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Public policies and the art of catching up: matching the historical evidence with a multi-country agent-based model

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Public policies and the art of catching up: matching the historical evidence with a multi-country agent-based model

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Abstract

In this paper, we study the effects of industrial policies on international convergence using a multi-country agent-based model which builds upon Dosi et al. (2019b). The model features a group of microfounded economies, with evolving industries, populated by heterogeneous firms that compete in international markets. In each country, technological change is driven by firms' activities of search and innovation, while aggregate demand formation and distribution follows Keynesian dynamics. Interactions among countries take place via trade flows and international technological imitation. We employ the model to assess the different strategies that laggard countries can adopt to catch up with leaders: market-friendly policies; industrial policies targeting the development of firms' capabilities and R&D investments, as well as trade restrictions for infant industry protection; protectionist policies focusing on tariffs only. We find that markets cannot do the magic: in absence of government interventions, laggards will continue to fall behind. On the contrary, industrial policies can successfully drive international convergence among leaders and laggards, while protectionism alone is not sufficient to support catching up and countries get stuck in a sort of middle-income trap. Finally, in a global trade war, where developed economies impose retaliatory tariffs, both laggards and leaders are worse off and world productivity growth slows down.

Keywords Endogenous growth, catching up, technology-gaps, industrial policies, agent-based models.

JEL classification F41, F43, O4, O3

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1 Introduction

Since the Industrial Revolution, the history of modern economies has been characterized by the so-called "great divergence" (Dosi et al., 1994b; Pritchett, 1997; Pomeranz, 2000): countries have become increasingly unequal in terms of living standards over time as a result of diverging growth performances. Against this background, countries that happened to be at the top of the ladder typically preached free trade while catching up ones practiced an ensemble of trade and industrial policies (Cimoli et al., 2009; Reinert, 2007; Cimoli et al., 2020) and, as they reached the top, they kicked away the ladder (Chang, 2002) and converted to the free trade discourse (even if rarely in its full practice). Historically, this has been the case of England vis-à-vis the Low Countries; then Germany and USA vis-à-vis England, then Japan vis-à-vis USA; now possibly China vis-à-vis, again, USA. The vicissitudes of the so-called "Washington Consensus" are a good case to the point. Viciously paddled by the US, it actually failed in promoting the catching up of developing countries which adhered to its recipes (Stiglitz, 2002; World Bank, 2005; Rodrik, 2005, 2006; Easterly, 2019). On the contrary, after being ostracized for some decades, industrial policies are finally getting a central role in the current economic and political debate (Lin and Chang, 2009; Lin, 2012; Rodrik, 2009; Cherif and Hasanov, 2019; Aiginger and Rodrik, 2020). Indeed, key lessons can be learned from former emerging countries (e.g., South Korea, China, etc.) which successfully caught up with the technological frontier relying on various forms of industry support (Cimoli et al., 2009; Cherif and Hasanov, 2019).

Accordingly, an increasing number of studies have explored different dimensions of industrial policies, on both empirical and theoretical grounds (we discuss some of the literature in Section 2). However, little efforts have been made to test their effectiveness using formal growth models.[1] In this paper, we try to fill this gap by developing a multi-country agent-based model to test the effects of various combination of industrial policies in promoting international technological convergence. Macroeconomic agent-based models (Fagiolo and Roventini, 2017; Dawid and Delli Gatti, 2018; Dosi and Roventini, 2019) are indeed particularly suited to study how growth (or lack of it) is generated from the activities of innovation and imitation by heterogeneous firms which learn and accumulate knowledge in highly uncertain economic environments. In such a framework, meso and macro phenomena such as structural change, industry specialization, economic divergence, and catching up emerge out of the complex microeconomic interactions of firms competing in international markets.

The agent-based model here builds upon Dosi et al. (2019b), wherein an ensemble of open economies are characterized by evolving industries populated by heterogeneous firms competing in both domestic and international markets. Firms strive to increase their market shares discovering new technologies and imitating their competitors. These processes can be successful only if firms invest in R&D investment and build absorptive capacity (Cohen and Levinthal, 1990) to grasp new knowledge. This results in an international flow of goods, knowledge and technologies across different economies. In line with the results generated by the K+S family of models (Dosi et al., 2010), the key drivers of long-run development lie in the interaction between Schumpeterian innovation dynamics and Keynesian\Kaldorian mechanisms of aggregate demand generation and distribution.[2]

[1] Some exceptions are Hausmann and Rodrik (2003), Greenwald and Stiglitz (2006) and Liu (2019) and in the Structuralist and post-Keynesian perspective Botta (2009), Cimoli and Porcile (2013) and Lavopa (2014).

[2] The K+S family now encompasses several extensions, accounting for: the financial sector (Dosi et al., 2013, 2015); coupled climate and economic dynamics (Lamperti et al., 2018, 2019); labour market and different institutional regimes (Dosi et al., 2017b, 2018, 2019a). There is also a growing body of open-economy ABMs focused on international or regional convergence/divergence such as Caiani et al. (2018); Dawid et al. (2014, 2018); Petrović et al. (2020); Wolf et al. (2013). Early evolutionary multi-country models are found in Dosi et al. (1994b) and Silverberg and Verspagen (1995). This paper finds some germane efforts in the recent agent-based literature. For instance, Dawid et al. (2014) and Dawid

As shown in Dosi et al. (2019b), the model accounts for a large set of stylized facts at the macroeconomic, sectoral and firm levels. In particular, it is able to reproduce divergent dynamics of countries and the emergence of a bimodal distribution of aggregate incomes with the formation of two clubs of leader and laggard economies. In this work, we take for granted the foregoing differentiation among countries and we start with a polarized world wherein leaders and laggards coexist.

We then study different policy scenarios to investigate under which conditions laggards may converge to the technological frontier, thus joining the club of developed countries. More specifically, we compare four different growth strategies. Fist, we consider a Washington Consensus scenario where governments do not intervene, trusting the "magic of the markets" to promote technological and economic convergence. We then study an industrial policy set-up, broadly defined as to include interventions in the fields of science and innovation aimed at fostering firms' capabilities and R&D investments, as well as trade restrictions for infant industry protection. Finally, we consider intermediate regimes where only protectionist or innovation policies are in place.

Simulation results show that market-friendly policies never allow laggard countries to catch up with the technological frontier: on the contrary, they reinforce the polarization among different clubs of economies. Conversely, industrial policies do foster convergence of the laggards. Although introducing some static costs (e.g. rising domestic prices), industrial policies yield strong dynamic gains associated to learning and absorption of foreign technologies. Nevertheless, convergence is conditional on the implementation of strong efforts of capability accumulation, learning and technological development in combination with infant industry protection. Accordingly, we find that protectionism is not sufficient to trigger catching up and laggards remain stuck in a sort of middle-income trap. Moreover, in presence of a global trade war, if developed economies retaliate introducing tariffs, both leaders and laggards countries are worse off in term of GDP per-capita and other macroeconomic indicators.

Finally, we present simulation experiments studying possible interactions of industrial policies with other policy variables. These include: exchange rate flexibility, the composition of R&D investments (i.e. innovation vis-à-vis imitation) and international barriers to imitation. While exchange rates adjustments do not appear to play a significant role, we find that lower imitation barriers entail faster convergence of laggards. Instead, the composition of R&D expenditures shows non-linear effects since catching up is stronger when there is a balance between innovative and imitative search, as compared to scenarios in which one of the two largely prevails.

The rest of the paper proceeds as follows. Section 2 discusses the literature on catch up and industrial policies. The model is presented in Section 3. In Section 4, we set the scene for the later simulation exercises; spelled out in Section 5. In Section 6 we present experiments on macro policies and protectionism. Finally, Section 7 concludes.

2 Catching up via industrial policies: lessons from the literature

The "great divergence" is a well established feature of the rise of modern capitalism (Dosi et al., 1994b; Pritchett, 1997; Pomeranz, 2000).[3] This is strongly related to the concentration of technological and

et al. (2018) study the impact of different cohesion policies, including forms of support to foreign technology adoption, in a two-region agent-based model. Moreover, Landini and Malerba (2017) and Landini et al. (2017) present history-friendly models of technological catch up inspired by the experience of specific industries and provide support to a variety of public interventions including: support to entry, capability-building policies and trade protection.

[3]The econometric literature on cross-country divergence is vast. An extensive literature review is presented in Durlauf et al. (2005). More recently the focus has shift on the identification of heterogeneous growth episodes (Jones and Olken, 2008; Berg et al., 2012). In historical time series, fresh evidence on the origins of growth episodes is found in Kejriwal and

organizational innovation in a relatively small club of (mainly western) countries, emerging as world leaders, while the rest of the world lagged behind. Historically, only few laggard countries have been able to to catch up (or eventually forge ahead) with most advanced nations. Some historical instances include the US and Germany overtaking England in the late 19th century, Western Europe and Japan significantly reducing their gap with respect to the US in the post-WWII period, the East Asian growth miracles and, more recently, the spectacular rise of China.

Given this historical background, one of the grand challenges for economists and political scientists alike has been the identification of the policies and institutions underlying the successful catching up episodes. As put forward by several growth scholars and economic historians (see e.g. Gerschenkron, 1962; Abramovitz, 1986; Freeman, 2019), catching up with the frontier is far from being automatic. In his classic work, Abramovitz (1986) identifies the development of social capabilities (e.g. education, infrastructures, financial institutions) together with what he calls technological congruence (i.e. domestic conditions favourable to the adoption of foreign technologies) as necessary elements for successful catch up. More recently, several empirical and theoretical works (see e.g. Fagerberg and Verspagen, 2002; Fagerberg et al., 2005; Lee, 2013; Verspagen et al., 2015; Lee and Malerba, 2018; Lee, 2019), have shed new light on the complex and multifaceted processes associated to the "art of economic catch up", to use the terminology by Keun Lee (Lee, 2019). The presence of a wide array of industrial policies appears indeed to be indeed a necessary condition for such processes. That was a robust implication of the analyses of all classic development scholars (List, 1856; Prebisch et al., 1950; Myrdal, 1957; Hirschman, 1958; Gerschenkron, 1962; Kuznets, 1966; Bairoch, 1996; and the reassessments in Chang, 2002; Cimoli et al., 2009; Reinert, 2007). One common feature of the catching up recipes involves indeed "going against market signals" (Amsden, 1989) and the revealed comparative advantages they entail, supporting instead increasing-return sectors (typically manufacturing), the development of strong backward and forward linkages among sectors and the need for big pushes led by public investments.

The classic perspective of development economics is well in tune with and enriched by evolutionary theories and the microeconomics they entail (Nelson and Winter, 1982; Dosi, 1988; Lall, 1992; Bell and Pavitt, 1993; Cimoli and Dosi, 1995; Cimoli et al., 2020), as well as with national innovation system perspective (Lundvall, 1992; Nelson, 1993; Freeman, 1995). As sadly known, however, the refinements in the analysis of the development process and the policy practices of (or better, inflicted to) developing countries went in opposite directions. Beginning in the late '70s, all kind of industrial policies became anathema and were replaced by the so-called Washington Consensus which postulated a set of market-oriented reforms including trade liberalization, privatization of public companies, fiscal discipline and tight monetary policies (cf. Williamson, 1990). However, the Washington Consensus did not deliver the Promised Land, either in its original formulation or in its augmented versions (as to include institutional reforms to achieve "good governance"). The poor growth records of many countries in Latina America and Sub-Saharan Africa revealed its general failure (World Bank, 2005; Rodrik, 2005, 2006; Easterly, 2019), while the success stories of Asian countries like Korea and Taiwan, and later China, offered a strong counter-evidence in favour of growth-promoting state interventions that are context-specific and take into account local constraints and conditions (more in Rodrik, 2005; Cimoli et al., 2009; Lee, 2019).[4] In turn, learning infants require protection from older, bigger, oppressive competitors on the sides of both trade and knowledge flows. Nevertheless, import substitution alone is not enough as it

Lopez (2013) and Russo et al. (2019).

[4]This "new consensus" has been supported by recent empirical works which found positive casual effects on productivity and employment associated to specific industrial policy interventions (Kalouptsidi, 2017; Criscuolo et al., 2019; Lane, 2019). For a recent survey on the new empirics of industrial policies see Lane (2020).

is likely to create lazy local monopolies and rents as the Latin American experience teaches (Khan and Blankenburg, 2009; Palma, 2009). Sustaining growth over the long run implies the continuous introduction of new goods and techniques (Dosi et al., 1990; Cimoli et al., 2009). This is obviously associated with a constant upgrading of production and export baskets as well as of countries position in the value chain (Hausmann et al., 2005; Pietrobelli and Rabellotti, 2011; Gereffi and Wyman, 2014; Berg et al., 2012; Tacchella et al., 2013). Accordingly, the literature using the so-called product space analyzes countries' exports to characterize their capabilities and future development pathways (Hidalgo et al., 2007; Hausmann and Hidalgo, 2011). The main insight is that successful development entails specialization in complex products. However, laggard countries often lack the required technological and institutional capabilities needed to produce complex goods. Conversely, they are more likely to move along products related to their existing capability set. This paper contributes to this literature by studying how industrial policies can effectively be used to promote learning and imitation, two key drivers of the capability-building process which are often overlooked in the product space setting.

Many of the lessons discussed here have been primarily addressed from the point of view of "appreciative theorizing" (as Nelson and Winter, 1982, p. 46 calls it), i.e. presenting historical case studies for selected regions or countries. Within this stream of literature, recent efforts have been directed towards the identification of "windows of opportunity" (Lee and Malerba, 2017), defined as radical changes in some main dimensions affecting industry competition (e.g. technology breakthroughs, new demand opportunities or changing institutions).[5] For instance, it has been pointed out that major advances in the areas of semiconductors and digital technologies allowed Korean firms to become world leaders in consumer electronics during the 80s, overtaking Japanese incumbents (Lee and Lim, 2001; Lee et al., 2005).

This paper complements these "appreciative" studies with a more formal approach. By doing that, one is bound to leave out most of the richness of the co-evolutionary processes historically involved in any episode of development. However, we hope to account for a few relatively invariant mechanisms and the impact of policies upon them. This is in line with recent history-friendly models that study the dynamics of catching up in global industries (Landini et al., 2017; Landini and Malerba, 2017). Results from these works also point at the relevance of various forms of public support as drivers of technological convergence for laggard countries.

3 The Model

Our work builds upon and extends the multi-country model presented in Dosi et al. (2019b). The model features N economies (indexed by i), M consumption-good industries (indexed by h), each populated by S domestic companies (indexed by j), and an aggregate capital-good sector producing homogeneous good for domestic producers of finals.

Firms in different countries are assumed to master heterogeneous technologies which evolve over time as a result of an endogenous process of innovation and imitation. For simplicity, search and innovation are only carried out by firms in the consumption-good sectors and the outcome takes the form of increasing labour productivity (i.e. Harrod-neutral technical change). Demand for consumption goods stems from workers expenditures and is allocated across firms according to their competitiveness

[5]A recent special issue of Research Policy collects a set of contributions studying the role of windows of opportunities in generating catch up cycles (Lee and Malerba, 2017). The industry considered include: mid-sized aircraft (Vértesy, 2017), mobile phone (Giachetti and Marchi, 2017), memory chip (Shin, 2017), wine (Morrison and Rabellotti, 2017), steel (Lee and Ki, 2017) and camera (Kang and Song, 2017).

via a process of market selection.

3.1 Timeline of the events

In each each time step, the following events take place:

1. Firms in the consumption-good industries perform R&D in order to discover new techniques and to imitate competitors closer to the technology frontier. If they are successful they improve their labor productivity and become more competitive.

2. Production, investment and employment decisions take place. Given their expected demand, consumption-good firms set their desired production, hire workers accordingly and, if necessary, expand their productive capacity.

3. The capital-good sector in each country receives orders from firms in the consumption-good industries, hire workers, and start production.

4. International imperfectly competitive consumption-good markets opens. Workers spend their income on both domestic and imported goods. Firms' market shares evolve according to their price competitiveness.

5. Entry and exit occur: Firms with quasi-zero market share exit the market and are replaced by new ones.

6. Machines ordered at the beginning of the period are delivered and become part of the capital stock for the next one.

7. Monetary wages and exchange rates, which will apply in the next period, are set at the national level.

At the end of each time step, the aggregate variables (e.g. GDP, investments, consumption, exports, imports, etc.) are computed by summing the corresponding microeconomic variables. Let us next provide a more detailed behavioural description of the model.

3.2 Innovation, imitation and technical change

The process of technical change is driven by consumption-good firms' search and discovery activities. Firms invest in R&D (RD) a fixed proportion of their past sales (SS):[6]

$$RD^i_{j,h}(t) = \rho SS^i_{j,h}(t-1), \tag{1}$$

with $\rho \in (0,1)$. Total R&D expenditures are then split between innovative (IN) and imitative (IM) efforts:

$$IN^i_{j,h}(t) = \lambda RD^i_{j,h}(t) \tag{2}$$

$$IM^i_{j,h}(t) = (1-\lambda) RD^i_{j,h}(t), \tag{3}$$

[6]This is an assumption shared by many evolutionary models (Chiaromonte and Dosi, 1993; Dosi et al., 1994a, 2010), in which R&D strategies are assumed to be entirely routinized and time-invariant. Notice that the assumption of fixed R&D expenditure coefficients is quite in tune with firms actual behaviours (Nelson and Winter, 1982; Dosi, 1988; Dosi and Egidi, 1991).

with $0 \leq \lambda \leq 1$. Innovation and imitation are modelled as two-step stochastic processes. In the first step, a draw from a Bernoulli distribution determines whether firms succeed in their search activities. The probabilities of success ($\theta[in]; \theta[im]$) depend positively on R&D expenditures and on firms' search capabilities ($\xi_{1,2} > 0$):

$$\theta[in]^i_{j,h}(t) = \min\left\{\theta_{max}; 1 - \exp[-\xi_1 IN^i_{j,h}(t)]\right\} \tag{4}$$

$$\theta[im]^i_{j,h}(t) = \min\left\{\theta_{max}; 1 - \exp[-\xi_2 IM^i_{j,h}(t)]\right\}, \tag{5}$$

where $\theta_{max} < 1$ is an upper bound capturing a "natural" degree of uncertainty involved in search activities.

Firms succeeding in innovation discover a new production technique associated with a labour productivity coefficient $A[in]$:

$$A[in]^i_{j,h}(t) = A^i_{j,h}(t-1)(1 + x^i_{j,h}(t)) \qquad \text{where:} \quad x \sim Beta(\alpha_1, \beta_1) \tag{6}$$

The multiplicative increase (x) is drawn from a re-scaled Beta distribution with parameters (α_1,β_1) and support $[\underline{x}_1, \bar{x_1}]$, with $\underline{x}_1 \in [-1, 0]$ and $\bar{x_1} \in [0, 1]$. The shape and support of the Beta distribution capture together the different technological opportunities and the ability of the firms to seize them. Given the high degree of uncertainty characterizing the innovation process, the newly discovered techniques may well be less productive than the ones currently mastered by firms: in this case the firm sticks to the old technology.

We extend the model in Dosi et al. (2019b) to explicitly account for firms' *absorptive capacity* in the imitation process (Cohen and Levinthal, 1990; Griffith et al., 2003). Absortive capacities affect two main dimensions of imitation: (i) the ability to access "technologically distant" coefficients (cf. the variable ϕ); (ii) the speed at which the newly imitated techniques are exploited (cf. the variable ω). As in the previous version of the model, successful imitators will access a new productivity coefficient ($\hat{A}$) from more productive competitors (i.e. the probability to access less efficient techniques is set to zero). More specifically, the probability for a successfully imitating firm j in country i to copy a specific competitor l in country k is related to the inverse of the (Euclidean) technological distance (d), now re-scaled by the absortive capacity variable ϕ:[7]

$$d_{j,l}(t) = \frac{1}{1 + \phi^i_{j,h}(t)[\hat{A}^k_{l,h}(t-1) - \hat{A}^i_{j,h}(t-1)]} \tag{7}$$

The evolution of $\phi^i_{j,h}$ is firm-specific and depends on past cumulated R&D expenditures ($RDcum$):

$$\phi^i_{j,h}(t) = \phi_0 \exp[-\phi_1 RDcum^i_{j,h}(t-1)], \quad \text{where: } \phi_0 = \begin{cases} 1 & \text{if } i = k \\ \epsilon & \text{if } i \neq k \end{cases} \tag{8}$$

with $\phi_1 > 0$ and $\epsilon \geq 1$. The parameter ϕ_1 reflects the skills and competencies of the firm, while ϵ accounts for structural barriers to foreign imitation (e.g. restrictive IPR legislation). Hence, as firms accumulate experience in *R&D*, the variable ϕ will fall, making more likely the access to technologically

[7] To get probabilities defined in $[0, 1]$ we normalize by the sum over l of $d_{j,l}$. This mechanism is grounded on strong empirical basis. Indeed, the literature on technology-gaps supports the idea that strong absortive capacities can help in overcoming the constraints to imitation posed by technological distance and by other institutional barriers to technology adoption (see e.g. Abramovitz, 1986; Dosi et al., 1990; Fagerberg et al., 2005).

distant techniques.

As a result of this process, firms will receive a productivity coefficient from competitors ($\hat{A}$). This new coefficient represents a potential that requires learning and adaptation in order to be fully exploited. Hence, firms cannot immediately master the new techniques as they only have access to a fraction ($A[im]$) which depends on the internal learning abilities. The speed at which the new coefficient will be internalized, indeed, is a function of the second dimension of absorptive capacity (ω):

$$A[im]^i_{j,h}(t) = (1 - \omega^i_{j,h}(t))A[im]^i_{j,h}(t-1) + \omega^i_{j,h}(t)\hat{A}^i_{j,h}(t), \tag{9}$$

where $A[im]$ is the actual productivity coefficient available from the imitation process. The absortive capacity variable (ω), again, evolves according to firm-specific cumulative R&D:

$$\omega^i_{j,h}(t) = \omega_0 - \omega_0 \exp[-\omega_1 RDcum^i_{j,h}(t-1)], \tag{10}$$

with $\omega_0 \in (0, 1]$ and $\omega_1 > 0$. Higher knowledge levels accumulated by firms (proxied by $RDcum$) will improve their speed in fully mastering the new technology, which will eventually approach the upper bound ω_0, defined by technology-specific conditions.

Finally, once both the innovation and imitation processes are completed, each firm selects the most efficient production technique, i.e. the one entailing the higher labor productivity:[8]

$$A^i_{j,h}(t) = \max\left\{A^i_{j,h}(t-1); A[in]^i_{j,h}(t); A[im]^i_{j,h}(t)\right\} \tag{11}$$

3.3 Prices, production and investments

Firms set prices (p) adding a mark-up (m) over the unit cost of production:

$$p^i_{j,h}(t) = (1 + m^i_{j,h}(t))\frac{W^i_{j,h}(t)}{A^i_{j,h}(t)} \tag{12}$$

The mark-up ratio evolves according the dynamics of past market shares (f):

$$m^i_{j,h}(t) = m^i_{j,h}(t-1)(1 + \upsilon\frac{f^i_{j,h}(t-1) - f^i_{j,h}(t-2)}{f^i_{j,h}(t-2)}), \tag{13}$$

with $\upsilon > 0$.

Consumption-good firms produce their output using both labour and capital. While labor productivity grows over time as result of technical change, the capital-output ratio (B) remains constant. Firms set desired production (Qd) according to adaptive demand expectations (D). In particular we assume myopic expectations: [9]

$$Qd^i_{j,h}(t) = D^i_{j,h}(t-1) \tag{14}$$

Desired production is constrained by productive capacity.[10] Thus, actual production (Q) is computed

[8]Notice that, after the choice of technique, in case $A^i_{j,h}(t) > \hat{A}^i_{j,h}(t)$ we set: $\hat{A}^i_{j,h}(t) = A^i_{j,h}(t)$.

[9]The results of the model are robust when more complex expectation rules are employed. For an extensive investigation of different expectation rules in the "K+S" model see Dosi et al. (2020a).

[10]As in the previous version of the model, we restrain from modelling inventories. This means that excess production is assumed to be perishable while excess demand is transformed into savings.

as:

$$Q^i_{j,h}(t) = \min\left\{Qd^i_{j,h}(t), \frac{K^i_{j,h}(t)}{B}\right\}, \tag{15}$$

where K is the stock of capital.

Capacity constrained firms invest to expand their capital stock. More specifically, expansion investments (Ie) occur whenever the desired capital stock (Kd) exceeds the actual one.

$$Ie^i_{j,h}(t) = Kd^i_{j,h}(t) - K^i_{j,h}(t), \tag{16}$$

with $Kd^i_{j,h}(t) = BQd^i_{j,h}(t)$. Firms invest also to cover (constant) capital depreciation (δ). Hence, replacement investments (Ir) are simply:

$$Ir^i_{j,h}(t) = \delta K^i_{j,h}(t), \tag{17}$$

with $\delta \in (0,1)$. The law of motion of capital stocks is then equal to:

$$K^i_{j,h}(t+1) = K^i_{j,h}(t) + Ie^i_{j,h}(t). \tag{18}$$

3.4 The capital-good sector

In each country, domestic firms acquire their machines from an aggregate (i.e. unmodeled "single firm") capital-good sector. Total production (Q_k) equals the sum of the orders from domestic firms (I^i):

$$Q^i_k(t) = I^i(t). \tag{19}$$

The labor productivity in capital-good sectors is assumed to track the average country level $A^i(t)$. In turn, employment is equal to:

$$L^i_k(t) = \frac{Q^i_k(t)}{A^i(t)} \tag{20}$$

Finally, prices track the unit cost of production.

3.5 International competition and selection

Each firm is competing in N national markets. As goods are homogeneous within each industry, firms' competitiveness depends only on the price they charge. Of course, in foreign markets, firms' prices (p) are affected by exchange rate (e), trade costs and tariffs. More specifically, given a firm j, operating in industry h and based in country i, its competitiveness (E) in country k is given by:

$$E^{i,k}_{j,h}(t) = \frac{1}{p^i_{j,h}(t)e^{i,k}(t)[1+\tau^k_h(t)]}, \quad \text{where: } \tau^k_h(t) = \begin{cases} 0 & \text{if } i = k \\ \tau_0 + tariff^k_h(t) & \text{if } i \neq k \end{cases} \tag{21}$$

with $\tau_0 > 0$ and $tariff \geqslant 0$. The term τ captures trade barriers determined by both structural (iceberg-like) costs for competing abroad (τ_0) and by a country-specific tariff. Here, the tariff encompasses all the possible measures that hamper the competitiveness of foreign firms in the domestic market. Hence, it must be interpreted in a broad sense, including both standard import tariffs and non-tariff barriers implemented by countries.[11] The average competitiveness ($\bar{E}$) for industry h in country k is computed

[11]It is widely acknowledged that non-tariff measures play a crucial role in infant industry protection. In fact, the development strategies of many now-rich countries have historically resorted on the policy mix between standard and

summing competitiveness (weighted by their market shares) across firms operating in h in different countries:

$$\bar{E}_h^k(t) = \sum_{i=1}^{N} \sum_{j=1}^{S} E_{j,h}^{i,k}(t) f_{j,h}^{i,k}(t-1). \tag{22}$$

Market selection regulates the distribution of demand for consumption goods across firms in international markets. Firms' market shares (f) evolve according to a quasi-replicator dynamics:[12]

$$f_{j,h}^{i,k}(t) = f_{j,h}^{i,k}(t-1)(1 + \chi \frac{E_{j,h}^{i,k}(t) - \bar{E}_h^k(t)}{\bar{E}_h^k(t)}), \tag{23}$$

with $\chi > 0$. In a nutshell, the market shares of the most competitive firms in each market will expand, while those of the least efficient ones (charging higher prices) will shrink. The parameter χ accounts for the strength of competition in the market. The market share in the global market of firm j competing in industry h is then:

$$f_{j,h}^{i}(t) = \sum_{k=1}^{N} f_{j,h}^{i,k} \frac{C^k(t)}{\bar{C}(t)}, \tag{24}$$

where C and $\bar{C}$ represents respectively national and world consumption. In each country, total consumption corresponds to the wage bill. For simplicity we assume that workers spend an equal proportion $s_h = 1/M$ of their income in each consumption-good industry.[13] Given the wage (W) and aggregate national employment (L), the domestic demand ($Dint$) of each firm corresponds to:

$$Dint_{j,h}^{i}(t) = W^i(t) L^i(t) s_h f_{j,h}^{i,k}(t), \qquad \text{with:} \quad i = k \tag{25}$$

Symmetrically, foreign demand ($Dexp$) is:

$$Dexp_{j,h}^{i}(t) = \sum_{k \neq i}^{N} W^k(t) L^k(t) e^{k,i}(t) s_h f_{j,h}^{i,k}(t) \frac{1}{(1 + \tau_h^k(t))} \tag{26}$$

Finally, total individual demand is simply $D_{j,h}^i(t) = Dint_{j,h}^i(t) + Dexp_{j,h}^i(t)$.

At the end of each time step, the Schumpeterian selection process result in firm entry and exit. Firms with quasi-zero market shares exit the market and are replaced by entrants. Thus, we keep the number of firms constant in each country and industry.[14] The technology of entrants evolves according to the domestic average productivity in the industry, in line with recent theoretical and empirical appraisals pointing out the cumulativeness and the specificity of national learning patterns (Fagerberg, 1994; Cimoli and Dosi, 1995; Fagerberg and Verspagen, 2002; Cimoli et al., 2009).[15] Moreover, in tune

alternative protection tools (see e.g. Bairoch, 1995). Recently, many countries are increasingly relying on non-tariff barriers to cope with the restrictions stemming from free trade agreements (International Monetary Fund, 2017).

[12]The quasi-replicator dynamics differs from the canonical one since it allows for negative market shares. Of course, through the entry and exit process, firms with near zero or negative market shares are replaced by new entities. For a deeper discussion of the replicator dynamics model see Silverberg et al. (1988), Dosi et al. (1995) and Dosi et al. (2016).

[13]Such assumption implies that sectoral income elasticities of demand are identical across industries and equal to 1. This is obviously a simplification: within the evolutionary tradition, the role of structural change driven by changes in patterns of consumption is extensively analyzed in Verspagen (1992), Montobbio (2002), Ciarli et al. (2010) and Lorentz (2015). A recent empirical investigation of structural change from a long-run perspective is presented in Nuvolari et al. (2019).

[14]Notice that this broadly consistent with the empirical evidence suggesting that entrants are (roughly) proportional to the number of incumbents (Geroski, 1995).

[15]More precisely, firms' initial techniques are obtained applying to the domestic average productivity in the industry a multiplicative shock drawn from a Beta (α_2, β_2) with support $[\underline{x}_2, \bar{x_2}]$ (where: $\underline{x}_2 \in [-1, 0]$ and $\bar{x_2} \in [0, 1]$).

with empirical findings (Caves, 1998; Bartelsman et al., 2005), we also assume that entrants are on average smaller than incumbents and that their initial stock of capital is equal to the minimum level in the industry.

3.6 Macroeconomic dynamics

As in Dosi et al. (2010), monetary wages are determined at the country level according to productivity dynamics:

$$W^i(t) = W^i(t-1)[1 + \psi g^i_{prod}(t-1)], \tag{27}$$

where g_{prod} is the lagged productivity growth and $\psi \geqslant 0$. In line with Lewis (1954) and Cornwall (1977)), we assume that in each country the supply of labour is infinitely elastic to variations in demand. Hence, total employment is determined by the total labour demand of consumption- and capital-good firms given their labour productivities.[16] Given the wage rate and the labor demand of firms, national consumption is equal to:

$$C^i(t) = W^i(t)L^i(t). \tag{28}$$

In a similar vein, the other macroeconomic variables are obtained from the bottom-up by aggregating across heterogeneous firms. Total GDP can be computed from the production side as:

$$Y^i(t) = \sum_{h=1}^{M}\sum_{j=1}^{S} Q^i_{j,h}(t) + Q^i_k(t) \tag{29}$$

The trade balance (TB) depends on exports (EXP) and imports (IMP) which respectively equal to:

$$EXP^i(t) = \sum_{h=1}^{M}\sum_{j=1}^{S} Dexp^i_{j,h}(t); \tag{30}$$

$$IMP^i(t) = C^i(t) - \sum_{h=1}^{M}\sum_{j=1}^{S} Dint^i_{j,h}(t). \tag{31}$$

The evolution of trade balance affects the dynamics of exchange rates (e):

$$e^i(t) = e^i(t-1)(1 + \gamma\frac{TB^i(t-1)}{\bar{Y}(t-1)} + u_i(t)) \qquad u_t \sim \mathcal{N},(0,\sigma_e), \tag{32}$$

where $\bar{Y}$ is world GDP, u is a white noise, and the parameter γ regulates the sensitivity of the adjustment defining the exchange rate regime.[17] The formulation is in tune with models of balance-of-payment constrained growth (see e.g. McCombie and Thirlwall, 1994; Thirlwall, 1979).

4 Setting the scene: a world of leader and laggard countries

In order to study under which conditions laggard countries can successfully catch up with those on the technological frontier, we initialize the model with a twin-peaked country GDP distribution. Indeed, the coexistence of a large group of poor countries and a relatively smaller club of rich ones is a well-

[16]For macroeconomic agent-based models explicitly accounting for decentralized labor-market dynamics see e.g. Dawid et al. (2012); Dosi et al. (2017a,b, 2018); Fagiolo et al. (2004); Riccetti et al. (2015) and the survey in Fagiolo and Roventini (2017).

[17]The exchange rate between two countries i and j is computed as: $e^{i,k} = \frac{e^i}{e^k}$.

established empirical fact (Quah, 1996; Bianchi, 1997; Henderson et al., 2008; Castaldi and Dosi, 2009). Hence, we set the initial conditions of the model using data from the last simulation step of the model in Dosi et al. (2019b). This approach is particularly convenient for our purposes as the model in Dosi et al. (2019b) is able to generate endogenously a bimodal distribution of GDP per worker (together with several other sylized facts at different levels of aggregation) towards the end of the simulation. This ensures that initial conditions are grounded on an empirically validated scenario. A difference with respect to this model is that results in Dosi et al. (2019b) were generated imposing identical parameters across countries. Here, instead, we will allow for different capabilities across country groups. Also, notice that the model is not directly calibrated to empirical data and cannot match precisely the moments of the empirical distribution. This would require an extensive calibration exercise that is beyond the scope of this work.

Needless to say, also the following simulation results underwent an extensive validation procedure checking the consistency of model outcomes with several empirical facts at all levels of aggregations, in tune with those discussed in (Dosi et al., 2019b). For instance, at the macroeconomic level, the model generates both endogenous growth and emergent poverty traps, as well as fat-tailed distributions of growth rates, denoting the coexistence of phases of expansion and recessions punctuated by major crises. At the micro level, one observes right-skewed distributions of firms' size, and fat-tailed densities of their growth (see e.g. Dosi et al., 2019b, for the full list of empirical regularities replicated by the model).

Figure 1 displays the initial cross-sectional distribution of GDP per worker. In such a scenario, we define two groups of countries, labelled respectively leaders and laggards, using the procedure proposed by Bianchi (1997). More specifically, we set a cut-off point (the dashed blue line in Figure 1) at the local minimum of the estimated kernel density. Consequently, all the countries with income levels above this threshold are classified as leaders and vice-versa. In Figure 2 we plot the initial distribution of sectoral productivity gaps among the two groups of countries just defined.[18] At the beginning of the simulation, laggards exhibit a strong productivity gap in almost all the industries.

Against this quite realistic "world economy", we run in the next Section different policy experiments and compare their outcome with a benchmark business-as-usual (BAS), free-market scenario where no policy intervention takes place.

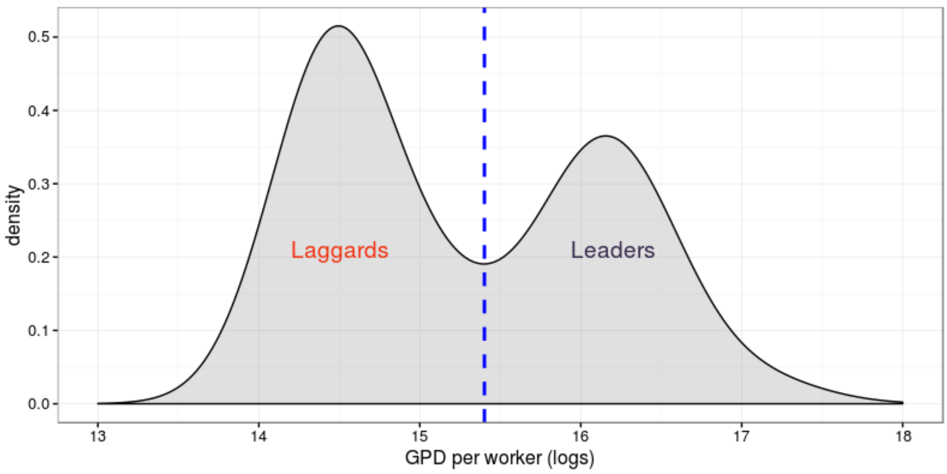

Figure 1: Initial distribution of GDP per worker and definition of leaders and laggards (kernel density estimation)

[18]Sectoral productivity gaps are computed as log-differences between averages productivities across groups.

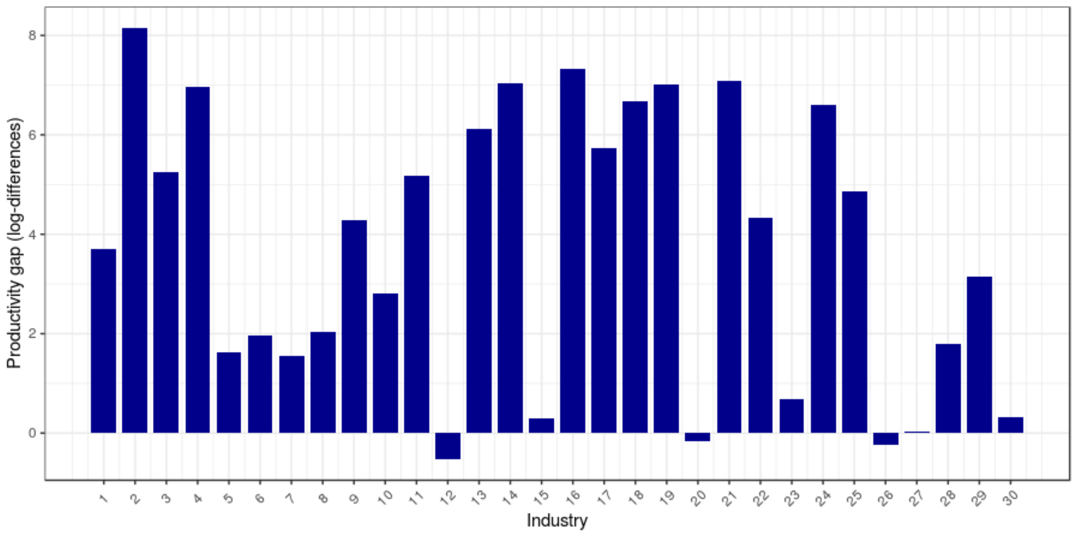

Figure 2: Initial sectoral productivity gaps between leading and laggard countries

5 Simulation results: how can countries catch up?

In this Section we discuss the results generated by a battery of 50 Monte Carlo runs for 500 time steps. Table A.1 reports the values of group-invariant parameters used for simulations. In line with Dosi et al. (2019b), we assume identical industries in terms of structural parameters, thus, providing symmetrical learning and demand opportunities. As a consequence, there are not "strategic" industries and policy experiments will be economy-wide. If there were, as in the real world, our conclusions would *a fortiori* apply.

5.1 Comparing learning and policy regimes

Let us start with a scenario representing a Solow-type of world in which knowledge is a pure public good (Solow, 1956; Arrow, 1962). In our model, this can be captured by imposing two simple conditions: (i) free access to imitation independently from firms' R&D expenditures (i.e. $\theta im = 1$, cf. Equation 5); (ii) the ability to imitate as independent from the technological distance between pairs of firms (i.e $\phi = 0$ in Equation 7). Both conditions ensure perfect knowledge spillovers implying that technologies mostly available in advanced countries, for some reason, can be freely adopted by laggards.

Figure 3 displays the evolution of GDP per-worker averages across country groups and its distribution at the end of the simulation.[19] In this scenario, the typical pattern of unconditional convergence across countries predicted by the standard Solow model clearly emerges. Laggards assimilate the most advanced techniques mastered by leaders and manage to catch up with the frontier relatively fast.[20] At the end of the simulation, the densities for the two groups overlap and there is no evidence of the strong bi-modal shape inherited from initial conditions.

What happens in a more realistic world where technological knowledge is partly tacit and imitation depends upon the interactions between R&D investments, absorptive capacities, appropriability conditions and technological distance? In this case economic convergence among leader and laggard countries does not occur. Our benchmark setting is a "business-as-usual" (BAS) scenario wherein laggards are characterized by relatively lower capabilities and R&D investments than leaders, and they do

[19] GDP variables are expressed at constant prices and exchange rates. GDP distributions across leaders and laggards are obtained by pooling observations across Monte Carlo runs.

[20] The speed of convergence is affected by the parameter ω_0 defining the maximum speed of learning.

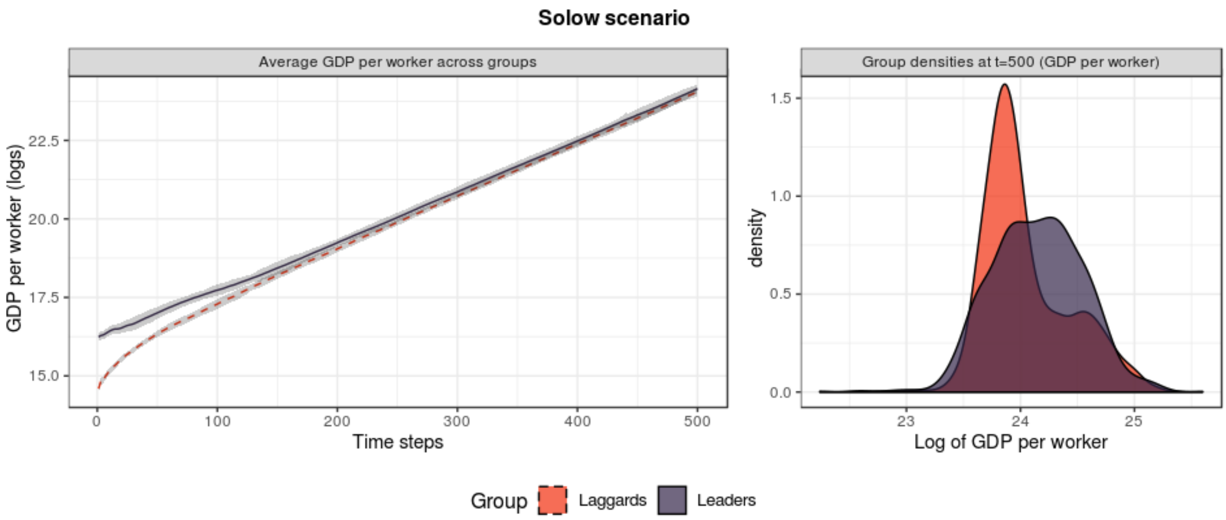

Figure 3: The Solow's scenario: average GDP per worker across groups and its distribution at t=500

not implement any form of industry protection (cf. the parametrization in Table 1). This captures the situation of many poor countries characterized by week innovation systems and strong dependence on imports from advanced nations. The top panels in Figure 4 report the dynamics of GDP per worker of leaders and laggards as well as its distribution at the end of the simulation. In the BAS regime, laggards dramatically fail to catch up with leaders, and the initial tendencies towards polarization are even reinforced as shown by the increasing distance of the two modes of the income distribution. This is the result of the "success breeds success" mechanisms present in the model (cf. Dosi et al., 2019b, for a discussion) and it resembles the trajectory of many developing countries that adhere to the policy doctrine of the "Washington consensus". Notice, however, that we deliberately assume identical countries in terms of resource endowments and, thus, we do not account for standard gains from trade associated to comparative advantages. Also, the model does not consider the role of multinational corporations and FDIs. Thus, we neglect two potential drivers of convergence for developing countries in the BAS setting. It should be stressed, nevertheless, that empirical support for both channels is at best weak.[21] As far as our model is concerned, given the presence dynamic increasing returns and widespread technological gaps, results are very likely not affected by the introduction of both static comparative advantages and FDIs.

Let us now introduce industrial policies and assess their impact. We capture different industrial policies via permanent changes in some structural parameters. The dimensions considered include: (i) the exogenous parametrization of search and absorptive capabilities which reflect the overall quality of the national innovation system, as well as the skills and competencies available in the country; (ii) the R&D investment share, being affected by direct (e.g. R&D subsidies) and indirect (e.g. procurement and tax credits) forms of public support; (iii) trade tariffs.

We explore three archetypal policy regimes, compared to the BAS setting, namely industrial policies (IP), innovation policies without tariff protection (INN) and tariff protection only (PROT). Table 1 shows the parametrization for each policy scenario. The IP regime is intended to mimic the experience of successful East Asian countries or, earlier, Germany and Japan. In such scenario, the gap in country-

[21] For instance, it is widely empirically acknowledged that sustained growth is driven by diversification towards complex products, rather than by a narrow focus on static comparative advantages (Dosi et al., 1990; Hausmann and Hidalgo, 2011; Berg et al., 2012). On the other hand, some empirical studies have questioned the role FDIs and MNCs for technological catch up (see e.g. Yu et al., 2015; Farla et al., 2016). For a critical review of the early empirical literature on free trade and economic growth see Rodriguez and Rodrik (2001).

Description	Parameter	Leaders	Laggards			
			Business as usual (BAS)	Only innovation policies (INN)	Only industry protection (PROT)	Industrial policies (IP)
R&D investment share	ρ	0.04	0.01	0.04	0.01	0.04
Search capabilities (innovation)	ξ_1	0.08	0.02	0.08	0.02	0.08
Search capabilities (imitation)	ξ_2	0.08	0.02	0.08	0.02	0.08
absorptive capacity (tech. distance)	ϕ_1	0.08	0.02	0.08	0.02	0.08
absorptive capacity (speed of learning)	ω_1	0.2	0.05	0.2	0.05	0.2
Tariff rate	$tariff$	0	0	0	100	100

Table 1: Policy scenarios: parameter values

wide capabilities and R&D investment with respect to leading nations has been closed as a result of policy efforts aimed at fostering the accumulation of knowledge while a general tariff is introduced to allow native firms to learn and build their own capabilities. For simplicity, we assume that both capabilities and R&D investment shares have been risen exactly to the level of leader countries. As a robustness check, we report in the Appendix results for a case with slowly increasing capabilities (cf. Figure B.1).[22] Albeit convergence occurs slowly, results are in line with those from the standard IP scenario. Historically, capability-building efforts are associated with transformative interventions such as reforms of the education system, strong support to innovative activities combining public research with direct and indirect support to firms' R&D and the implementation of large organizational changes at the firm level. In the INN setting, laggards only implement innovation policies and are assumed to have the same capabilities of leaders. This scenario resembles the exercise conducted in Dosi et al. (2019b) wherein countries where assumed to be structurally identical. In the PROT setup, laggards only impose tariffs without stimulating parallel enhancements in technological capabilities and R&D expenditures.

Results for the IP, INN and PROT scenarios are compared to BAS, as shown in Figure 4. The implementation of industrial policies results in a process of convergence of backward economies and in a reversal of polarizing forces. In that, our model is able to reproduce a growth dynamics similar to the one followed by East Asian tigers from the 70s and, later on, by China. Consistently, with results in Dosi et al. (2019b), even when countries have identical economy-wide capability parameters, the cumulative mechanisms in the model make large incumbents in leader nations keep their competitive advantage over small entrants located elsewhere. In turn, this suggests that infant industry protection is a necessary condition for catching up.

Interestingly, when laggards focus only on protectionist policies, the process of convergence is also much weaker and at the end of the simulation there is still a positive and significant income gap across the two groups of countries. This is reminiscent of the trajectory followed by some Latin American countries in the post-war period where import-substitution policies were implemented with a strong inward-looking orientation and without substantial efforts in upgrading their innovation systems. As shown by our model, such an exclusive focus on trade restrictions pushes laggard countries into a middle-income trap and to a general failure to reach the income status of developed economies.

5.2 Assessing different policy combinations

Table 2 compares the three main scenarios discussed above with a set of stand-alone policy measures to test their relative importance. This also allows us to discuss whether isolated interventions in specific areas are sufficient to spur the catching up process. As proxies of convergence we use the income

[22]In the simulation we assumed that laggards close the gap in economy-wide capabilities at 1% rate per period.

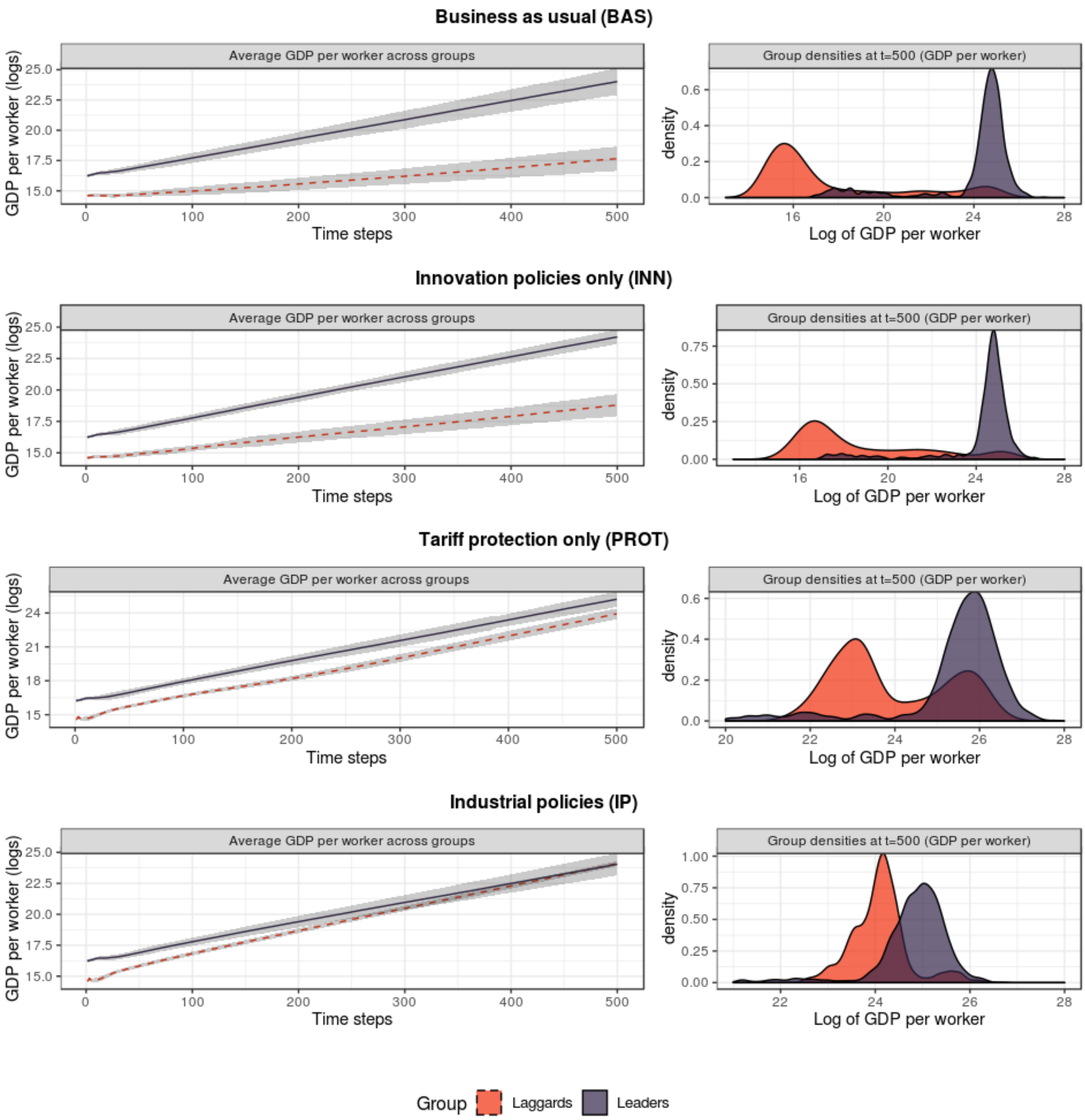

Figure 4: Main policy experiments: evolution of average GDP per worker across groups (left panels); kernel densities of GDP per worker at t=500 (right panels)

Experiment	GDP per worker (Leaders)		GDP per worker (Laggards)		Avg. Coef. Var.	Avg. Prod. Gap (A-B)
	Avg. Growth Rate	Final level (A)	Avg. Growth Rate	Final level (B)		
Main scenarios						
Business as usual (BAS)	0.0156	23.6300	0.0061	17.4717	1.4634	6.1583
	(0.0001)	(0.0431)	(0.0002)	(0.0858)	(0.0278)	(0.0788)
Only innovation policies (INN)	0.0160	23.8302	0.0084	18.5746	1.3947	5.2556
	(0.0001)	(0.0363)	(0.0003)	(0.1141)	(0.0180)	(0.1179)
Only industry protection (PROT)	0.0152	23.4340	0.0164	22.3671	1.1586	1.0669
	(0.0001)	(0.0283)	(0.0001)	(0.0301)	(0.0234)	(0.0368)
Industrial policies (IP)	0.0156	23.6504	0.0190	23.6443	0.8361	0.0061
	(0.0001)	(0.0337)	(0.0000)	(0.0178)	(0.0133)	(0.0387)
Stand-alone policy measures						
Support to R&D	0.0154	23.5832	0.0170	22.6909	1.1138	0.8924
	(0.0001)	(0.0361)	(0.0000)	(0.0211)	(0.0126)	(0.0414)
Search capabilities (innovation)	0.0152	23.4520	0.0164	22.3747	1.1862	1.0773
	(0.0001)	(0.0421)	(0.0001)	(0.0243)	(0.0191)	(0.0460)
Search capabilities (imitation)	0.0153	23.5171	0.0163	22.3123	1.2140	1.2049
	(0.0001)	(0.0423)	(0.0001)	(0.0261)	(0.0295)	(0.0506)
Abs. capacity (tech. distance)	0.0154	23.5341	0.0161	22.2288	1.1491	1.3053
	(0.0001)	(0.0337)	(0.0001)	(0.0305)	(0.0168)	(0.0443)
Abs. capacity (speed of learning)	0.0154	23.5388	0.0161	22.2311	1.1560	1.3077
	(0.0001)	(0.0335)	(0.0001)	(0.0315)	(0.0201)	(0.0359)

Notes: GDP per worker is in log-levels. Final GDP per worker levels, the standard deviation and the productivity gap are computed as averages of the last 50 time observations. Monte-Carlo standard errors are in brackets.

Table 2: Main policy experiments: summary of results

dispersion of GDP per worker (measured by the coefficient of variation) and the productivity gap among the two groups of leaders and laggards, both computed during the last 50 simulation steps.[23] We run one-by-one experiments with single policy parameters (cf. Table 1) in combination with the standard tariff. As expected, results suggest some positive effects on convergence but of lower magnitudes than in the IP scenario. Notwithstanding some degrees of heterogeneity, in all the instances considered both the final productivity gap and the standard deviation of GDP per worker remain much higher than in the IP case.[24]

Simulation results so far show that the IP regime appears to be the most effective in fostering the catching up of developing countries. Industrial policies, of course, interact with other structural parameters and policies which may hamper or facilitate the success of laggards. More specifically, in the IP scenario, let us experiment with different parameter values for the composition of R&D between innovative and imitative search (λ) and barriers to foreign imitation (ϵ). Results for both parameters are reported respectively in Figure 5 and Figure 6 using the measures of convergence already adopted in Table 2.

Simulation experiments indicate that the composition of R&D expenditures of the laggards has a considerable impact on growth dynamics of both leaders and laggards. Contrary to intuition, search efforts by backward countries (almost) exclusively devoted to imitation do not represent the best policy for catching up. We find a U-shaped pattern whereby too big a focus on imitation only hampers the convergence process, resulting in higher overall productivity gap. From this perspective, albeit very important, imitation efforts by laggard countries should be accompanied by parallel indigenous innovation attempts. This is reminiscent of the apparent paradox pointed out by Lee (2019): "you

[23] The productivity gap is measured as the log-difference of average GDP per worker levels between leaders and laggards. It may possibly become negative in case of forging ahead of the laggards.

[24] This result is in line with Cherif and Hasanov (2019), who identify the moonshot approach of South Korea as the most effective in comparison to more conventional recipes based on gradual leapfrogging and on fixing only specific domains of the innovation system.

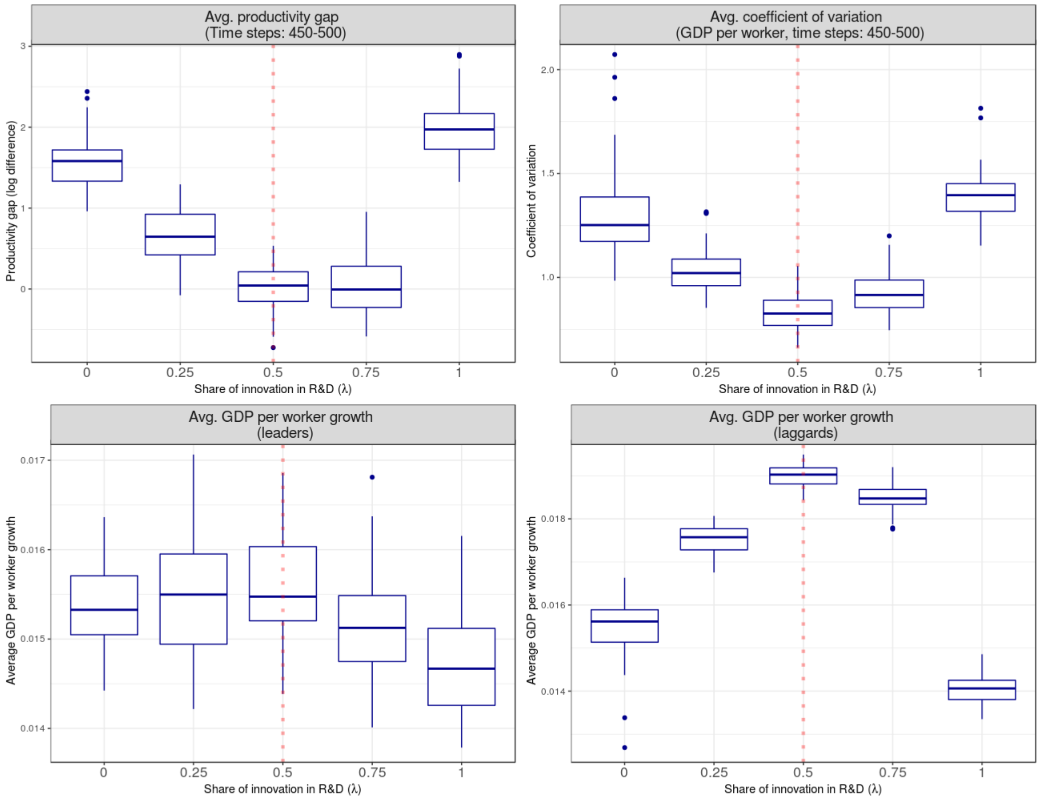

Figure 5: Composition of R&D expenditures: innovation vs. imitation (IP scenario) - boxplots of Monte Carlo distributions across parameter values (red dotted line indicates benchmark parametrization)

cannot catch up if you keep catching up".

Interestingly, highly skewed allocations of R&D for laggards in favour of imitation also affect the growth rates of leaders, thus, resulting in lower world GDP growth rates. Of course, these results are influenced by the fact that R&D investments in the model only affect the probability of being successful in imitation/innovation and not the "quality" of the outcome. Yet, it is remarkable how the pattern emerges without the need for further assumptions regarding the R&D process.

Barriers to foreign imitation (stemming from e.g. strong IPR regimes) are often identified as major obstacles to technological catching up of backward countries (Cimoli et al., 2009, 2014). This is confirmed also in our model as we find strong negative effects on growth performances of laggards associated to higher international imitation obstacles. Both the final productivity gap and GDP per worker dispersion rise significantly as ϵ increases. In turn, this entails that structural bottlenecks to adoption and diffusion of foreign technologies in backward countries are likely to pose serious threats to the effectiveness of industrial policies. Together, strikingly, under strong imitation barriers, growth slows down also for leaders and, thus, for the world as a whole.

6 Macro policies and the political economy of international relations: exchange rates, protectionism and retaliation

Our results show that a mark of the success in industrial policies is the ability of governments to protect infant industries while, at the same time, nurturing learning. However, crucial questions concern, first, the role of more conventional adjustment mechanism and policies thereof such as exchange rates and, second, the political economy of international relations whereby protectionist policies might be followed by retaliatory measures by advanced countries.

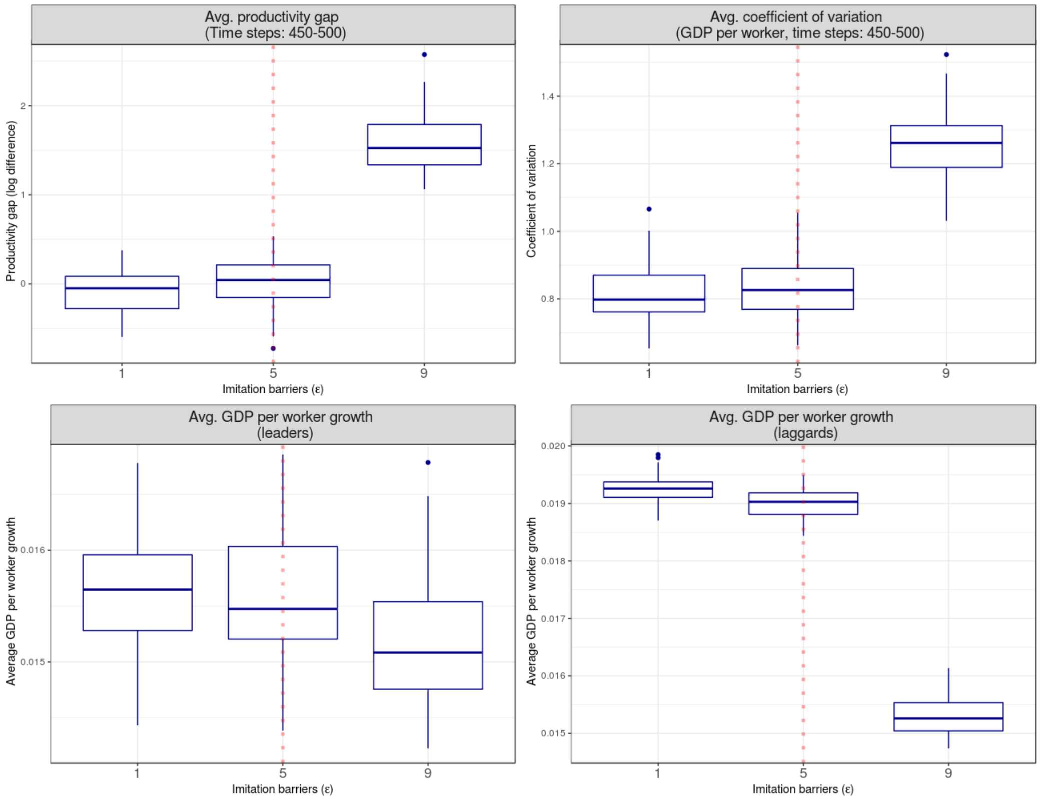

Figure 6: Barriers to foreign imitation (IP scenario) - boxplots of Monte Carlo distributions across parameter values (red dotted line indicates benchmark parametrization)

First, we study whether different degrees of exchange rate flexibility may interact, if at all, with industrial policies. In Figure 7 we report results for different values of the exchange rate adjustment parameter (γ) in the IP scenario. We find that more flexible exchange rates exert only negligible positive effects on the final productivity gap across groups. At the same time, faster exchange rates adjustments do not appear to reduce final income dispersion. These results suggest that overall the dynamics of exchange rates plays a very limited role in the catching up process. This applies, even more so, to the BAS scenario with basically no long term effects of exchange rates adjustments, in tune with our earlier findings in Dosi et al. (2019b).[25]

Let us now focus on the interactions between tariff levels and the duration of the protection period. We experiment with three initial tariff levels (i.e. 100, 500 and 1000) and different rate of tariff decrease (i.e. 0.01, 0.025, 0.05). We also include the case with constant tariffs as a benchmark for comparison. Figure 8 displays the results. Holding constant the duration of the protection period, tariff size positively affects the convergence of laggards. Despite being associated with larger static losses (i.e. rising initial consumer prices), higher tariffs translate in faster growth rates of GDP per worker for laggards while having no substantial effects on the economic performance of leaders. As a consequence, both the average productivity gap and the dispersion of GDP per worker in the final periods of the simulation tend to fall. As for the length of the protection period, our results show that, depending on the initial tariff level, a relatively high rate of tariff decrease may hamper the catch up of the laggards. More specifically, significant increases in the final productivity gaps and income dispersion emerge for rates of tariff decrease greater or equal to 2.5%. Overall, these results suggest that both the tariff level and its rate of decrease should reflect the initial distribution of technological gaps and providing sufficient time for firms to learn and build the necessary capabilities to compete in international markets.

[25]Results for the BAS scenario are available upon request from the authors.

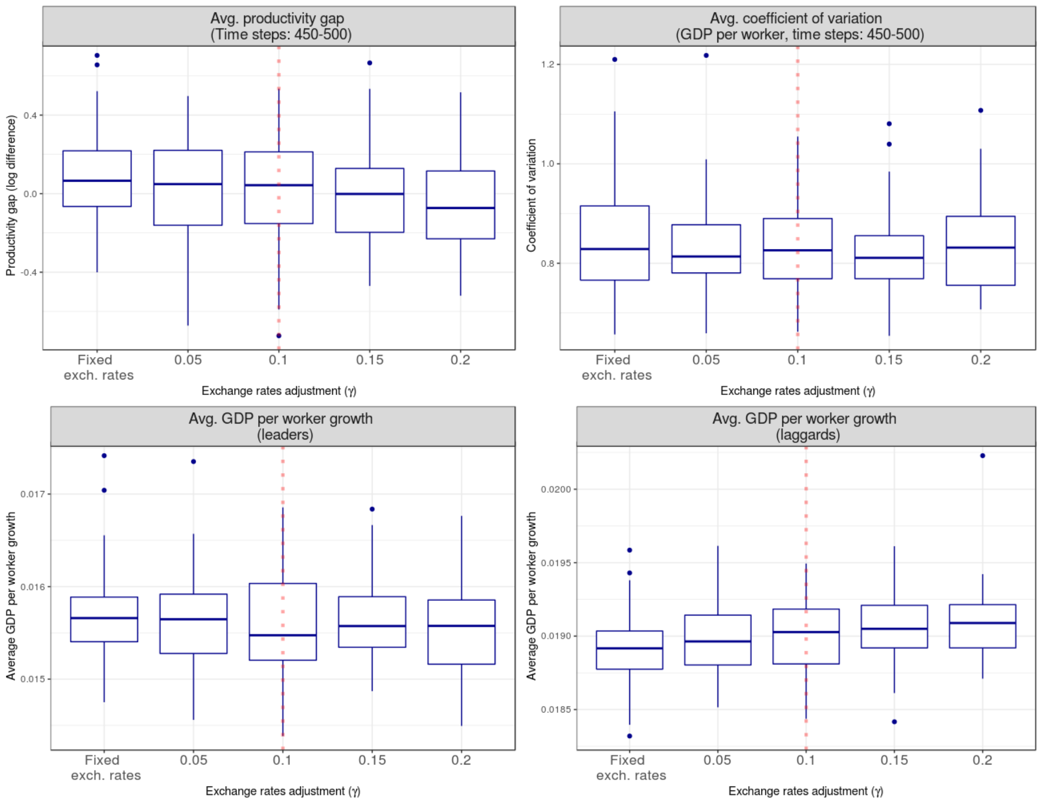

Figure 7: Exchange rates flexibility (IP scenario) - boxplots of Monte Carlo distributions across parameter values (red dotted line indicates benchmark parametrization)

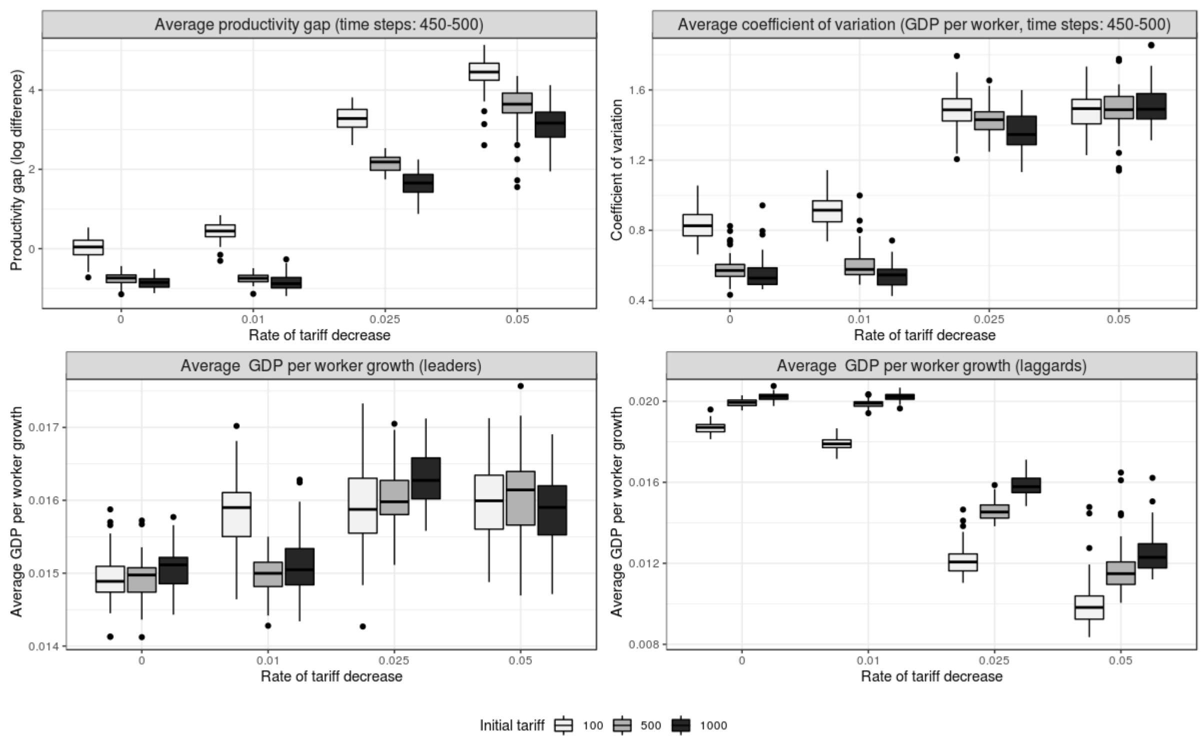

Figure 8: Tariff size and duration of protection period - boxplots of Monte Carlo distributions

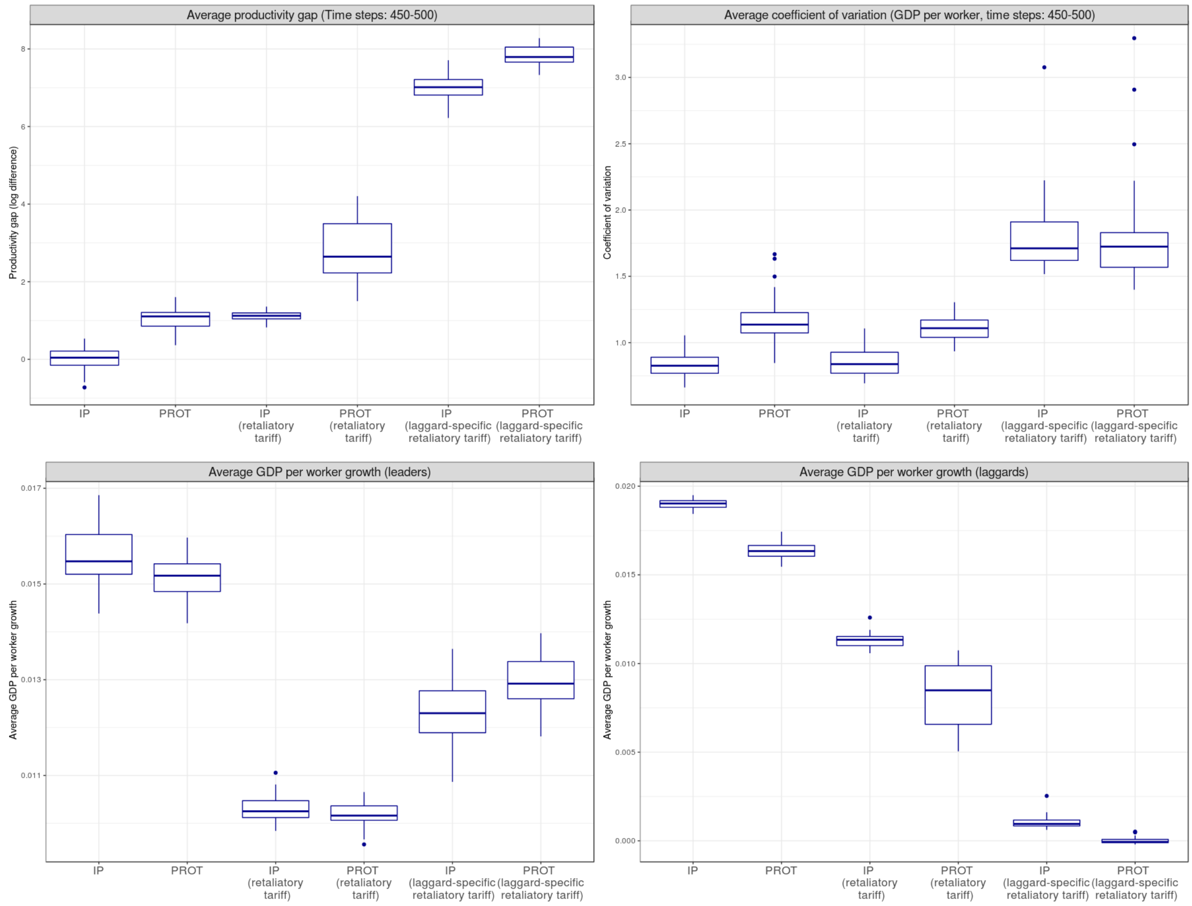

Figure 9: Retaliatory tariff experiments - boxplots of Monte Carlo distributions

So far, we have assumed that only developing countries can impose tariffs. As a final experiment, we study a scenario in which leaders may introduce a retaliatory tariff of the same amount of that adopted by laggards.[26] The effects of a retaliatory tariff are analyzed in Figure 9, which reports Monte Carlo boxplots for the IP and for the PROT settings. These are contrasted with the baseline IP and PROT experiments in absence of retaliatory tariffs. Results suggests that in the "trade war" scenario, both leaders and laggards are worse off. GDP per worker growth of both groups falls and the final productivity gap increases. This stems from the large drop in world consumption associated to the adoption of the tariff by leaders, which account for a considerably larger proportion of world aggregate demand than laggards. In turn, lower aggregate demand, translates in lower R&D expenditures and in a general slowdown of productivity growth. For the sake of comparison, we also report results for a scenario in which leaders impose a tariff only on laggards (i.e. a laggard-specific retaliatory tariff). Although growth increases for leaders, they are still worse off with respect to the case with no tariff response. For laggards, instead this translates in an even more dramatic fall in growth rates which drives a drop in world productivity growth, also resulting in stronger divergence.

Our results highlight the widespread negative effects of generalized protectionist policies and suggest that leading countries would be better off if they do not respond to the trade tariffs introduced by laggards. This is coherent with the historical experience and suggests a negative impact on the world economy of recent protectionist trends (cf. the U.K. and the U.S.).

[26]For simplicity, the tariff is introduced at the beginning of the simulation. Results are robust even when the response of the leaders comes with some lags. They are available upon request from the authors.

7 Concluding remarks

In this paper, we have extended the agent-based model in Dosi et al. (2019b) to study how backward countries can catch up with the technological frontier and climb the income ladder by means of different policy combinations. The initial condition is a world economy characterized by a group of leading countries and another of laggard ones, exhibiting large productivity gaps in most of the industries.

Our results vindicate the notion that the implementation of industrial policies is a fundamental instrument for developing countries to foster economic growth and catch up with leading economies. Indeed, in a "Washington consensus" scenario, where there are no policy to speak of, simulation results show a strong and persistent divergent process with an increasing productivity gap for laggards. Such result stems from the inability of firms in developing economies to absorb the technological knowledge generated abroad, stifled by the lack of protection for local infant industries. On the contrary, international catching up emerges when laggards implement an ensemble of industrial policies which foster the development of domestic technological capabilities. This resembles the experiences of East Asian economies and China. Policies ought to involve much more than sheer tariffs. The latter alone are not sufficient and laggards remain locked in a middle-income trap, as historically happened to many South American countries.

Again in line with the historical evidence, an uneven playing field with asymmetric abilities for developing countries to nurture their local industries appears to be a win-win scenario for the world economy as a whole, as indeed happened in the long phase of "conditional convergence" prior to WWI. Conversely, we find that in a global trade war where leading countries can impose retaliatory tariffs, everyone is worse off and also world GDP and productivity growth considerably slow down. Overall, these results complement from a macro perspective those from models of industry dynamics presented in Landini et al. (2017) and Landini and Malerba (2017).

Our work can be extended along several routes of research. First, the most obvious development would concern the acknowledgement that "microchips are not potato chips" (Dosi et al., 1990; Cimoli et al., 2020; Dosi et al., 2020b), that is, sectors differ in their learning opportunities and income elasticities as robustly captured even by the simple evidence on "product complexity" (Hidalgo et al., 2007; Tacchella et al., 2012, 2013). In turn, all this implies that policies targeted at specific high opportunity sectors are likely to be even more important than the "blanket" policies discussed here. Second, a less rudimentary characterization of international trade certainly involves modelling global value chains, trade in capital goods and international investment by MNCs. More specifically, more efforts should be devoted to the investigation of the role played in the catch up process by domestic industries for capital and intermediate goods. Finally, the model at this stage does not consider product quality and it can be extended to account for heterogeneous varieties and product competition. What is highly encouraging is that the paramount role of industrial, trade and technology policies emerges even in the foregoing heroically simplified setup.

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Appendix A Benchmark parametrization

Table A.1 provides the values of parameters for the benchmark run.

Description	Symbol	Value
Number of countries	N	60
Number of industries	M	30
Number of firms (each industry)	S	20
Sectoral demand shares	s_h	$1/30$
Capital-output ratio	B	3
Mark-up adjustment parameter	υ	0.04
R&D allocation parameter	λ	0.5
Maximum rate of adoption	ω_0	0.05
First stage probabilities upper bound	θ_{max}	0.75
Beta distribution parameter	(α_1, β_1)	(1,5)
Beta distribution support	$[\underline{x}_1, \bar{x_1}]$	[-0.05,0.25]
Beta distribution parameter (ent.)	(α_2, β_2)	(1,5)
Beta distribution support (ent.)	$[\underline{x}_2, \bar{x_2}]$	[-0.03,0.15]
Foreign imitation penalty	ϵ	5
Foreign competition penalty	τ_0	0.05
Replicator dynamics parameter	χ	1
Wage sensitivity parameter	ψ	1
Exchange rates flexibility	γ	0.1
Exchange rates shocks std. dev.	σ_e	0.002
Depreciation rate	δ	0.02
Monte-Carlo replications		50

Table A.1: Benchmark Parametrization (group-invariant parameters)

Appendix B The IP scenario with slowly increasing capabilities

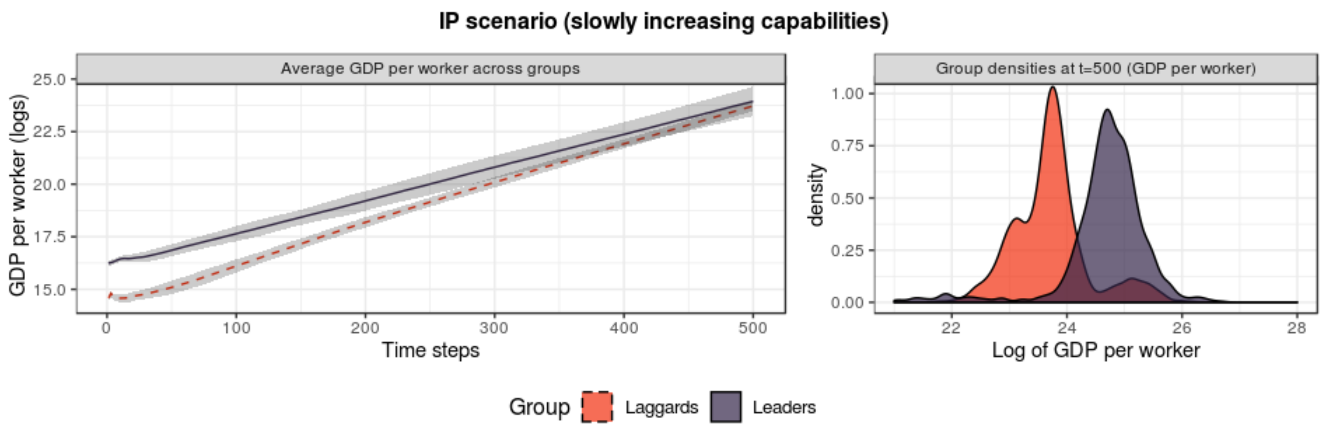

Figure B.1: The IP scenario with slowly increasing capabilities