INSTITUTE
OF ECONOMICS

Scuola Superiore
Sant'Anna

LEM | Laboratory of Economics and Management

Institute of Economics
Scuola Superiore Sant'Anna

Piazza Martiri della Libertà, 33 - 56127 Pisa, Italy
ph. +39 050 88.33.43
institute.economics@sssup.it

LEM
WORKING PAPER SERIES

A North-South agent based model of segmented labour markets. The role of education and trade asymmetries

Lucrezia Fanti [a]
Marcelo C. Pereira [b,c]
Maria Enrica Virgillito [c,a]

[a] Department of Economic Policy, Università Cattolica del Sacro Cuore, Milan, Italy.
[b] Institute of Economics, University of Campinas, Brazil.
[c] Institute of Economics, Scuola Superiore Sant'Anna, Pisa, Italy.

2023/17 **April 2023**
ISSN(ONLINE) 2284-0400

A North-South agent based model of segmented labour markets. The role of education and trade asymmetries*

Lucrezia Fanti[†1], Marcelo C. Pereira[‡2,3], and Maria Enrica Virgillito[§3,1]

[1] *Universita' Cattolica del Sacro Cuore*
[2] *University of Campinas*
[3] *Scuola Superiore Sant'Anna*

Abstract

Drawing on the labour-augmented K+S agent-based model, this paper develops a two-country North-South ABM wherein the leader and the laggard country interact through the international trade of capital goods. The model aims to address sources of asymmetries and possible converge patterns between two advanced economies that are initially differentiated in terms of the education level they are able to provide. Education is modeled as a national-level policy differently targeting the three usual levels, that is primary, secondary and tertiary. After being educated and entering the labour force, workers face a segmented market, divided into three types of job qualification, and the resulting position levels inside firms, i.e., elementary, technical and professional occupations. The three resulting labour market segments are heterogeneous in terms of both requested education level and offered wages. To address the role of trade and education, we experiment with different education-policy and trade settings. Ultimately, we are interested in understanding the coupling effects of asymmetries in education, which reverberate in segmented labour markets and differentiated growth patterns. Notably, our focus on capital-goods trade, rather than consumption goods, allows us to assess a direct link between *productive capabilities in producing complex products* and country growth prospects.

JEL classification: C63, J3 , E24, O1

Keywords: Agent-Based Model; Education; International Trade; Technology Gap; Labour Market

*We thank participants to EAEPE 2022 annual conference, LH seminar series and ABM4Policy 2022 workshop. We gratefully acknowledge support from the Italian Ministry of University and Research (MUR), PRIN 2017 project: "Lost highway: skills, technology and trade in Italian economic growth, 1815-2018" (prot. 2017YLBYZE). – and by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), process No. 2015/24341-7.

†Corresponding author: Department of Economic Policy, Università Cattolica del Sacro Cuore, Via Lodovico Necchi 5, 20123, Milan (Italy). E-mail address: `lucrezia.fanti@unicatt.it`

‡Institute of Economics, University of Campinas, Rua Pitágoras 353, 13083-970, Campinas, SP (Brazil). E-mail address: `mcper<at>unicamp.br`

§Institute of Economics, Scuola Superiore Sant'Anna, Piazza Martiri della Liberta' 33, 56127, Pisa (Italy). E-mail address: `m.virgillito<at>santannapisa.it`

1 Introduction

Education and trade have been under the spotlight of economic growth theory in the past forty years, with special attention devoted to the accumulation of human capital and trade-oriented growth strategies (Lucas, 1988; Barro, 2013; Manning, 1982; Kim and Kim, 2000). According to a neoclassical perspective, while trade represents an opportunity to exploit comparative advantages and specialize in the production of goods derived from abundant endowments, education should allow to reap the benefits of human capital accumulation. Both elements are considered as potential sources for economic development, the so called *missing X* (Adelman, 2001). Notwithstanding the neoclassical prediction of growth convergence, economic asymmetries among countries have never been as significant since the WWII as they are nowadays, with the emergence of new *core-periphery* patterns, and China defining the shape of international trade since its entry to the WTO in 2001. Trade flows remain very polarized, and multilateral trade agreements are becoming less relevant than bilateral ones. Education remains also asymmetric, but there is historical evidence, such as the case of Germany, South Korea, and China, supporting the massive reorientation of the education policies to foster the qualification of the labour force in some countries.

From an evolutionary economics perspective, the role of international trade is not always an opportunity to virtuous growth trajectories, particularly when trade is based on comparative advantages and, at the same time, absolute disadvantages. Indeed, according to the *getting the price wrong* concept (Amsden, 1991), to achieve development the emphasis should lie on developing local learning capabilities and "disciplining" the capitalists' short-termism. What matters is not the exchange itself but rather the accumulation of knowledge and productive capabilities in complex organizations to create growth opportunities. Therefore, asymmetries are quite probable, and path dependency from initial conditions is expected to affect growth trajectories, therefore convergence should not be expected. The role of composition – in a country's bundle of exports – in affecting the growth process has been extensively addressed in this literature (Cimoli, 1988; Cimoli and Porcile, 2010). However, less attention has been devoted to the interaction between national education policies and international trade mechanisms in determining the long-term growth and the ensuing patterns of convergence versus divergence. Indeed, education, or the lack thereof, might affect workers' learning opportunities and, in turn, the firm-level productivity.

How, and in which respect may education and trade interact to impact countries' growth and convergence? Under which conditions do North-South or core-periphery structures amplify or, rather, fade away? Our work hypothesis is that the underlying propagation mechanism goes from education to the patterns of production and specialization, via cumulative innovation and learning opportunities, and ultimately, to growth. If countries differ in the level of education they are able to provide to most of the population, this will eventually impact upon the skills the labour force can absorb, and the job positions workers can fulfil in the labour market. Ultimately, education might impact the possible growth patterns by possibly constraining the type of technologies and products in which the country is able to compete on international markets. Indeed, a leader country will be able to produce more advanced, high value-added goods, such as capital goods and sophisticated intermediate inputs, to serve the demand of the "laggard" countries. From this perspective, trade flows may therefore accelerate the crystallization of initial asymmetries driven by different national education policies (Dosi et al., 2009).

To assess these propagation mechanisms, we develop an Agent-Based Model (ABM thereafter) able to account for different stylized national education policies, segmented labour markets, and international trade of capital goods (or machines). Drawing on the labour-augmented Schumpeter Meeting Keynes (K+S) agent-based model (Dosi et al., 2010, 2017, 2020), this paper develops a new two-country, North-South ABM wherein the leader and the laggard country interact through the international trade of machines. The model aims to uncover the sources of asymmetries, and eventual convergence patterns, between two advanced economies which are initially differentiated in terms of the education level they ensure to the population. Education is modelled as a national policy targeting differently the three usual levels, that is primary, secondary and tertiary. After being educated, workers enter a segmented labour market, divided into three types of education-based job qualifications. When hired by a firm, workers join one of three occupations – elementary, technical or professional – according to the education level and firms' demand. The three resulting market segments are heterogeneous in terms of both offered education levels and requested occupations, wages, and tenure skills.

To address the interactions between trade and education, we experiment with alternative model configurations. Ultimately, we are interested in understanding the effects of an educational asymmetry between countries, which reverberates in the segmented labour markets and, expectedly, on differentiated growth patterns. Notably, our focus on capital-goods trade, rather than consumption goods, allows us to assess a link between productive capabilities, and not just export volumes, and country growth prospects.

Our results show that primary-education workers are more exposed to occupational instability, therefore leading to differentiated aggregate labour market outcomes, such as higher unemployment and vacancy rates. A relatively weaker educational performance affects the laggard country in terms of both a backwards technological profile and slower productivity and output growth rates. Indeed, the model shows how differences in education policies can persistently affect country performance, trade balance and labour markets. This can be explained by dynamic feedbacks along different channels: (i) from education to innovation and productive capabilities; (ii) from education to labour market on fulfilling firm's segmented demand and productivity potential; (iii) from innovation and productive capabilities to international trade; and (iv) from labour and capital-goods markets, including trade, to country output growth.

Surprisingly, when evaluating the potential for convergence of the imitation by domestic firms of the competitors abroad, the model suggests that imitation, instead of an equalizing mechanism between North and South countries, may become an amplifying factor of divergence. Indeed, trying to imitate firms that are distant from your technological and absorptive capabilities may end up in repetitive – and costly – imitation failures. Frequently, just trying to imitate other domestic firms, at the local technological frontier, end ups in a higher rate of successful imitation, pushing firms following this strategy ahead of others pursuing the former path. In that respect, the development of gradually-evolving capabilities in country, rather than focusing on large, but less likely, external imitation leaps, showed to be a more viable path to at least partial convergence.

The paper is organized as follows. Section 2 reviews the literature on the three channels we analyse, namely, North-South technology asymmetries, the interplay between education, innovation and productivity dynamics, and the impact of differentiated education profiles on segmented labour markets and their aggregate outcomes. Section 3 presents the structure of our model and introduces the new channels we implement within the labour-augmented K+S ABM. After the model validation and stylized fact identification (Section 4), in Section 5 we propose two policy experiments aimed at evaluating the role of education and international trade on crucial macroeconomic outcome variables. Finally, in Section 6 we present our conclusions.

2 The roots of North-South asymmetries

In this Section we discuss the theoretical background of our model. In particular, we propose a brief review of the main contributions investigating the root causes of asymmetries between countries and economic areas (Subsection 2.1), and the role of education policy and international trade therein (Subsection 2.2).

2.1 Technological gap and international trade

From a theoretical stand point we can identify three major approaches to explain the North-South development asymmetries and the role of international trade therein, namely neoclassical, structuralist/institutionalist, evolutionary/technological gap theories.

The neoclassical explanation mainly relies on the hypothesis that countries' asymmetries in productivity, growth rates, and the ensuing development patterns, are due to different endowments of production factors (i.e., capital, labour and natural resources) affecting, in turn, international trade (Hicks, 1953; Johnson, 1950). The role of international trade in an open economy is therefore defined in terms of comparative or absolute advantages and internal specialization profiles, depending on the endowments of such factors (the Heckshe-Ohlin theorem) or on relative prices (the Stolper-Samuelson theorem).

On a different direction, early structuralist approaches studied development and trade patterns in terms of institutional asymmetries governing labour and goods markets between developed and developing areas, leading to different income distributions (Rosentstein-Rodan, 1943; Lewis, 1954). A second generation of structuralist scholars has also highlighted the role of differentiated industrialization, structural change, and patterns of the productive structure in northern and southern areas, in order to explain the determinants of economic convergence and divergence (Dutt, 1989; Taylor, 2004; Botta, 2009; Dosi et al., 2021).

Finally, stemming from seminal contributions like Posner (1961); Nelson (1967); Dosi et al. (1990); Cimoli et al. (1990), and still in line with the institutional-structuralist tradition, evolutionary scholars have explained country asymmetries and trade flows as mainly driven by technological gaps (Fagerberg, 1987, 1994). On this ground, a crucial role is played by the heterogeneity in technological and capability spaces leading to different patterns of specialization. A more recent empirical strand of this literature has been devoted to the explanation of countries' growth and development trajectories. The main source of heterogeneity is derived from the relative *complexity* of produced and exported goods, which depends on the different capability endowments of countries (Hidalgo et al., 2007; Tacchella et al., 2013), usually by exploiting the BACI trade database. Schumpeterian and Keynesian efficiency indicators, at product and country levels, have been proposed in Dosi et al. (2022) to assess growth rate, volatility, and crisis durations.

As highlighted by the dependency theory (Prebisch, 1950; Hirschman, 1958; Kvangraven, 2020), countries may achieve relatively weaker or stronger international positioning depending on their productive, technological, and learning capabilities, leading, in turn, to different profiles of goods production (Cimoli et al., 1990; Cimoli and Dosi, 1995; Cimoli and Porcile, 2014). As a consequence, countries producing and exporting more complex goods – embedding superior technological capabilities and advanced knowledge – prevail in the international competition, presenting robust growth and productivity patterns. On the contrary, laggard countries typically fall behind in terms of crucial macroeconomic variables due to both technological dependence and weaker capabilities of the workforce (Verspagen, 1993; Dosi et al., 2009).

The patterns described above not only relate to asymmetries between developed and developing countries, the North-South pattern, but also among developed areas, regions or countries, in a *core-periphery* pattern such as the case of Northern/Centre and Southern/Eastern European countries (Storm and Naastepad, 2015; Landesmann et al., 2015; Celi et al., 2019) linked by inter-sectoral dependency structures (Cresti and Virgillito, 2023). On this ground, Post-Keynesian scholars have investigated the effect of export-driven growth strategies on structural asymmetries, either between developed and developing countries (Palley, 2012), or inside Europe (Stockhammer, 2011). In particular, the progressive expansion of the European productive facilities towards the Eastern economies represents a further source of interdependence. This trend has the potential to foster the development of uneven patterns due to the fragmentation of a growing number of industrial activities along the value chains and the productive outsourcing (e.g., German automotive industry) (Simonazzi et al., 2013; Pavlínek, 2018; Cresti and Virgillito, 2022).

To summarize, a number of theoretical and empirical studies have shown that different intensities of the innovation and imitation processes within and between firms may lead, respectively, to divergence and convergence patterns among developed areas, or between these and developing regions that are catching-up (Fagerberg and Godinho, 2005; Lee, 2013). Nevertheless, heterogeneous institutional and labour market configuration may either foster or undermine the process of catching-up. This occurs because of the interaction between these structural components and the internal productive and technological configuration. Such interaction crucially determines the ability of a country to successfully absorb and employ imported technologies which would favour the convergence process (Verspagen, 2002; Dosi et al., 2009). On this ground, as highlighted by the evolutionary literature on National and Sectoral Innovation Systems (NIN/SIS), policies oriented towards high-quality and universal education, knowledge accumulation, and worker-skills development represent a key element for laggard countries to pave the grounds for development and convergence (Lundvall, 1992; Freeman, 2002).

2.2 Education investment and segmented labour markets

Differences in education policies, and the segmentation of labour market associated with the rising productive complexity, represent another crucial source of asymmetries between regions and countries.

The neoclassical literature on education and its impact on growth, productivity and labour market dynamics has been traditionally rooted into both endogenous growth theory – from Lucas (1988) to the skill-biased technical change hypothesis (Acemoglu, 2002) – and human capital theory (Becker, 1962). This supply-side, individual-based approach considers labour productivity only in terms of workers' marginal contribution to firms' output by looking at individual skill and knowledge endowment as a production-function-augmenting analytical device. Therefore, education is only considered as a proxy for workers individual skills, and frequently as the only variable capturing the effect of knowledge accumulation on firms' performance. In this theoretical perspective, possible gaps between worker's individual characteristics and job requirements – the so-called skill or educational mismatch – represent just a metric by which the fitness of the workforce to meet the production needs can be evaluated (see, among others, Hersch (1991); Allen and van der Velden (2001)). Therefore, labour markets frictional issues in terms of required educational attainment and skills, or firms performance weaknesses, only lie on individual worker characteristics, regardless of firms' organizational structure, productive processes, or technological trajectories (Fanti et al., 2021; Cetrulo et al., 2020). Moreover, educational prowess has been also identified as one of the key element determining country performance in neoclassical models of international trade and growth (see, among others, Manning (1982); Kim and Kim (2000)).

On an alternative perspective, the evolutionary tradition has also investigated the role of education profiles and workers skills. Authors in this stream interpret them as key elements shaping firms' internal knowledge base because of the interaction between idiosyncratic learning processes and the dynamic accumulation of the capabilities developed during these procedures. Such complex and interactive processes affect the firm-level organizational, technological, and power structures (Dosi et al., 2001; Dosi and Marengo, 2015; Dosi et al., 2021).

Following the evolutionary literature, and looking at the process of worker skills accumulation/destruction as driven by job-tenure and learning-by-doing processes, and unemployment periods, Dosi et al. (2018, 2019) show how skills accumulation crucially affects both firm-level production processes and macroeconomic outcomes, such as hysteresis and crisis vulnerability. Evolving along this line, Fanti et al. (2022) recently highlight that heterogeneous labour market institutional architectures may also affect North-South productive divergence. The authors show that heterogeneity leads, in turn, to weaker labour absorption and lower remuneration in the South, subsequently reverberating into asymmetric technological profiles and production patterns between regions and countries.

Countries' education profiles are also relevant in terms of *labour markets segmentation* – seconded by other sources of worker heterogeneity (e.g., age, gender, race) – leading to differentiated occupational opportunities and wage potentials (Doeringer and Piore, 1985). On this respect, the empirical literature documents the persistent internal segmentation of labour markets (Reich et al., 1973). Such observations further undermine the neoclassical hypothesis under which leading competitive forces are supposed to absorb possible (temporary) frictional and market fragmentation issues, by the operation of rational profit-maximizing employers hiring workers only considering individual characteristics and relative wages. Indeed, the literature on Segmented Labour Markets (SLM), has extensively documented the usual *dual* structure of labour markets, i.e., divided into *primary* and *secondary* segments characterized by, respectively, better or worse occupational and wage conditions. The dualism crucially shapes the aggregate labour market outcomes, and can be driven by multiple factors, among others: (i) differences on the supply and demand of high- and low-skill workers (Taubman and Wachter, 1986), (ii) institutional factors as unionisation degree or minimum-wage regulations (Osterman, 1978), and (iii) the role of technical change and de-localization on the dominance of new high-skill and high-wage labour market segments while low-skill/wage workers are left behind (Hudson, 2007). Therefore, the SLM approach allows addressing crucial policy issues related to the employment and wage inequality conditions characterizing different workers categories. It provides insights that can drive targeted policy interventions – such as education strategies and training programs favouring worker transition from secondary to primary segments of the labour market – aimed at reducing inequality while enhancing aggregate countries performance and possible convergence strategies.

Thus, increasing educational attainment and skill-level of workers seem to be an important vector that dynamically interacts with heterogeneous firm-level technological, productive, and organizational capabilities, to drive sectoral trajectories and, therefore, country and region performance patterns (Dosi et al., 2009). In this respect, aggregate investment in education can be interpreted as one of the key elements to link workers' capability profile and firms' technological dynamics, within a segmented labour market, to allow for distinctive productivity and output growth trajectories (Winter, 1997; Dosi et al., 2001).

3 The model

The proposed model is based on the labour-augmented Schumpeter Meeting Keynes model (K+S) (Dosi et al., 2010, 2017, 2020), a *general disequilibrium*, stock-and-flow consistent, agent-based macroeconomic model.[1] The K+S country economy is populated by workers, firms, and banks, which interact and behave according to bounded-rational rules. It is formally composed by four populations of heterogeneous agents, namely L_t^S

[1]For information on agent-based-modelling methodology in general, and particularly in macroeconomics, see (Cincotti et al., 2022; Dosi and Roventini, 2019).

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].

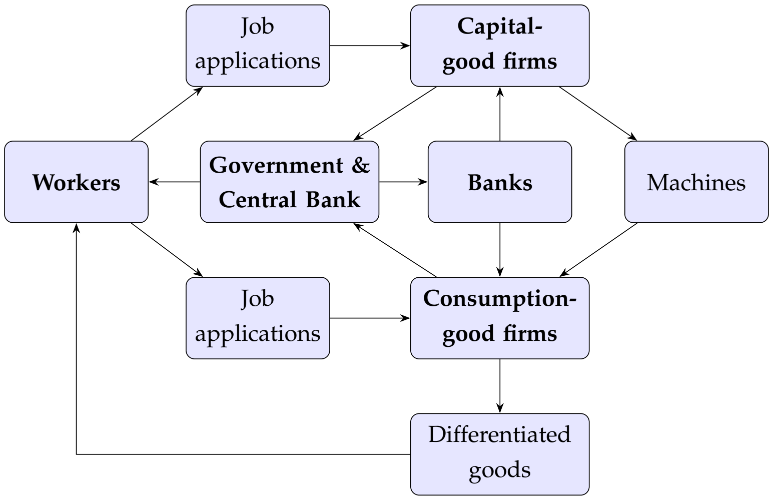


Figure 1: Internal organization of each modelled country, agents indicated in bold typeface. Source: Dosi et al. (2017).

The original K+S is a closed-economy, single-country model organized as depicted in Figure 1. Capital-good firms invest in R&D and produce heterogeneous machine-tools whose stochastic productivity evolves endogenously over time. Consumption-good firms buy machines and combine them with labour in order to produce a homogeneous, quality-differentiated good for workers/consumers. The banking sector is represented by a fixed number of banks collecting deposits and providing interest-paying loans to finance firms' production and investment plans. Workers apply for jobs, and firms hire workers 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 and banks profits, pays unemployment benefits, imposes a minimum wage, absorbs excess profits and losses from the central bank and keeps a non-explosive public debt trajectory in the long run. Further details on the base labour-augmented K+S model can be obtained in Dosi et al. (2020). From here we focus on the changes and additions implemented in the model to support the analysis presented next.

For the current analysis, we extend the K+S base to support open-economy countries that trade capital goods (machines) under a single currency, labour markets are segmented, governments are responsible for educational policies which define worker qualification distribution, and workers migrate to escape unemployment. In particular, we configure a two-country, North-South arrangement, wherein a laggard and a leader country interact. Both countries present identical internal organizations (Figure 1), differentiated only in terms of the government expenditure on education. A larger share of the GDP expended in educational policy translates into more years of schooling and higher qualification for future workers. Firms demand differentiated worker profiles, according to the

[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.

technologies they master. Firms with more qualified workforce are able to exploit more productive techniques, and to be more competitive. Capital-good firms of both countries can export machines to consumption-good firms worldwide, as per Figure 2, and may try to imitate superior technologies developed by foreign firms.

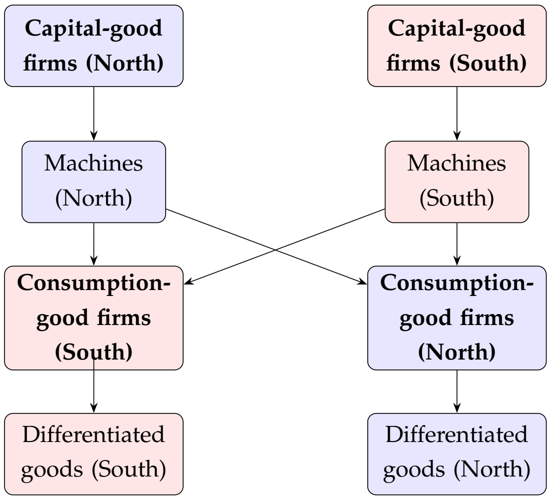


Figure 2: Operation of the North-South capital-goods trade.

The model extension strategy is presented in Figure 3. In what follows, we describe in detail these extensions and the economic processes they involve, that is, the interplay between education development and productivity dynamics, the new segmented search-and-match labour market mechanism, and the international trade of machines.

Therefore, in each simulated period of the new model, the following events take place in order:

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

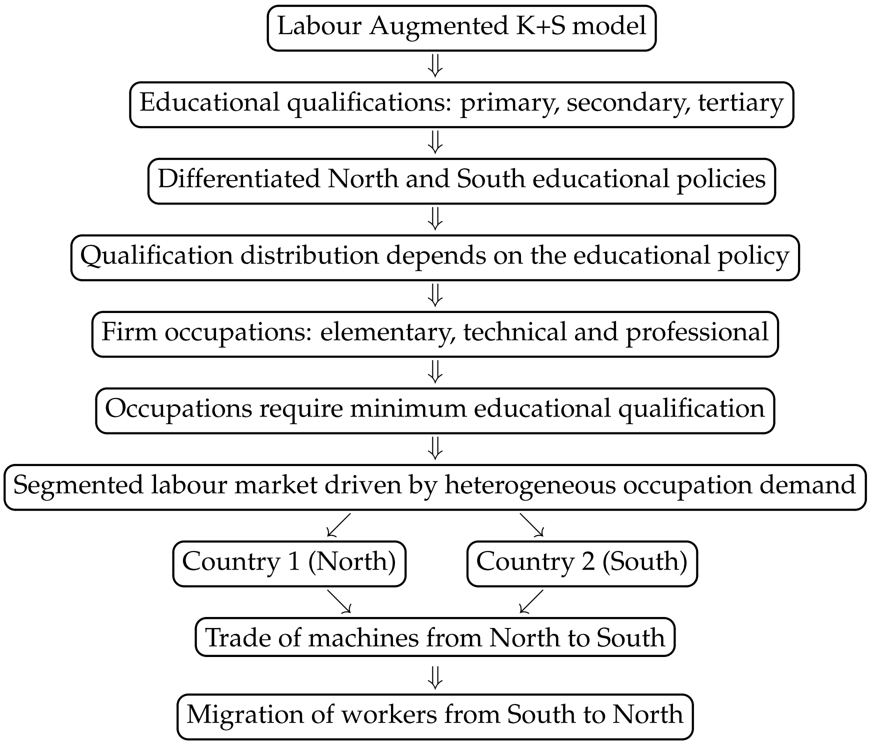


Figure 3: Strategy of extensions proposed to the original K+S model.

3.1 Education attainment and productivity

Workers in the model receive a variable level of formal education. The individual attainment is measured in terms of years of schooling $ed_\ell \in [0, 16]$, attributed to each worker ℓ in the labour market, and differentiated in three general levels of education: (1) primary ($ed_\ell \leq 8$), (2) secondary ($8 < ed_\ell \leq 12$), and (3) tertiary ($ed_\ell > 12$).[3] After schooling, workers enter the labour market having a fixed working lifetime $T_r \in \mathbb{N}$, a parameter, before retiring. Every retired worker is replaced by a freshly-educated one.

Education is publicly and freely provided by the government by allocating a share G_t^{ed} of the GDP for public expenditure in education:

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

$\epsilon_{ed} \in [0, 1]$ is a parameter, and Y_t is the nominal GDP. To obtain an educational attainment profile which is proper to an advanced country, the government must spend a share equal to ϵ_{ad}, a parameter in $[0, 1]$, every year.[4] So, if the ratio $\epsilon_{ed}/\epsilon_{ad} < 1$, the expected educational attainment distribution is left-skewed in comparison to an advanced country, and conversely.

[3]The maximum value corresponds to 16 years of schooling, excluding repetitions, which is the equivalent to achieving a bachelor degree in many countries. In very rough terms, the years of schooling are cumulatively composed by 8 years of primary (elementary) education, 4 of secondary (intermediary), and 4 of tertiary (university).

[4]The advanced country profile used for calibrating the model assumes 16% of population has no or just primary education (complete or not), 58% achieved the secondary level, and 26%, the tertiary (Barro and Lee, 2013).

To represent the effect of public expenditure on education, for each worker ℓ entering the labour market in t, the education level is drawn from a Beta distribution with the support proportionally adjusted to the (past) government expenditure:

$$ed_\ell \sim 16 \text{ beta}\left(g\, \alpha_{ed}, \beta_{ed}/g\right), \qquad g = \left(\frac{\epsilon_{ed}}{\epsilon_{ad}}\right)^{\vartheta_{ed}}, \tag{2}$$

where $(\alpha_{ed}, \beta_{ed}) \in \mathbb{R}^2_+$ are parameters defining the Beta probability density function 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 $\epsilon_{ed} \neq \epsilon_{ad}$. We empirically calibrate the parameters shaping the Beta distribution using data from Barro and Lee (2013).

Country R&D performance is influenced by the education expenditure, which modulates the probability for firm i to obtain access to innovation ($\theta^{in}_{i,t}$) and imitation ($\theta^{im}_{i,t}$):

$$\theta^{in}_{i,t} = 1 - e^{-\zeta_1\, g\, IN'_{i,t}}, \tag{3}$$

$$\theta^{im}_{i,t} = 1 - e^{-\zeta_2\, g\, IM'_{i,t}}. \tag{4}$$

$(\zeta_1, \zeta_2) \in \mathbb{R}^2_+$ are parameters, and $(IN'_{i,t}, IM'_{i,t})$ are the standardized share of workers allocated to innovative and imitative R&D activities, respectively.[5]

Worker ℓ individual (fixed) education level ed_ℓ drives consumption-good firm productivity and, together with the current accumulated skills $s_{\ell,t}$ (i.e. learning-by-doing), define her individual labour productivity:

$$A_{\ell,t} = \frac{s_{\ell,t}}{\bar{s}_t} A^\tau_i \left(\frac{ed_\ell}{\overline{ed}_{ad}}\right)^{\tau_{ed}}, \tag{5}$$

where $\bar{s}_t$ is the average overall skill level, and A^τ_i, the standard notional productivity of the specific machinery vintage that the worker is using for the operation she is involved in.[6] $\tau_{ed} \in \mathbb{R}_+$ a scaling parameter defining the intensity of a deviation from the expected education level of an advanced country $\overline{ed}_{ad} = 16\, \alpha_{ed}/\left(\alpha_{ed} + \beta_{ed}\right)$, as defined in Eq. 2.

Capital-good sector productivity is affected by labour force education as well:

$$B_{i,t} = B^\tau_i \left(\frac{ed^1_{t-1}}{\overline{ed}_{ad}}\right)^{\tau_{ed}}, \tag{6}$$

where $B_{i,t}$ is the effective labour productivity of firm i to produce machines at time t, B^τ_i is the notional labour productivity to produce the current machine vintage (Dosi et al., 2010), and ed^1_t, the average education level of workers in capital-good sector.

3.2 Labour search-and-match dynamics

In the labour market, workers are grouped in three occupational categories $c = 1, 2, 3$, depending on the education level. Accordingly, firm labour demand $L^d_{j,t}$ in both capital- and consumption-good sectors (see Dosi et al. (2017) for details) is segmented:

$$L^{d,1}_{j,t} = \left(1 - \theta_2 - \theta_3\right) L^d_{j,t}, \qquad L^{d,2}_{j,t} = \theta_2 L^d_{j,t}, \qquad L^{d,3}_{j,t} = \theta_3 L^d_{j,t}, \tag{7}$$

[5] For details on otherwise unchanged technological dynamics on the K+S model, see Dosi et al. (2010).

[6] See Dosi et al. (2018) for details on the K+S learning-by-tenure process.

being $\theta_2, \theta_3 \in [0,1]$, $\theta_2 + \theta_3 \leq 1$, parameters, $L^{d,c}_{j,t}$, $c = 1,2,3$, the labour demand of firm j at time t for workers with primary-, secondary-, and tertiary-education, roughly corresponding to elementary, technical, and professional occupations, respectively. R&D labour demand in capital-good sector consists of tertiary-education ($c = 3$) workers only.

Firms in both sectors decide whether to hire (or fire) workers according to the expected production $Q_{i,t}$ or $Q^d_{j,t}$ (Dosi et al., 2010). If it is increasing, $\Delta L^{d,c}_{j,t} > 0$, $c = 1,2,3$, new workers on each category are (tentatively) hired in addition to the existing number $L^c_{j,t-1}$ 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 $f_{j,t-1}$:

$$\mathrm{E}(L^s_{j,t}) = \left[\omega\,(1 - U_{t-1}) + \omega_u U_{t-1}\right] L^S f_{j,t-1}, \tag{8}$$

where $L^S \in \mathbb{N}$ is the (fixed) total labour supply, U_t is 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 queues into three sub-queues, according to the worker category c. Considering the set of workers in the sub-queues $\{\ell^{s,c}_{j,t}\}$, each firm select the subsets of desired workers $\{\ell^{d,c}_{j,t}\}$ to make a job (wage) offer:

$$\{\ell^{d,c}_{j,t}\} = \{\ell_{j,t} \in \{\ell^{s,c}_{j,t}\} : w^r_{\ell,t} \leq w^{o,c}_{j,t}\}, \quad c = 1,2,3. \tag{9}$$

Firms in consumption-good sector target those workers that would accept the wage offer $w^{o,c}_{j,t}$ corresponding to the worker category, 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 hiring process takes place one category at a time, from higher to lower education level (i.e., $c = 3,2,1$). Remaining open positions in level $c+1$ are transferred to the labour demand $L^{d,c}_{j,t}$ of the level c immediately below, if any.[7] Firm j hires up to the total demand $L^{d,c}_{j,t}$ for each category or up to all workers in each sub-queue, whichever is lower. The total number of workers $L_{j,t} = \sum_{c=1}^{3} L^c_{j,t}$ the firm will employ in t, given the current workforce $L_{j,t-1}$, is bound by:

$$0 \leq L^c_{j,t} \leq L^{d,c}_{j,t} \leq L^{s,c}_{j,t}, \qquad L^{z,c}_{j,t} = L^c_{j,t-1} + \#\{\ell^{z,c}_{j,t}\}, \qquad z = d,s, \quad c = 1,2,3. \tag{10}$$

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

$$w^{o,1}_{j,t} = \min\left(\left[1 + WP_{j,t}\right] w^{o,1}_{j,t-1}, \quad p_{j,t-1} A_{j,t-1}\right), \tag{11}$$

$$w^{o,c}_{j,t} = \max\left(\left[1 + WP_{j,t}\right] w^{o,c}_{j,t-1}, \quad \left[1 + \phi_c\right] w^{o,c-1}_{j,t}\right), \qquad c = 2,3, \tag{12}$$

that are accepted by the worker if she has no better offer. The upper bound for category 1 wages is the break-even wage (zero-unit-profit myopic expectation) 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

[7] Firms may hire a set of workers with lower education than desired, to reduce the production losses associated to an open position. However, by hiring a worse mix of categories, worker productivity $A_{\ell,t}$ is reduced, according Eq. (5), in comparison to the desired labour segmentation.

parameters defining a lower bound to the wage-category structure. The wage premium $WP_{j,t}$ is based on the current growth rate of productivity at firm j and the country, and follows the rules defined in Dosi et al. (2017) as well the workers's reservation ($w^r_{\ell,t}$) and satisfying ($w^s_{\ell,t}$) wages.

An employed worker of category c accepts the best offer $w^{o,c}_{j,t}$, 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.

Laggard-country workers migrate to the leading one at a constant rate, so country y population evolves over time according to $\delta \in [-1, 1]$, a parameter:

$$L^S_{y,t} = (1 + \delta_y)\, L^S_{y,t-1}, \qquad y = 1, 2. \tag{13}$$

3.3 International trade and technical change

The two countries trade only capital goods (machines). Consumption-good exports are not considered. Countries share the same currency, so no exchange rate is required, and there are no import tariffs. Capital-good market operates under imperfect information, as suppliers send brochures to clients in all countries to advertise their machines, and prospect clients can only acquire machines from suppliers they got brochures. The origin country of machine is not considered, as there are no additional costs or delays for imported machines. Therefore, the machine market dynamics is similar to the one introduced in Dosi et al. (2010).

Machine exports $X^1_{y,t}$, by capital-good firms, and imports $Im^2_{y,t}$, by consumption-good ones, define country y balance of trade (or net exports):

$$X^{net}_{y,t} = X^1_{y,t} - Im^2_{y,t}, \qquad \sum X^{net}_{y,t} = 0, \qquad y = 1, 2. \tag{14}$$

As the model is stock-flow consistent at the world level, the total net exports must add up to one.

The technology of capital-good firms evolve in an international set-up. Firms may try to imitate machines developed in other countries, closely following the process defined in Dosi et al. (2010). The origin of technology has no effect in the imitation-search process. Imitation success probability is inversely proportional to the technological gap between imitating and imitated firms, but considering the international market to define the standardized references to machine price (p^*_t) and unit operating cost (c^*_t) for clients. However, once firm i succeeds on imitating a foreign firm h, the different education profiles between the host countries imply in distinct absorptive capacities:

$$A^{im}_{i,t} = \frac{g_i}{g_h} A_{h,t-1}, \tag{15}$$

$$B^{im}_{i,t} = \frac{g_i}{g_h} B_{h,t-1}. \tag{16}$$

$(A_{i,t}^{im}, B_{i,t}^{im})$ are the productivities achieved by firm i when imitating firm h machines defined by $(A_{h,t-1}, B_{h,t-1})$. (g_i, g_h) are the relative-adjusted government expenditures g of the countries where firms i and h are established, as defined in Eq. 2.

This concludes the extensions introduced in the K+S models for this paper. An in-depth presentation of the remaining model behavioural rules, not modified here, can be found in Dosi et al. (2010, 2015, 2017, 2018).

In Appendix A, we perform an extensive sensitivity analysis of the extended model, to further understand the consequences of extensions and the impact of new and existing parameters on the new model's results. The parameter and initial condition values, as well the stock-flow consistency matrices, are presented in Appendix B.

4 Model validation and stylized facts identification

The extended model proposed above is run for 500 time periods, which is sufficient to robustly characterize the statistical properties of interest.[8] As the model includes stochastic (random) components, a multi-run Monte Carlo (MC) experiment is performed to properly assess results.[9]

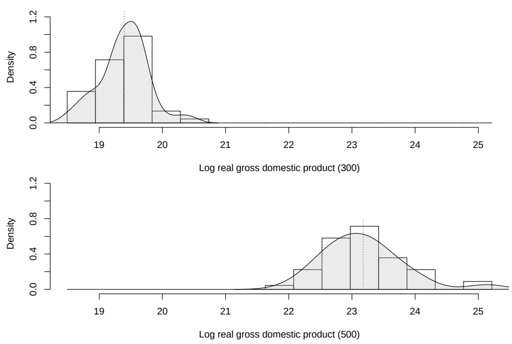
In order to validate the model set-up, we provide an overview of the results showing the asymmetries deriving from the *only* initial difference between countries, the value of parameter ϵ_{ed} which governs the total educational expenditure. Figure 4 report systematic and persistent distributional differences in terms of GDP and productivity between the North (country 1) and the South (country 2). To understand how the model reacts to the different educational profiles, we show the density distribution of real GDP and aggregate labour productivity for both countries at period $t = 200$ (panel a) and period $t = 300$ (panel b), from a 50 Monte Carlo (MC) run experiment.[10]

Notably, in Figure 4 panels (a) and (b), the GDP of the North (leader) country (North) presents more symmetric distributions and higher means as compared to South (laggard) country. The latter shows more right-skewed distributions, with pronounced left-tails. Looking at the aggregate productivity in panels (c) and (d), which include capital- and consumption-good firms, a similar skewness distinction characterizes the two countries, but with a less clear difference on the means, even on the long run. The access to high-productivity imported machines by the Southern firms that survive seems to prevent the divide here but cannot avoid the wider distribution supports. Despite these, a pattern of leader-laggard dynamics emerges in terms of comparative country performance, and in the South, with a more likely very low-end productive trajectory in a number of simula-

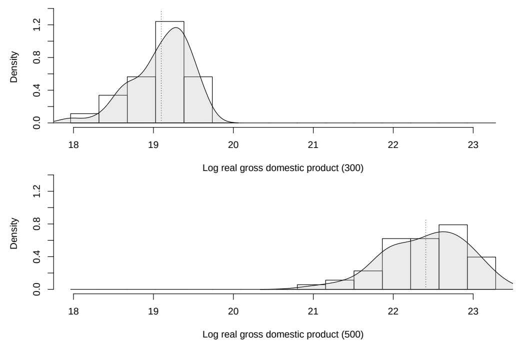
[8]The first 100 "warm-up" simulated periods are discarded these from the analysis, to allow for proper model "beak-in" from initial conditions before introducing country differentials. For convenience, in all references below, $t = 1$ effectively corresponds to period 101 of the simulation.

[9]Considering the properties of the time series of interest here, a MC sample of size 50 was deemed sufficient for the current analysis.

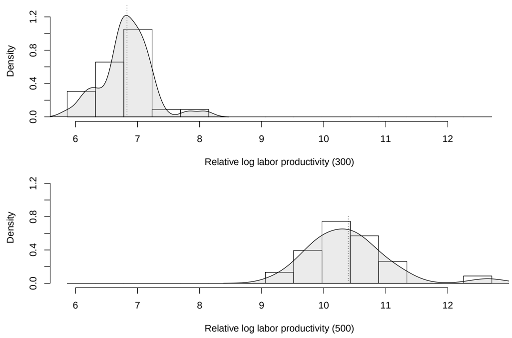
[10]The different parametrization between countries is only introduced at $t = 1$. To ensure an unbiased comparison, machine trade and migration are enabled also at this time.



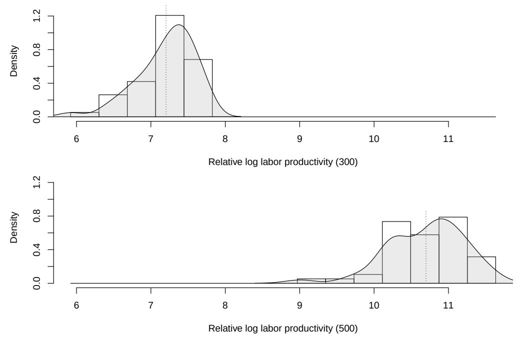
(a) North (leader) country GDP



(b) South (laggard) country GDP



(c) North (leader) country productivity



(d) South (laggard) country productivity

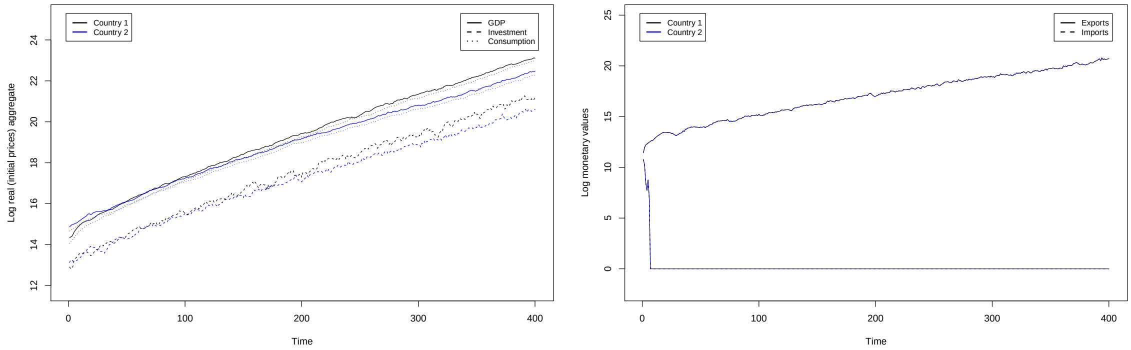
Figure 4: Country asymmetries in GDP and productivity distributions.
Results from 50 Monte Carlo runs, $t = 200, 400$ (upper, lower), means at dotted line.

tion runs. Remarkably, such asymmetries uniquely derive from the different educational setting.

The leader-laggard patterns are empirically in line with the advanced economies experiencing relative slowdown and weakening of (part of) the productive structure (Berlingieri et al., 2017). In such cases, forms of neo-dualism seem embedded both within industries and across geographical areas. Therefore, the coexistence of a group of dynamic firms, the so called "gazelles", and a larger group of less performing ones, the "turtles" (Dosi et al., 2012, 2021), undermines the overall country growth performance.

The distinctive macro-level trajectories are shown in Figure 5 where GDP, and domestic and international demand components are presented. The artificial time series show distinct growth paths over time, with increasing divergence in both internal aggregate demand components, i.e., consumption and investment. However, the macro-level dynamics is also affected by the imports and exports of machines. Indeed, the North completely and quickly dominates the exports of capital-goods, while the South becomes mainly a machine importer, despite the persistence of a few small domestic producers.

The initial results hint that the North benefits from an absolute factor advantage out of the education of the workforce, and the ensuing labour market operation. Higher overall years of schooling bring an increased probability to successfully innovate and, in particular, imitate, due to superior absorptive capabilities. This pushes the productivity ladder



(a) Real GDP, investment, consumption

(b) Exports and imports

Figure 5: Country asymmetries in macro-variable time trajectories.
Medians from 50 Monte Carlo runs, excluding warm-up period.
Country colour: North (1) black, South (2) blue.

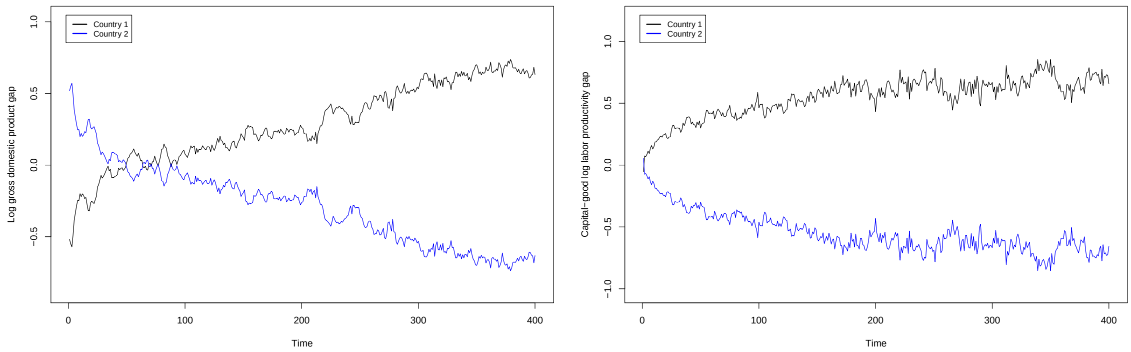
worldwide, because of the technology-embedded machine exports, despite the stronger domestic effects reducing the low-end productivity dispersion. Yet, new technology discoveries are completely concentrated in the North, letting the southern capital-good producers dependent on (unlikely) imitation of northern competitors. However, the import of capital-goods by the southern consumption-good firms also represents a possibility for the South to benefit from innovations of the North. This is the main reason for, although a persistent leader-laggard dynamics in the international trade of machines, the South still presents a comparable growth trajectory in the internal components of demand dominated by consumption goods.

We now investigate the asymmetric trajectories of the North and the South using a measure of the relative gap, computed for each country as the ratio of the difference between the variable of interest in the North (Var_N) and in the South (Var_S), using the level in the North as reference. So, $gap_N = (Var_N - Var_S)/Var_N$ is the gap from the North country perspective and, conversely, $gap_S = -gap_N$ is the South's take. An increasing trend of the absolute gap indicates a growing divergence.

Starting from Figure 6, the persistent gaps in terms of aggregate performance outcomes, that is GDP (panel a)[11], and labour productivity on capital-good sector (panel b) are evident. The model endogenously reproduces a North-South or leader-laggard dynamics in line with the evolutionary theory on technology gaps and growth differentials across countries (Fagerberg, 1987; Cimoli, 1988; Fagerberg, 1994; Botta, 2009).

The North-South pattern is also reflected in the labour market outcomes, such as the unemployment and vacancy rates for each type of occupations (elementary, technical, professional) based on the education attainment (primary, secondary, tertiary), as shown in Figure 7. In particular, at the country level the model reproduces a persistent structural unemployment rate for lower-level occupations in the laggard country matched. Associated

[11]The initial GDP advantage of the South is due to the mismatch of the firms demand for specialized labour, because of the change in educational expenditure, leading to short-term (technical/professional) labour shortages in the consumption-good sector of the North, the largest contributor to the GDP.



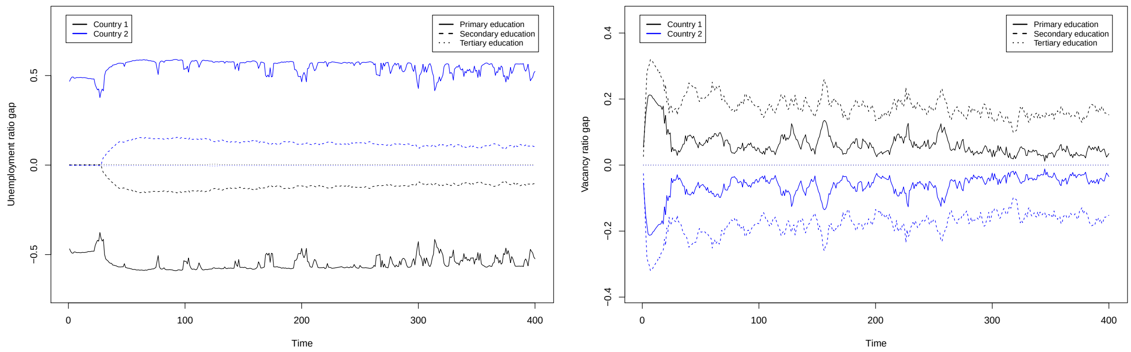
(a) GDP gap **(b)** Productivity gap (capital-goods only)

Figure 6: Country gaps in GDP and productivity.
Time-series medians from 50 Monte Carlo runs, excluding warm-up period.
Country colour: North (1) black, South (2) blue.

to a reduced number of vacancies, there is a negative correlation between unemployment and vacancy rates, in line with the empirical evidence on the Beveridge curve, and with the usual results of the original labour-augmented K+S model (Dosi et al., 2017).

At the cross-country level, Figure 7 presents a considerable gap between the leader and the laggard in terms of unemployment rate (panel a), negatively correlated with the occupation level. Is also shows a persistent but slowly shrinking gap in vacancy rates (panel b). The gap is particularly pronounced for technical occupations requiring secondary or higher education, highlighting the limited capacity for absorption of technical workers in the southern labour market, mainly due to the mismatch produced by the scarcity of professional workers required by the more advanced technologies. Therefore, the segmented labour market reveals to be an adequate set-up in order to characterize the different exposure to unemployment according to the occupational status. While professional-occupation categories are almost insensitive to unemployment, low elementary workers are those most exposed to the negative labour market outcomes (Biagi and Lucifora, 2008; Riddell and Song, 2011; Berghammer and Adserà, 2022).

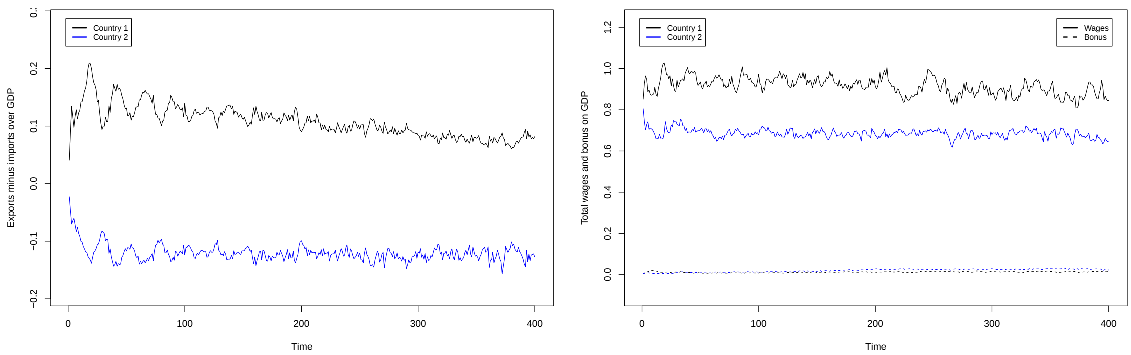
Looking at trade imbalances between the two countries (Figure 8), a persistent North-South dynamics with an emerging net exporter (or importer) manifests (panel a) (Cimoli et al., 1990; Cimoli and Porcile, 2010). Notably, the North (South) is also the country recording a relatively higher (lower) wage share (panel b), with a persistent functional gap in income distribution (Fanti, 2021; Riccio et al., 2022). What factors trigger such dynamics? The lower education expenditure in the South results in a worse workforce occupational profile, with a lower share of qualified workers and the prevalence of a primary-education, low-pay working class. At the macroeconomic level, the labour market segmentation leads, in turn, to a higher probability for the laggard country of being technologically dependent in terms of the capital goods required to produce the consumption ones. Machines are indeed mostly imported instead of being domestically produced. The channel from structural, supply-side conditions, that is workforce qualification and technological advancement, reverberate into demand-side outcomes, that is, the import of machines



(a) Unemployment gap by occupation **(b)** Vacancy gap by occupation

Figure 7: Country gaps in unemployment and vacancy.
Time-series medians from 50 Monte Carlo runs, excluding warm-up period.
Country colour: North (1) black, South (2) blue.

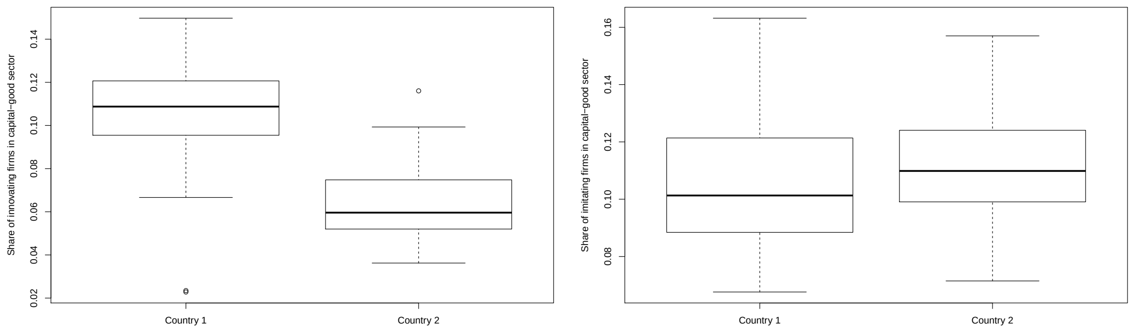
and, notably, a different pattern of income distribution, biased in disfavour of workers in the South.



(a) Balance of trade **(b)** Wage share

Figure 8: Country performance in trade and wages as share of GDP.
Time-series medians from 50 Monte Carlo runs, excluding warm-up period.
Country colour: North (1) black, South (2) blue.

The South country does indeed try to catch up via imitation activities, even though they most frequently are not successful. Indeed, the inferior absorptive capabilities (Equations 15 and 16), derived from the lower domestic education expenditure, will lead firms to face higher constraints to innovate and imitate. As a result, southern firms are typically in a disadvantage position to compete in the domestic and international markets. These results are corroborated by the distinct innovation and the imitation rates of the two countries. According to Figure 9, northern capital-good firms show, on median, a substantially higher innovation rate (panel a) when compared to the southern ones. Nevertheless, the latter try to catch up with the former through (international) imitation, slightly more effective in the South (panel b). However, a higher imitation rate simply means this is the main progress path to southern firms, given the structural constraint on innovation. The composed technical advancement pace (share of innovating plus imitating firms) is still considerably more favourable to the North.



(a) Innovating-firm share

(b) Imitating-firm share

Figure 9: Country share of innovating and imitating firms in capital-good sector.
Distributions from 50 Monte Carlo runs, $t \in [201 - 400]$.
Bar: medians, box: 2nd/3rd quartiles, whiskers: minimum/maximum, points: outliers.
Country number: North (1), South (2).

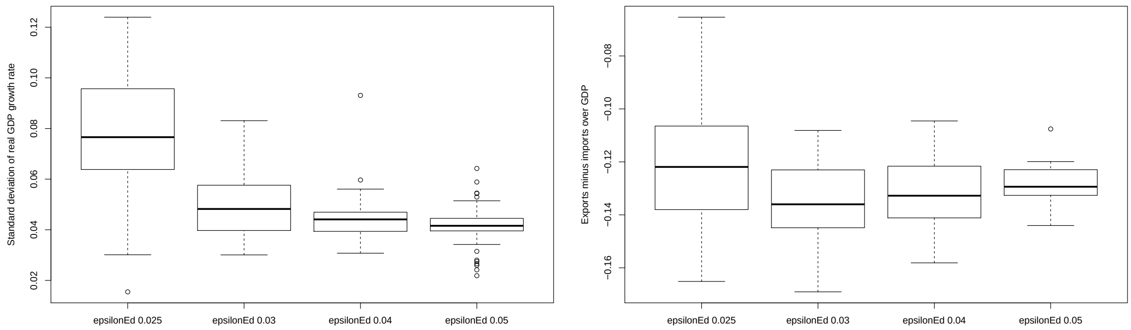
According to this first battery of results, differentiated long-term aggregate levels of public expenditure in education significantly affect segmented labour markets, by means of worker educational attainment, the corresponding occupation qualifications, and, endogenously, the differentiated exposure to unemployment. In addition, the education-induced asymmetries between countries results on the technological dependence of the South, which falls behind of the North in terms of macroeconomic performance. To summarize, vis-à-vis the original labour-augmented K+S model's set of stylized facts (SFs), the new model extension allows the match of the following set of additional SFs:

- **SF1:** technological dependence as a source of weaker aggregated performance;
- **SF2:** negative correlation between educational attainment and unemployment;
- **SF3:** technological innovation as a source of divergence among countries;
- **SF4:** negative correlation between the wage share and the level of development;
- **SF5:** failure of catching-up via technology-embedded import strategies.

5 Policy experiments: the role of education and international imitation

Given the important role played by parameter ϵ_{ed} (share of GDP expended in education) on the model dynamics, we now perform a set of policy experiments based on it. Firstly, we investigate its role on the main macroeconomic variables in the South.

Figure 10 shows the distribution of GDP growth volatility (panel a) and trade balance (panel b) for four levels of expenditure, $\epsilon_{ed} = 0.025, 0.03, 0.04, 0.05$, in the South country. We compare the baseline value (0.04) used in the analysis above with three alternative scenarios: the same expenditure as in the North (0.05), and two lower values (0.03 and 0.025). The different gaps in education level affect the volatility of GDP growth, measured as the



(a) GDP volatility **(b)** Balance of trade

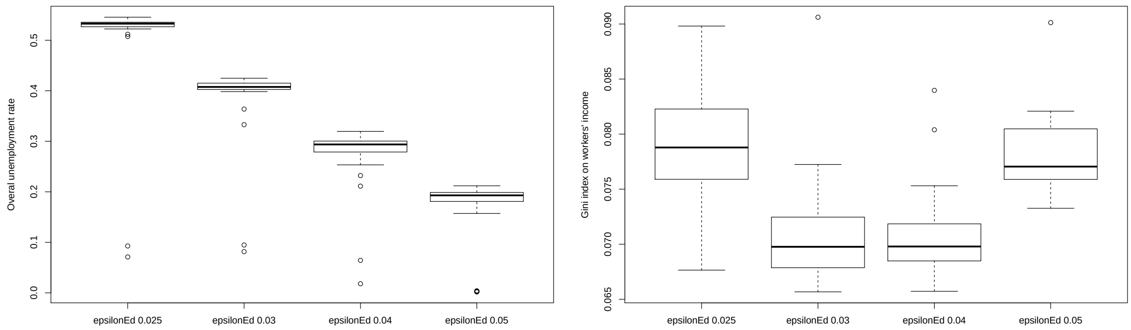
Figure 10: South-country domestic and international macroeconomic performance for alternative educational expenditure as share of GDP ($\epsilon_{ed} = 0.025, 0.03, 0.04, 0.05$).
Distributions from 50 Monte Carlo runs, $t \in [201 - 400]$.
Bar: medians, box: 2nd/3rd quartiles, whiskers: minimum/maximum, points: outliers.

standard deviation, which shows an overall negative correlation. Such result replicates only partially in the case of the balance of trade (exports minus imports), as the distribution supports of net exports increased as the education expenditures shrank. The median net exports, however, remained relatively constant across scenarios. The very fact that trade balance presents a negative value even under the same education levels reflects the inner idiosyncratic dynamics of trade in the model, that endogenously reproduces and accumulates asymmetries as an emergent property, even in the absence of initial differences among countries. Therefore, the trade dynamics is also the result of a self-reinforcing, path-dependent phenomenon occurring by the cumulative stratification of loosing and winning positions between countries, in line with (Dosi et al., 2019).

The effects of educational policy on labour market is also important, as shown in Figure 11, whereby (panel a) there is a clear negative correlation between the overall unemployment rate and education attainments. When looking at inequality among workers (panel b), however, the Gini index shows a U-shaped relation with education. This result broadly mimics the known relationship between inequality and stage of development (Imbs and Wacziarg, 2003), hereby using the education as proxy. Such observation derives, in the model, from the relative concentration, in the South, of higher wages among the (few) employed vis-à-vis the (many) unemployed workers (as per panel a in Figure 7).

In a second analytical step, we investigate the role of international imitation for the build-up of countries asymmetries and divergence. For that, we introduce a counterfactual set-up, that is, a scenario wherein international imitation (the model baseline) is not allowed. We look at the effect of international or domestic-only imitation on crucial macroeconomic outcomes, as GDP growth, trade balance, and successful innovation and imitation rates, of the South.

Figure 12 shows that, in the baseline scenario (international imitation), the persistent technological dependence from the North implies on the South falling systematically behind in regard to both growth and exports. A classic path-dependent lock-in situation is

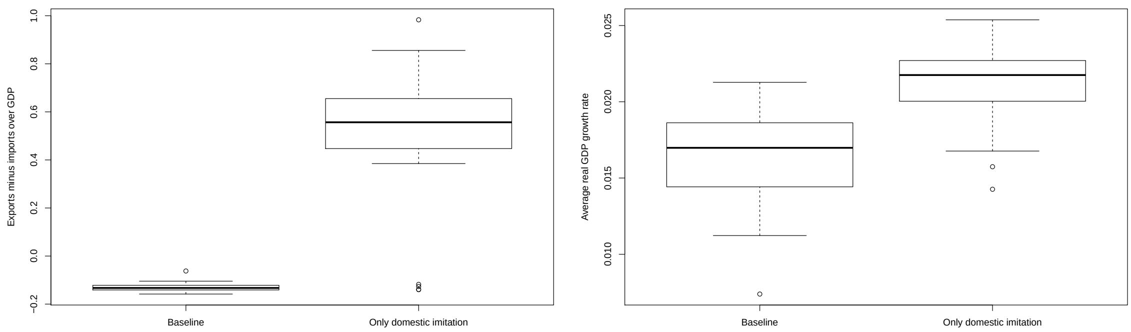


(a) Unemployment rate

(b) Gini index on worker income

Figure 11: South-country unemployment and inequality performance for alternative educational expenditure as share of GDP ($\epsilon_{ed} = 0.025, 0.03, 0.04, 0.05$).
Distributions from 50 Monte Carlo runs, $t \in [201 - 400]$.
Bar: medians, box: 2nd/3rd quartiles, whiskers: minimum/maximum, points: outliers.

established here (Arthur, 1989), with little opportunity for the laggard country to reclaim the leading position.

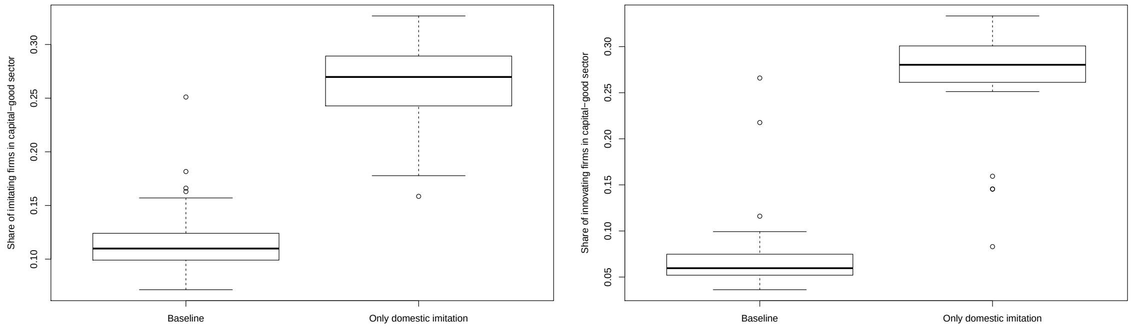


(a) Balance of trade

(b) GDP growth

Figure 12: South-country domestic and international macroeconomic performance for alternative technological imitation scenarios (international/baseline vs. domestic only).
Distributions from 50 Monte Carlo runs, $t \in [201 - 400]$.
Bar: medians, box: 2nd/3rd quartiles, whiskers: minimum/maximum, points: outliers.

However, counter-intuitively, when southern firms only have the possibility of imitating the machines produced by a domestic leader technologically closer to them, they have a higher probability of imitation success because of the reduced requirements in terms of absorptive capabilities. Indeed, Figure 13 shows a more than two-fold increase in the share of firms that successfully imitate (panel a). In turn, a larger population of firms closer to the (domestic) technological frontier increase also the probability of successful innovations (panel b). In aggregate terms, this continuous feedback process may induce a virtuous development pattern with the possibility of the country not only reaching technological independence, at a certain point, but also of becoming the leader in international trade. The South technological "segregation" may help it on avoiding the lock-in, in a similar process to the one described by the *local productive arrangement* literature (Lastres and Cassiolato, 2005). Indeed, as pointed in Figure 12, a dense network of local imitation may turn out to be effective in reverting the trade balance deficit in this case (panel a) and spur growth (panel b).



(a) Imitating-firm share

(b) Innovating-firm share

Figure 13: South-country innovative performance for alternative technological imitation scenarios (international/baseline vs. domestic only).
Distributions from 50 Monte Carlo runs, $t \in [201 - 400]$.
Bar: medians, box: 2nd/3rd quartiles, whiskers: minimum/maximum, points: outliers.

From a policy perspective, these results are in line with the evolutionary literature suggesting the relevance of policy programs aimed at favouring industrial interventions targeted to country- and sector-specific technological and capability profiles (Cimoli et al., 1990; Dosi et al., 2009) within comprehensive institutional ecosystems, such as National or Sectoral Innovation Systems (Lundvall, 1992; Freeman, 2002).

6 Conclusions

Building on the labour-augmented K+S model, we propose one of the first agent-based models able to investigate the role of education and international trade on North-South type of asymmetries, and on the convergence-divergence patterns between leader and laggard countries. We start by differentiating the two regions/countries in terms of the aggregate investment in education in order to study how different educational profiles of the workforce may reverberate on both technological and production aggregate performance and labour market structure and dynamics.

To this purpose, we explicitly introduce segmented labour markets leading to different dynamics in terms of market outcomes. Our results show that differences in the educational attainments of workers persistently affect North-South asymmetries in terms of macroeconomic performance, balance of trade and labour market operation. In particular, the dynamic feedback effects endogenously reproduced by the simulation model propagate through different and interrelated channels, that is from education to imitation-innovation processes and to labour market operation; from innovation to international trade patterns; and from labour market and trade to GDP and aggregate productivity growth trajectories.

We perform a some policy experiments based on the amount of public expenditure in education. This way, we can corroborate the negative impact exerted by lower educational attainments on aggregate performance and, particularly on GDP growth volatility and trade deficits, innovation and imitation success rates, and labour market outcomes. We also investigate the role of international or domestic-only imitation to study possible catching-up opportunities. We show that, when restricting international imitation, a reverse specialization pattern may emerge, with the South reclaiming a leadership position on the trade of machines while spurring growth. Notably, this result is the outcome of a laggard country which indeed posses industrial and productive capabilities at a crossroad: should it try to rebuild the internal productive structure, or abandon it in favour of external technological dependence?

Indeed, in terms of the validity of the model results, and the ensuing policy implications, the recent Inflation Recovery Act and the Chips and Science Act, promoted by the US, are nothing else than industrial policies aimed at rebuilding the internal industry capabilities, in order to regain international relevance in the production and trade of strategic industrial intermediate products, now largely dominated by China. In this respect, our North and South regions should be interpreted as two relatively advanced countries, rather than a rich and a poor one. Here, the South is threatened by the possibility of being trapped into a middle-income stage, as occurred for many Latin-American and southern European countries. Notably, our South may represent also the possibility of successful catching-up strategies, as the Asian Tigers and China did, and, to a lesser extent, Mexico and the Visegrad countries.

Future extensions of the present model should entail the analysis of the effect of different policy-oriented strategies, in order to better explore into the alternatives of catching-up, and, at the opposite side, the risk of lock-ins.

References

Acemoglu, D. (2002). Directed technical change. *The Review of Economic Studies 69*(4), 781–809.

Adelman, I. (2001). Fallacies in development theory and their implications for policy. *Frontiers of development economics: The future in perspective*, 103–134.

Allen, J. and R. van der Velden (2001). Educational mismatches versus skill mismatches: effects on wages, job satisfaction, and on-the-job search. *Oxford Economic Papers 53*(3), 434–452.

Amsden, A. H. (1991). Diffusion of development: The late-industrializing model and greater east asia. *The american economic review 81*(2), 282–286.

Arthur, W. B. (1989). Competing technologies, increasing returns, and lock-in by historical events. *The economic journal 99*(394), 116–131.

Barro, R. (2013). Education and economic growth. *Annals of Economics and Finance 14*(2), 301–328.

Barro, R. and W. Lee (2013). A new data set of educational attainment in the world, 1950-2010. *Journal of Development Economics 104*, 184–198.

Becker, G. S. (1962). Investment in human capital: A theoretical analysis. *Journal of Political Economy 70*(5), 9–49.

Berghammer, C. and A. Adserà (2022). Growing inequality during the great recession: Labour market institutions and the education gap in unemployment across europe and in the united states. *Acta Sociologica 65*(4), 374–397.

Berlingieri, G., P. Blanchenay, and C. Criscuolo (2017). The great divergence (s). Technical report, OECD Science, Technology and Industry Policy Papers, No. 39, OECD Publishing, Paris.

Biagi, F. and C. Lucifora (2008). Demographic and education effects on unemployment in europe. *Labour Economics 15*(5), 1076–1101.

Botta, A. (2009). A structuralist north-south model on structural change, economic growth and catching-up. *Structural Change and Economic Dynamics 20*(1), 61–73.

Celi, G., A. Ginzburg, D. Guarascio, and A. M. Simonazzi (2019). *Crisis in the European Monetary Union. A Core-Periphery Perspective*. Routeledge.

Cetrulo, A., D. Guarascio, and M. E. Virgillito (2020). Anatomy of the italian occupational structure: concentrated power and distributed knowledge. *Industrial and Corporate Change 29*(6), 1345–1379.

Cimoli, M. (1988). Technological gaps and institutional asymmetries in a North-South model with a continuum of goods. *Metroeconomica 39*(3), 245–274.

Cimoli, M. and G. Dosi (1995). Technological paradigms, patterns of learning and development: An introductory roadmap. *Journal of Evolutionary Economics 5*(3), 243–268.

Cimoli, M., G. Dosi, and L. Soete (1990). Technological gaps, institutional differences and patterns of trade: a north-south model. In F. Arcangeli (Ed.), *Frontiers on Innovation Diffusion*. Oxford University Press.

Cimoli, M. and G. Porcile (2010). Specialization, wage bargaining and technology in a multigoods growth model. *Metroeconomica 61*(1), 219–238.

Cimoli, M. and G. Porcile (2014). Technology, structural change and bop-constrained growth: A structuralist toolbox. *Cambridge Journal of Economics 38*(1), 215–237.

Cincotti, S., M. Raberto, and A. Teglio (2022). Why do we need agent-based macroeconomics? *Review of Evolutionary Political Economy 3*(1), 5–29.

Cioppa, T. M. and T. W. Lucas (2007). Efficient nearly orthogonal and space-filling latin hypercubes. *Technometrics 49*(1), 45–55.

Cresti, L. and M. E. Virgillito (2022). Strategic sectors and essential jobs: a new taxonomy based on employment multipliers. *Available at SSRN*.

Cresti, L. and M. E. Virgillito (2023). Weak sectors and weak ties? labour dependence and asymmetric positioning in gvcs. Technical report, Laboratory of Economics and Management (LEM) Working Paper Series, Sant'Anna School of Advanced Studies.

Doeringer, P. and M. Piore (1985). *Internal Labor Markets and Manpower Analysis*. Routledge.

Dosi, G., M. Cimoli, and J. E. Stiglitz (2009). *Industrial Policy and Development: the Political Economy of Capabilities Accumulation*. Oxford University Press.

Dosi, G., G. Fagiolo, M. Napoletano, A. Roventini, and T. Treibich (2015). Fiscal and monetary policies in complex evolving economies. *Journal of Economic Dynamics and Control 52*, 166–189.

Dosi, G., G. Fagiolo, and A. Roventini (2010). Schumpeter meeting Keynes: A policy-friendly model of endogenous growth and business cycles. *Journal of Economic Dynamics and Control 34*(9), 1748–1767.

Dosi, G., R. B. Freeman, M. C. Pereira, A. Roventini, and M. E. Virgillito (2021). The impact of deunionization on the growth and dispersion of productivity and pay. *Industrial and Corporate Change 30*(2), 377–408.

Dosi, G., M. Grazzi, C. Tomasi, and Z. Alessandro (2012). Turbulence underneath the big calm? the micro-evidence behind italian productivity dynamics. *Small Business Economics 39*, 1043–1067.

Dosi, G., D. Guarascio, A. Ricci, and M. E. Virgillito (2021). Neodualism in the italian business firms: training, organizational capabilities, and productivity distributions. *Small Business Economics 57*, 167–189.

Dosi, G. and L. Marengo (2015). The dynamics of organisational structures and performances under diverging distributions of knowledge and different power structures. *Journal of Institutional Economics 11*(3), 535–559.

Dosi, G., L. Marengo, and M. E. Virgillito (2021). Hierarchies, knowledge, and power inside organizations. *Strategy Science 6*(4), 371–384.

Dosi, G., R. Nelson, and S. Winter (2001). *The nature and dynamics of organizational capabilities*. OUP Oxford.

Dosi, G., K. Pavitt, and L. Soete (1990). *The Economics of Technical Change and International Trade*. New York University Press, Washington Square, New York.

Dosi, G., M. C. Pereira, A. Roventini, and M. E. Virgillito (2017). When more Flexibility Yields more Fragility: the Microfoundations of Keynesian Aggregate Unemployment. *Journal of Economic Dynamics and Control 81*, 162–186.

Dosi, G., M. C. Pereira, A. Roventini, and M. E. Virgillito (2018). Causes and consequences of hysteresis: aggregate demand, productivity, and employment. *Industrial and Corporate Change 27*(6), 1015–1044.

Dosi, G., M. C. Pereira, A. Roventini, and M. E. Virgillito (2019). What if supply-side policies are not enough? the perverse interaction of flexibility and austerity. *Journal of Economic Behavior & Organization 162*, 360–388.

Dosi, G., M. C. Pereira, A. Roventini, and M. E. Virgillito (2020). The labour-augmented k+ s model: a laboratory for the analysis of institutional and policy regimes. *EconomiA 21*(2), 160–184.

Dosi, G., M. C. Pereira, and M. E. Virgillito (2018). On the robustness of the fat-tailed distribution of firm growth rates: a global sensitivity analysis. *Journal of Economic Interaction and Coordination 13*(1), 173–193.

Dosi, G., F. Riccio, and M. E. Virgillito (2021). Varieties of deindustrialization and patterns of diversification: why microchips are not potato chips. *Structural Change and Economic Dynamics 57*, 182–202.

Dosi, G., F. Riccio, and M. E. Virgillito (2022). Specialize or diversify? and in what? trade composition, quality of specialization, and persistent growth. *Industrial and Corporate Change 31*(2), 301–337.

Dosi, G. and A. Roventini (2019). More is different... and complex! the case for agent-based macroeconomics. *Journal of Evolutionary Economics 29*, 1–37.

Dosi, G., A. Roventini, and E. Russo (2019). Endogenous growth and global divergence in a multicountry agent-based model. *Journal of Economic Dynamics and Control 101*, 101–129.

Dutt, A. (1989). Uneven development in alternative models of north-south trade. *Eastern Economic Journal XV*(2).

Fagerberg, J. (1987). A technology gap approach to why growth rates differ. *Research Policy 16*, 87–99.

Fagerberg, J. (1994). Technology and international differences in growth rates. *Journal of Economic Literature 32*, 1147–1175.

Fagerberg, J. and M. Godinho (2005). Oxford handbook of innovation. In J. Fagerberg and R. Mowery, D.C. andNelson (Eds.), *Technological change and Economic theory*. Oxford University Press.

Fagiolo, G., M. Guerini, F. Lamperti, A. Moneta, and A. Roventini (2017). Validation of agent-based models in economics and finance. Technical Report 2017/23, Laboratory of Economics and Management (LEM), Sant'Anna School of Advanced Studies, Pisa, Italy.

Fanti, L. (2021). 'kaldor facts' and the decline of wage share: An agent based-stock flow consistent model of induced technical change along classical and keynesian lines. *Journal of Evolutionary Economics 31*, 379–415.

Fanti, L., D. Guarascio, and M. Tubiana (2021). Skill mismatch and the dynamics of italian companies' productivity. *Applied Economics 53*(59), 6790–6803.

Fanti, L., M. Pereira, and M. Virgillito (2022). The north-south divide: sources of divergence, policies for convergence. *Journal of Policy Modelling*.

Freeman, C. (2002). Continental, national and sub-national innovation systems—complementarity and economic growth. *Research policy 31*(2), 191–211.

Hersch, J. (1991). Education match and job match. *Review of Economics and Statistics 73*(1), 140–144.

Hicks, J. (1953). An inaugural lecture. *Oxford Economic Pagers 5*, 117–135.

Hidalgo, C., B. Klinger, A. Barabási, and R. Hausmann (2007). The product space conditions the development of nations. *Science 317*(5837), 482–487.

Hirschman, A. (1958). The rise and decline of development economic. In M. Gersovitz, C. Diaz Alejandro, G. Rains, and R. Rosenzweig (Eds.), *The Theory and Experience of Economic Development*. George Allen and Unwin, London.

Hudson, K. (2007). The new labor market segmentation: Labor market dualism in the new economy. *Social Science Research 36*(1), 286–312.

Imbs, J. and R. Wacziarg (2003). Stages of diversification. *American economic review 93*(1), 63–86.

Johnson, H. (1950). Equilibrium growth in an international economy. *The Canadian Journal of Economics and Political Science 19*, 478–500.

Kim, S. and Y. Kim (2000). Growth gains from trade and education. *Journal of International Economics 50*(2), 519–545.

Kvangraven, H. (2020). Beyond the stereotype: Restating the relevance of the dependency research programme. *Development and Change 52*(1), 76?112.

Landesmann, M., S. Leitner, and R. Stehrer (2015). Competitiveness of the European economy. Technical Report 01, European Investment Bank (EIB).

Lastres, H. M. and J. E. Cassiolato (2005). Innovation systems and local productive arrangements: new strategies to promote the generation, acquisition and diffusion of knowledge. *Innovation: Management Policy and Practice 7*(2/3), 172–187.

Lee, K. (2013). *Schumpeterian Analysis of Economic Catch-Up*. Cambridge University Press.

Lewis, W. (1954). Economic development with unlimited supplies of labour. *Manchester School of Economic and Social Studies 21*, 139–191.

Lucas, R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics 22*, 3–42.

Lundvall, B. A. (1992). *National Systems of Innovation - Towards a Theory of Innovation and Interactive Learning*. London: Pinter Publishers.

Manning, R. (1982). Trade, education and growth: the small-country case. *International Economic Review 23*(1), 83–106.

Morris, M. D. (1991). Factorial sampling plans for preliminary computational experiments. *Technometrics 33*(2), 161–174.

Nelson, R. (1967, December). Technology gap: analysis and appraisal. Technical report, Conference paper.

Osterman, P. (1978). An empirical study of labor market segmentation. *ILR review 28*(4), 508–523.

Palley, T. I. (2012). The rise and fall of export-led growth. *Investigation Economica 71*(280), 141–161.

Pavlínek, P. (2018). Global production networks, foreign direct investment, and supplier linkages in the integrated peripheries of the automotive industry. *Economic Geography 94*(2), 141–165.

Posner, M. (1961). International trade and technological change. *Oxford Economic Paper 13*, 323–341.

Prebisch, R. (1950). Crecimiento, desequilibrio y disparidades: interpretación del proceso de desarrollo económico. *En: Estudio económico de América Latina, 1949-E/CN. 12/164/Rev. 1-1950-p. 3-89*.

Rasmussen, C. and C. Williams (2006). *Gaussian processes for machine learning*. Cambridge, MA: MIT Press.

Reich, M., D. Gordon, and R. Edwards (1973). A theory of labor market segmentation. *The American Economic Review 63*(2), 359–365.

Riccio, F., L. Cresti, and M. E. Virgillito (2022). The labour share along global value chains: Perspectives and evidence from sectoral interdependence. Technical report, Laboratory of Economics and Management (LEM) Working Paper Series, Sant'Anna School of Advanced Studies.

Riddell, W. C. and X. Song (2011). The impact of education on unemployment incidence and re-employment success: Evidence from the us labour market. *Labour Economics 18*(4), 453–463.

Rosentstein-Rodan, P. (1943). Problems of industrialisation of eastern and south-eastern europe. *The Economic Journal 53*(210/2011), 202–2011.

Salle, I. and M. Yildizoglu (2014). Efficient sampling and meta-modeling for computational economic models. *Computational Economics 44*(4), 507–536.

Saltelli, A., M. Ratto, T. Andres, F. Campolongo, J. Cariboni, D. Gatelli, M. Saisana, and S. Tarantola (2008). *Global sensitivity analysis: the primer*. New York: John Wiley & Sons.

Simonazzi, A., A. Ginzburg, and G. Nocella (2013). Economics relations between germany and southern europe. *Cambridge Journal of Economics 37*, 653–675.

Sobol, I. M. (1993). Sensitivity analysis for non-linear mathematical models. *Mathematical Modelling and Computational Experiments 1*(4), 407–414.

Stockhammer, E. (2011). Peripheral europe's debt and german wages. *International Journal for Public Policy 7*(1–3), 83–96.

Storm, S. and C. Naastepad (2015). Europes hunger games: Income distribution, cost competitiveness and crisis. *Cambridge Journal of Economics 39*(3), 959–986.

Tacchella, A., M. Cristelli, G. Caldarelli, A. Gabrielli, and L. Pietronero (2013). Economic complexity: conceptual grounding of a new metrics for global competitiveness. *Journal of Economic Dynamics and Control 37*(8), 1683–1691.

Taubman, P. and M. L. Wachter (1986). Segmented labor markets. In O. Ashenfelter and L. L. (Eds.), *Handbook of Labor Economics (vol. 2)*. North-Holland.

Taylor, L. (2004). *Reconstructing Macroeconomics: Structuralist Proposals and Critiques of the Mainstream*. Harvard University Press, Cambridge, MA.

Verspagen, B. (1993). *Uneven Growth Between Interdependent Economies: An Evolutionary View of Technology Gaps, Trade and Growth*. Ashgate Publisher.

Verspagen, B. (2002). Technology-gaps, innovation-diffusion and transformation: an evolutionary interpretation. *Research Policy 31*(8), 1291–1304.

Winter, S. G. (1997). Knowledge and competences as strategic assets. In A. Klein (Ed.), *The Strategic Management of Intellectual Capital*. New York: Elsevier Ed.

Appendix A

In addition to the empirical validation of the model, presented above, we perform a global sensitivity analysis (SA) to understand how alternative model parametrizations affect our main findings.[12]

Global sensitivity analysis (SA) is performed for $t \in [200, 400]$ on a set of output variables (the "metrics") relevant to the current discussion, namely net export (X_t^{net}) and unemployment rate for workers holding primary- (U_t^1), secondary- (U_t^2) and tertiary- (U_t^3) education.[13] All the model's parameter and initial condition values, test ranges, and SA statistics are presented in Table 1 on Appendix B. SA is performed across the entire parametric space, inside the closed ranges defined by Table 1 (columns MIN. and MAX.), and the synthetic SA statistics are reported (columns μ^*, DIRECT and INTERACTION) for the most sensitive among the tested output variables, that is the unemployment rate for primary educated workers (U_t^1) (results for the remaining variables can be requested to the authors). Two SA methodologies are employed, elementary effects (EE) and Sobol variance decomposition (SVD).

EE analysis is summarized by the μ^* statistic in Table 1, 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 three times, to compensate for stochastic components in the model.

The SVD analysis is reported in Table 1 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 Kriging meta-model fitted using samples from a near-orthogonal Latin hypercube DoE. Each DoE point is sampled 10 times. For all parameters and initial conditions reported in Table1 (the "factors") in this K+S version, as a first step we apply the Morris elementary effects (EE) method.[14] This is important because it allows identifying those factors which

[12] This procedure addresses a frequent criticism to ABM's concerning the importance of "lucky" parameter choices for the results. On the validation of agent-based models, see Fagiolo et al. (2017). For technical details on the employed SA methodology, see Dosi et al. (2018).

[13] Other relevant metrics, like macro aggregates, inequality measures, and industrial performance indicators were already SA-tested 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.

[14] Briefly, EE 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 (Morris, 1991; Saltelli et al., 2008).

significantly affect the selected model metrics. The EE analysis (Table 1) indicates that U_t^1 is the metric significantly sensitive to the larger number of factors (14).[15].

In order to quantify the effect of each relevant factor over the selected metrics, directly or in interaction with other factors, as a second step we perform a Sobol Variance Decomposition (SVD).[16] Because of the high computational cost to produce the SVD using the original simulation model, a simplified version of it — a meta-model — is estimated using the Kriging method and employed for the SVD.[17] 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 (Cioppa and Lucas, 2007).

The SVD results (Table 1) indicate a smaller subset of 4 *important* factors for two of the chosen metrics (U_t^1 and U_t^3).[18] These factors, in overall order of importance, define: (i) the amount of public expenditure in education which is proper to an advanced economy (ϵ_{ad}), (ii) the amount of public expenditure in education (ϵ_{ed}); iii) the shape of the Beta distribution from which the productivity of new entrant firms is randomly drawn (β_2); iv) the maximum technological advantage for new entrants in the capital-good sector (x_5). The first two factors were introduced for this version of the model and were expected to be relevant, as it is now confirmed. The last two parameters are usual important factors for many K+S variables, as identified by the literature (Dosi et al., 2018, 2021). The remaining two metrics (X_t^{net} and U_t^2) are not significantly sensitive to any factor in direct effect.

In summary, the model appears to be remarkably robust to different parametrizations, except for a few selected structural parameters. However, even the parameters which directly influence the analysed outcomes do that in a rather marginal manner.

[15] The selection criteria is to consider the top 80% EE contributors at 5% significance.

[16] 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. It allows to precisely disentangle both direct and interaction quantitative effects of the factors over the entire parametric space (Sobol, 1993; Saltelli et al., 2008).

[17] To summarize, the Kriging meta-model "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 (Rasmussen and Williams, 2006; Salle and Yildizoglu, 2014).

[18] The selection criteria is to consider the top 80% SVD contributors.

Appendix B

Symbol	Description	Value	Min.	Max.	μ^*	Direct	Interaction
Education							
ϵ_{ed}	Public education expenditure as share of GDP	0.050	0.010	0.100	0.584	0.258	0.001
ϵ_{ad}	Education expenditure of advanced country (%GDP)	0.050	0.040	0.100	0.584	0.276	0.001
ϑ_{ed}	Sensitivity of education attainment to expenditure	0.500	0.000	2.000	0.285	0.027	0.001
τ_{ed}	Leverage of education on productivity	0.500	0.000	2.000	0.160	0.010	0.001
$(\alpha_{ed}, \beta_{ed})$	Beta distribution parameters (education attainment)	(6.560,3.600)	(4.000,5.000)	(9.000,2.000)	(0.055,0.080)	(0.047,0.000)	(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)	(0.053,0.065)	(0.000,0.000)	(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)	(0.065,0.107)	(0.000,0.003)	(0.001,0.001)
Labour market							
δ	Growth rate of worker population (country 1/2)	(0.001,-0.001)	0.000	(0.001,-0.001)	-	-	-
ϵ	Minimum desired wage increase rate	0.020	0.005	0.200	0.020	0.007	0.001
τ_T	Skills accumulation rate on tenure	0.010	0.001	0.100	0.020	0.003	0.001
τ_U	Skills deterioration rate on unemployment	0.010	0.001	0.100	0.065	0.003	0.001
T_r	Number of periods before retirement (work life)	120	60	240	0.096	0.001	0.001
T_s	Number of wage memory periods	4	1	8	0.082	0.002	0.001
ω	Number of firms to send applications (employed)	5	1	20	0.035	0.000	0.001
ω_u	Number of firms to send applications (unempl.)	10	1	20	0.086	0.021	0.001
ψ_2	Aggregate productivity pass-trough	1.000	0.950	1.050	0.210	0.001	0.001
ψ_4	Firm-level productivity pass-trough	0.500	0.000	1.000	0.077	0.001	0.001
ψ_6	Share of firm free cash flow paid as bonus	0.200	0.000	0.500	0.010	0.004	0.001

(continue...)

SYMBOL	DESCRIPTION	VALUE	MIN.	MAX.	μ^*	DIRECT	INTERACTION
Policy and credit market							
Φ^b	Bail-out reference as share of incumbent net wealth	0.500	0.000	1.000	0.081	0.005	0.001
ϕ	Unemployment subsidy rate on average wage	0.400	0.000	1.000	0.063	0.001	0.001
tr	Tax rate	0.100	0.000	0.300	0.090	0.001	0.001
r	Prime interest rate	0.010	0.005	0.050	0.025	0.000	0.001
μ_{deb}	Mark-up of interest on debt over prime rate	0.300	0.100	0.500	0.047	0.001	0.001
μ_{res}	Mark-up of interest on reserve to prime rate	-0.500	-0.200	-1.000	0.101	0.000	0.001
Λ	Prudential limit on debt (sales multiple)	3	1	4	0.055	0.000	0.001
Technology							
η	Maximum machine-tools useful life	19	10	40	0.006	0.001	0.001
ν	R&D investment propensity over sales	0.040	0.010	0.200	0.068	0.000	0.001
ξ	Share of R&D expenditure in imitation	0.500	0.200	0.800	0.016	0.003	0.001
b	Payback period for machine replacement	8	1	20	0.053	0.006	0.001
m_1	Capital productivity in capital-good sector	1	0.1	10	0.039	0.001	0.001
m_2	Capital productivity in consumer-good industries	10	1	100	0.066	0.004	0.001
(α_1, β_1)	Beta distribution parameters (innovation process)	(3,3)	(1,1)	(5,5)	(0.089,0.137)	(0.002,0.008)	(0.001,0.001)
(α_2, β_2)	Beta distribution parameters (entrant productivity)	(2,4)	(1,1)	(5,5)	(0.199,0.137)	(0.060,0.280)	(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)	(0.064,0.010)	(0.000,0.000)	(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]	(0.050,0.046)	(0.022,0.019)	(0.001,0.001)

(continue...)

SYMBOL	DESCRIPTION	VALUE	MIN.	MAX.	μ^*	DIRECT	INTERACTION
Industrial dynamics							
γ	Share of new customers for capital-good firm	0.500	0.200	0.800	0.016	0.003	0.001
ι	Desired inventories share	0.100	0.000	0.300	0.019	0.001	0.001
κ_{max}	Maximum threshold to capital expansion	0.500	0.100	1.000	0.076	0.039	0.001
μ_1	Mark-up in capital-good sector	0.100	0.010	0.200	0.020	0.000	0.001
ω_1	Firm competitiveness weight for price	1.000	0.200	5.000	0.060	0.003	0.001
ω_2	Firm competitiveness weight for unfilled demand	1.000	0.200	5.000	0.005	0.000	0.001
ω_3	Firm competitiveness weight for quality	1.000	0.200	5.000	0.051	0.004	0.001
χ	Replicator dynamics coefficient (inter-firm)	1.000	0.200	5.000	0.065	0.000	0.001
υ	Mark-up adjustment coefficient	0.040	0.010	0.100	0.012	0.001	0.001
f^2_{min}	Min share to firm stay in consumption-good industry	10^{-5}	10^{-6}	10^{-3}	0.064	0.000	0.001
o	Weight of market conditions for entry decision	0.500	0.000	1.000	0.040	0.001	0.001
u	Planned utilization by consumption-good entrant	0.750	0.500	1.000	0.056	0.005	0.001
x_5	Max technical advantage of capital-good entrant	0.300	0.000	1.000	0.366	0.278	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]	(0.018,0.052)	(0.005,0.002)	(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]	(0.077,0.016)	(0.005,0.006)	(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]	(0.079,0.029)	(0.001,0.007,)	(0.001,0.001)
$[F^1_{min}, F^1_{max}]$	Min/max number of capital-good firms	[1,100]	[1,20]	[20,400]	(0.041,0.028)	(0.004,0.004)	(0.001,0.001)
$[F^2_{min}, F^2_{max}]$	Min/max number of consumer-good firms	[1,100]	[1,20]	[20,400]	(0.020,0.070)	(0.000,0.003)	(0.001,0.001)
Initial conditions							
μ_0	Initial mark-up in consumption-good industries	(0.2,0.3)	(0.1,0.1)	(0.5,1.0)	0.073	0.000	0.001
w^{min}_0	Initial minimum wage and social benefit floor	0.500	0.100	1.000	0.023	0.011	0.001
L^S	Number of workers	2.510^5	1.310^5	5.010^5	0.119	0.002	0.001
Λ_0	Prudential limit on debt (initial fixed floor)	1000	500	2000	0.103	0.004	0.001
B	Number of banks	10	5	15	0.030	0.000	0.001
NW^b_0	Multiple on minimum initial net wealth of banks	10	1	100	0.004	0.000	0.001
(F^1_0, F^2_0)	Initial number of capital/consumption-good firms	(10,50)	(5,20)	(20,200)	(0.026,0.118)	(0.000,0.001)	(0.001,0.001)
(NW^1_0, NW^2_0)	Multiple on initial net wealth for capital/consumption	(1,2)	(0,0)	(10,10)	(0.066,0.050)	(0.001,0.001)	(0.001,0.001)

Table 1: Model parameters and initial conditions, calibration values, minimum-maximum range for sensitivity analysis, elementary effects μ^* statistic ($n = 780$ samples) and Sobol decomposition direct and interaction effects indexes ($n = 1000$ samples).
Baseline values. Sensitivity analysis statistics relative to Unemployment rate for primary educated workers (U^1_t) (the most sensitive variable).
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	$+Eq_t$	$-Eq_t^1$	$-Eq_t^2$					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 2: Stock-flow consistency: balance-sheet matrix, single country view.

	Workers	Capital-good firms		Consumption-good firms		Banks		Central bank	Government	Foreign firms	$\sum$
	(households)	*current*	*capital*	*current*	*capital*	*current*	*capital*				
Transactions											
Consumption	$-C_t$			$+S_t^2$							0
Investment		$+S_t^{1,d}$			$-I_t^{nom,d}$						0
Government expenditure	$+G_t$								$-G_t$		0
Wages	$+W_t$	$-W_t^1$		$-W_t^2$							0
Taxes	$-Tax_t^w$	$-Tax_t^1$		$-Tax_t^2$		$-Tax_t^b$			$+Tax_t$		0
Trade, imports					$-Im_t^2$					$+X_t^{1,f}$	0
Trade, exports		$+X_t^1$								$-Im_t^{2,f}$	0
Profits, firms and banks		$-$ net Π_t^1	$+$ net Π_t^1	$-$ net Π_t^2	$+$ net Π_t^2	$-$ net Π_t^b	$+$ net Π_t^b				0
Op. result, central bank								$-\Pi_t^{cb}$	$+\Pi_t^{cb}$		0
Bonuses	$+Bon_{t-1}$				$-Bon_{t-1}^2$						0
Dividends	$+Div_{t-1}$		$-Div_{t-1}^1$		$-Div_{t-1}^2$		$-Div_{t-1}^b$				0
New equity	$-cEntry_{t-1}$		$+cEntry_{t-1}^1$		$+cEntry_{t-1}^2$						0
Liquidation equity	$+cExit_{t-1}$		$-cExit_{t-1}^1$		$-cExit_{t-1}^2$						0
Bad debt			$+BadDeb_{t-1}^1$		$+BadDeb_{t-1}^2$	$-BadDeb_{t-1}$					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 3: Stock-flow consistency: transaction-flow matrix for a single country.
To ensure consistency for the world, if C is the number of countries, $\sum \Delta IntRes_t^c = 0, \quad c = 1, 2, ..., C.$
$\Delta X_t = X_t - X_{t-1}, \quad$ net $\Pi_t^z = \Pi_t^z - Tax_t^z, z = 1, 2, b, \quad S_t^{1,d} = S_t^1 - X_t^1, \quad I_t^{nom,d} = I_t^{nom} - Im_t^2.$