention. The EE computation is performed directly over model samples from an optimized 10-trajectory one-at-a-time design of experiments (DoE). Each DoE sampling point is sampled five times, to compensate for stochastic components in the model.

The SVD analysis is also reported in Table 6 by two statistics: (DIRECT column) the decomposition of the direct influence of each factor on the variance of the tested output variable (adding up to 1), and (INTERACTION column) its indirect influence share, by interacting with other factors (non-linear/non-additive effects). The SVD analysis is performed using a KMM fitted using samples from a near-orthogonal Latin hypercube DoE. Each DoE point is sampled 10 times.

The EE analysis (Table 6) indicates that t_X^k and $\hat{X}_{y,t}^k$ are the metrics sensitive to the larger number of those factors while t_X^c and $\hat{X}_{y,t}^c$ are the least sensitive.[19] In total, 14 unique *relevant* factors were identified after discarding very small effects (μ^*). Table 9 presents them.

The SVD could only be applied to metrics $\hat{X}_{y,t}^k$ and $\hat{X}_{y,t}^c$, because the nature of the change of t_X^k and t_X^c (once per simulation run) is inadequate for a variance-based method like SVD. The results (Table 6) indicate a smaller subset of influential factors for $\hat{X}_{y,t}^k$ and $\hat{X}_{y,t}^c$ may be relevant for analysis.[20] In Table 9 we present the 7 relevant factors, after discarding small effect ones.

The SA results seem to indicate that selected metrics are mostly insensitive to the *new* parameters introduced in this version of the model. Only χ_x, the replicator parameter regulating the intensity of international competitiveness on the consumption-good mar-

[16]The EE analysis proposes both a specific design of experiments, to efficiently sample the parametric space under a multi-path, one-factor-at-a-time strategy, and a absolute importance statistic to evaluate direct and indirect (non-linear/non-additive) effects of the parameters on model results and their statistical significance (see Dosi et al. (2018) for details and other references).

[17]The SVD is a variance-based, global SA method consisting in the decomposition of the chosen metrics variance into shares according to the contribution of the variances of the factors selected for analysis. This methodology deals better with non-linearities and non-additive interactions than EE or the traditional local SA methods, but does not provide an estimation of the mean effect produced. It allows to precisely disentangle both direct and interaction quantitative effects of the factors over the entire parametric space (see Dosi et al. (2018)).

[18]The KMM "mimics" the K+S model using a simpler, mathematically-tractable approximation, fitted over a representative sample of the original model response surface. Kriging is a spatial interpolation method that under fairly general assumptions provides the best linear unbiased predictors for the response of complex, non-linear computer simulation models. The meta-model is estimated by numerical maximum likelihood using a set of observations multi-sampled from the original model using a high-efficiency, nearly-orthogonal Latin hypercube design of experiments (see Dosi et al. (2018)).

[19]The selection criterion is to consider the top 70% EE contributors at 5% significance.

[20]The selection criterion is to consider the top 70% SVD contributors.

METRIC	TOP INFLUENTIAL FACTORS	
	EE	*SVD*
$\hat{X}^k_{y,t}$	β_2, x_5, α_2, ϑ_{ed}, κ_{max}	x_5, β_2, α_2, κ_{max}
$\hat{X}^c_{y,t}$	ω_U, Φ_2	β_2, x_5, ϵ_{ed}, χ, κ_{max}, f_0, ω_3
t^k_X	ϵ_{ed}, α_2, β_2, χ_x, τ_{ed}, x_5	
t^c_X	ω_U, β_2 , τ_T, Φ_1, x_5, χ	

Table 9: Relevant sensitivity analysis factors identified by elementary effects (EE) and Sobol variance decomposition (SVD) for selected model metrics. See Table 6 for factor details. Source: authors' analysis.

ket, and f_0, the replicator minimum import/export share, are mildly influential. That is, they are not able to qualitatively change the obtained results even if changed significantly from the baseline, meaning that the country-level institutional set-ups – and the related asymmetries – are the main driver of trade partners.

The most important parameters in Table 9, as usual for the K+S model (see Dosi et al., 2010, 2015, 2017; Fanti et al., 2023, 2024), are the ones connected with the technology, investment, and domestic market dynamics (α_2, β_2, κ_{max}, ω_3, χ, Φ_1, Φ_2, x_5), or with the educational and labour-market set-up (ϵ_{ed}, τ_{ed}, ϑ_{ed}, ω_U, τ_T).[21] This just confirms that the changes proposed here do not significantly affect this fact. It also means the observed international trade patterns can be only significantly altered if the domestic countries' institutional configuration is substantially changed.

[21]The description and the effect for each factor are available in Table 6, Appendix B.