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Modelling the effects of rapid technological change and international protection of intellectual property in the inequalities between countries

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Abstract

This paper examines the effects of rapid technological change and the intellectual property rights (IPR) regime on income inequality across countries. The analysis is carried out through computer simulations of a multi-country multi-sector evolutionary economic model with endogenous technological change, change in consumption patterns and diversification. It considers multiple countries engaging simultaneously in innovation and emulation. The results show that rapid technological change results in higher global GDP but also higher inequalities between countries. In this context, the relaxation of international protection of intellectual property rights could further increase global GDP and serve as an equalizing force, reducing the inequalities between countries. However, low-income countries do not benefit much from mechanisms that facilitate emulation in all countries equally. They require special interventions that foster their innovation and emulation capacities and increase the set of technologies available in their economies, so they are not left behind. These results are highly significant and relevant in the current context of rapid technological change with digital transformation and Industry 4.0.

Key words: Innovation Policy, Income inequality, Diversification, Structural Transformation, Productive Capacities, Economic Development, Intellectual Property Rights.

Contents

Acknowledgements

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1. Introduction

The world is at the peak of the "Age of ICT" and the beginning of a new techno-economic paradigm of Industry 4.0 (Perez, 2010; Schwab, 2013; UNCTAD, 2021). The great divides between countries that we see today started after the first industrial revolution (Maddison, 2001). Since then, every wave of progress was associated with widening inequality between countries. By 2018, the gap in the average income per capita between developed and developing countries had reached over $40,000 (UNCTAD, 2021). How will Industry 4.0 affect inequalities between countries?

A significant concern nowadays is that the rapid pace of technological change would make it more difficult for developing countries to learn and apply these new technologies into their production, hindering the opportunities of these countries to catch up (UNCTAD, 2021). At the same time, past technological waves provided windows of opportunity for few developing countries to catch up and others to leap ahead, as in the Republic of Korea during the onset of the Age of ICT in the 1970s (Perez, 2002).

This paper examines the effects of rapid technological change and the intellectual property rights (IPR) regime on income inequality across countries. It focuses on the relationship between "new to the world" innovation (herein called innovation) and "new to the country" innovation (herein called emulation) and their impact on developed and developing countries' welfare and inequality between countries. Technological change in developing countries is usually the result of the emulation[1] of more technologically advanced countries. Such emulation is affected by international rules regarding technology transfer, such as international protection of intellectual property rights (IPR).

This analysis is closely related to the problem studied in the literature on product cycle models, which has analyzed the relationship between innovation, technology diffusion, and whether and to what extent developed and developing countries benefit from technology transfer (Krugman, 1979; Grossman and Helpman, 1991; Helpman, 1993). This literature is divided mainly into models based on variety expanding innovation and quality ladders. In general, both approaches consider only two countries (North and South) and adopt full specialization of exports (North and South never export the same product). In product cycle models based on variety expanding innovation, the North innovates and creates new products through product innovation; after a while, the South emulates the North and produces that exact product. Thus, initially, the North exports the product to the South, and later the South exports that product to the North (Krugman, 1979; Grossman and Helpman, 1991). In the quality ladders framework, a product is again created initially in the North through product innovation. The South emulates that production, but the North innovates to create a new vintage of the product. In this case, the North will be the producer and exporter of that latest vintage until the South again emulates the production. A full specialization pattern moves back and forth between North and South (Grossman and Helpman, 1991).

Despite the over three decades of studies in this literature, there is still no clear answer to who benefits from technological transfer. The findings of the models in this literature suggest that innovation and emulation affect inequality across countries depending on their interlinkages (how innovation affects emulation and vice versa). For example, in a seminal paper in this literature, Krugman (1979) considers two countries, an innovating North and an emulating South, and innovation and emulation as exogenous and independent. The results of his model suggest that slowing innovation or increasing emulation narrows the wage gap between the North and the South (reduces inequality), and it even leads to a decline in living standards in the North. Faster innovation benefits the North but is detrimental to the South, while slower innovation and more rapid emulation have the opposite effect. On the other hand, Grossman and Helpman (1991), another seminal work of the literature, endogenize innovation and emulation in a two-country model. The result of their model suggests a positive feedback loop between innovation and emulation. They found that faster technology transfer (emulation in the South) could create incentives for innovation in the North. The result is that long-run growth is higher with technology transfer.

Another finding is that the speed of innovation and emulation affects the inequality between countries. For example, Helpman (1993) provides a welfare study of the impact of changes of IPR regimes. He uses models

[1] In the literature of technological change emulation is usually referred as imitation. In this paper the term is used as in Reinert (2008) “imitating in order to equal or excel,” and refer to the “new to the country” product innovation.

with exogenous and endogenous innovation and emulation, considering an innovating North and emulating South. He found that although the North benefits from stronger IPR that reduces technology transfer, both regions lose with stronger IPR when the emulation happens at a slow pace.

A limitation of most models in this literature is that they consider that only the North innovates, and only the South emulates.[2] In reality, both North and South can innovate and emulate. For example, from 1996 to 2018, China, which is considered part of the "global South," accounted for high shares of the patents in many new technologies: 72% in solar photovoltaic, 47% in big data, 43% in the Internet of Things, 26 % in 3D printing and 20% in artificial intelligence (UNCTAD, 2021). Developed countries also emulate others' production; this is done, for example, through licensing within the IPR regime.

Another limitation is that most studies consider only two countries, North and South. However, the global North and global South are not homogenous. There are different levels of capabilities and output within each group. An example of a study that considers more than two countries is Lin (2010), which proposes a model with three countries (North, Middle, and South), in which the North innovates, the Middle emulates and is a source of FDI to the South, which do not innovate nor emulate. The model assesses the impact of tightening FDI from the Middle to South and found that there are situations in which tightening FDI will benefit the Middle at the expense of the North and South; thus, North and South have different interests of Middle. Nevertheless, this strand of the literature does not consider other countries besides North, Middle, and South, which can also affect innovation and emulation in these three countries.

This paper takes a different approach to the models of the product cycle literature. It uses a multi-country multi-sectoral evolutionary economic model with endogenous product and process innovation and emulation proposed by Freire (2019). Using this model, this paper expands the analysis to many countries that can simultaneously engage in product and process innovation and emulation. Given the complexity of models with many countries and sectors, the analysis is conducted through computer simulations. This paper analyses the impact of different rates of innovation and emulation on the total GDP of the poorest (low-income), median (middle-income), and richest (high-income) countries.

2. The model

This section presents a brief description of the model used in this paper, proposed by Freire (2019). A detailed presentation of the model is beyond the scope of this paper. For information, the Appendix contains the list of variables and equations of the model. Freire's model formalizes Pasinettis's (1993) theoretical framework of structural change and economic dynamics of open economies and adds endogenous technological change, change in consumption patterns, and diversification of economies.

In the model, many countries produce a variety of products and trade with each other. Labour is the only factor of production.3 The units of the analysis of the model are the sectors that constitute an economy. Each country's economy comprises one household sector, many production sectors, and one research and development sector (R&D).

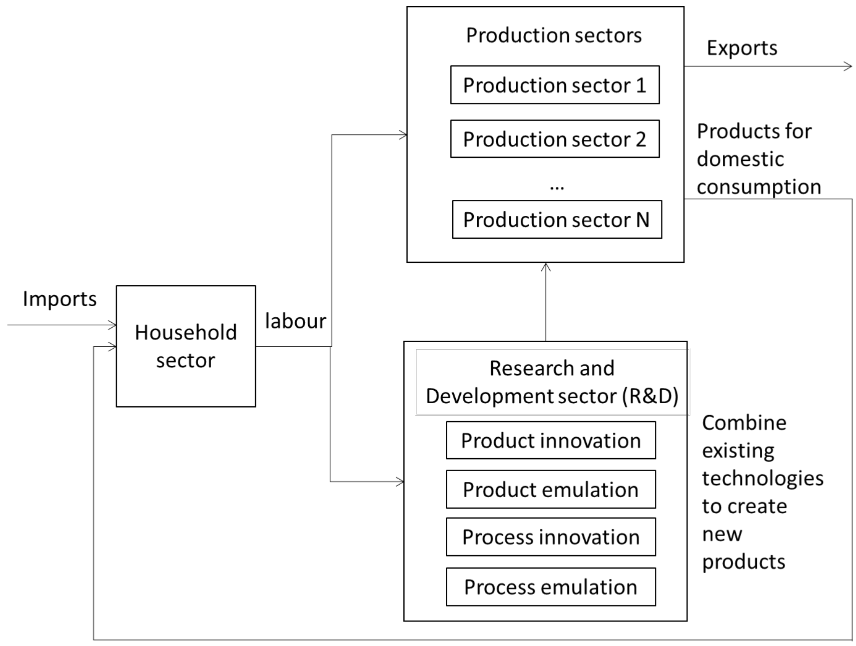
The household sector comprises the country's population, provides labour to other sectors, and consumes products (domestic or imports). Consumption coefficients give the consumption per capita of each commodity. Labour is uniform in quality so that each unit of labour is equivalent as a means of production and remunerated by a uniform wage rate. Labour is mobile between production and R&D, but it is not mobile between countries (no migration). In each period and each country, a proportion of the population is engaged in the production sectors; the rest is either working in the R&D or is unemployed.

Each production sector produces one single good, and all products are final goods. Labour productivity levels in each production sector are given by labour coefficients, which reflect the amount of labour required to produce one unit of product. Different from Pasinetti's framework, a specific set of labour-embodied technologies characterizes each production sector. Technology is defined as a means to fulfil a human purpose, following Arthur (2011), and it can be a method or process. The model assumes monopolistic competition in domestic and international markets, and markups for prices of the products.

2 An exception is Grossman and Lai (2004) use a North-South model in which both countries can innovate and emulate. They find that stronger IPR protection benefits the North at the expense of the South.

3 This is a common assumption in models of structural dynamics, and focus the analysis on the processes of technological change instead of capital accumulation, e.g. see Passinetti (1993).

Figure 1. Country's economy: household, R&D and production sectors



Source: Author based on Freire (2019).

Each country has one R&D sector in which workers search for combinations of technologies that result in products that fulfil human needs. The wage of the workers comes from the production sectors through the price markups of their products. Thus, the sum of markups in the production sectors limits the number of workers in the R&D sector. Another constraint is the number of people not employed in the production sector and who can join the innovation efforts. The model assumes that production sectors have priority in engaging workers before R&D sectors.

All products are tradable, and countries can trade freely without trade costs. All output produced is consumed. Domestic production can be consumed domestically, exported, or both. Domestic consumption is the sum of the domestic consumption of the commodity locally produced and of that imported. Total exports of a given country do not need to match the country's total imports. The balance of payments of countries is not necessarily balanced at each period.

The model divides time into periods. Within each period, the model determines which country specializes in which products based on the demand, prices of products, and the amount of labour available for production. At each period (short-run) and country, the following state variables are given: labour coefficient of each sector, coefficient of consumption per capita of each commodity, markup prices, and wage. Prices, quantities produced, markups and wages are endogenous. The price of products is the amount of labour required for the production times the wage rate multiplied by the markup of the sector. In addition to the markup mechanism, which results in more than one country selling products for the same price, the model also accounts for the incomplete specialization of production and trade due to the limit in labour available for production. Therefore, the model does not assume ex-ante full specialization and allows for situations where similar products with different labour costs coexist in the global market.

In the long-term dynamics of the model, the economy changes with changes in consumption patterns and technical progress. However, different from Pasinetti's framework, both changes are endogenous to the model. Similar to Pasinetti's framework, consumption patterns change according to a generalized version of Engel's law: (i) as incomes increases, there is a hierarchical order on the rate of satisfaction of needs, (ii) there are changes in consumption due to appearance of new products; (iii) there is a saturation of consumption. The saturation point of each product is not correlated with the hierarchy of essential goods. A less essential good could reach its saturation point earlier than an essential product. The appearance of a new product also changes the saturation point of the existing products. People may demand more and more of a product and less and less of others. The model also adopts the Keynesian view of consumer demand, in which households use a two-step decision process and decide on their demand for goods only after their actual incomes are known. First, households receive their income and, based on that and the current prices of products, decide on consumption preferences for the next period. If the income received is lower than the latest expenditure, then people choose to consume less. If, on the other hand, the income received is higher than the latest expenditure, then people will decide to consume more. When households consume in the following period, firms decide the level of employment to fulfil that demand, which determines income in the next period.

Regarding technological change, the model considers that all countries can perform product and process innovation and emulation. Process and product innovations, which create a product or process that is new to the world, are assumed to be less frequent events than emulation, which is an innovation that creates a product or a process that is new only to the country. Those who try to emulate have more information about the potential new product than those trying to create a new product for the world. Emulators may not know how to produce the new product initially, but they know the services it provides and the human needs it fulfils, and they know that there is a demand for the product.

In the model, the evolution of economies is path-dependent. The goods that a country can produce at any point affect what the country will produce next. In each period and each country, there is an "adjacent possible," as per Kauffman (2010), of potential new sectors that could be created in a single step by the permutation of the existing set of technologies. For example, if a country has three technologies (a, b and c), the adjascent possible of the country will be the permutations of these technologies (aa, ab, ac, ba, bb, bc, ca, cb, cc). Therefore, product innovation and emulation have to be part of the adjacent possible of the country. The model considers that some potential new products in the adjacent country's adjacent possible are not relevant solutions. They may be a permutation of technologies, but they do not fulfil any human need. Therefore, only a subset of the adjacent possible would result in a new process or product through process innovation, product innovation, or emulation

The R&D sector performs innovation and emulation in each country. The emergence of new processes or products in one country triggers the effort of emulation in other countries. There are also knowledge spillovers between sectors because the technologies used in the production of a product in one sector can be combined with technologies of different sectors to create new processes and products. The closer the economy is to full employment, the higher is the effort towards process innovation to reduce the labour requirement in the existing production base. Similarly, the higher the level of unemployment, the higher is the effort towards product innovation to create new sources of demand and employment.

Of the number of people dedicated to process innovation, part of them works on process innovation new to the world. The remaining works on the emulation of process innovation that happened in other countries. The backwardness of the production base determines the allocation between these two groups. The higher the share of sectors that uses technologies that are not at the frontier (i.e., have lower productivity than the same sector in other countries), the higher the share of people dedicated to process innovation that emulates the most advanced technologies.

As for product innovation, the share of people dedicated to finding new to the world innovations and the people devoted to emulation is given by the economy's diversification. If the economy is less diversified, there are many opportunities for imitating the products that already exist in more diversified countries. Thus, more people will be engaged in the emulation process than in creating products that are new to the world. On the other hand, if an economy is already much diversified, there are fewer products in the world that are not already produced by that economy. As a consequence, fewer people will be engaged in the emulation of production, and more people will be trying to innovate. Thus, the higher the diversification, the higher the share of people involved in product innovation instead of emulation, and vice versa. The rate of product emulation is also affected by the demand for the product. Sectors that are rapidly expanding attract more emulation efforts than slow-growth or declining sectors.

The outcome of the work of one person engaged towards product innovation or emulation takes the form of a Poisson process; thus, product innovation (emulation) are random processes in which a product innovation (emulation) does not affect the time that it takes for the next product innovation (emulation), but the average time between product innovations (emulations) is known (arrival rate of the Poisson process). For the objectives of this paper, two critical parameters in the model are the arrival rates of product innovation ($\lambda_k^{product}$) and product emulation ($\lambda_k^{emulation}$). The analysis simulates rapid technological change by increasing the arrival rate of product innovation ($\lambda_k^{product}$) and simulates changes in the international level of protection of IPR by changing the arrival rate of emulation ($\lambda_k^{emulation}$), as further discussed in the next section.

3. Simulation and results

This section verifies how different rates of product innovation and emulation would affect the GDP of countries, the inequality across countries, and their level of diversification. To conduct those tests, we run simulations of the model 100 times, considering 50-time units to test different runs of the stochastic process that uses the same set of initial parameters. For this analysis, we consider ten countries initially trading six products. The countries have the same population size (100 people) and, initially, the same labour and consumption coefficients. Therefore, they have the same productivity, income, and consumption levels. We track results related to diversification and output (GDP) for all countries and inequality across countries. The Appendix lists the initial parameters.

For each set of simulations, we vary the parameters related to the arrival rate of product innovation ($\lambda_k^{product}$) and product emulation ($\lambda_k^{emulation}$). As discussed in the previous section, the former varies the rate of technological change, and the latter replicates the level of international protection of IPR by making emulation more difficult. For example, for a given value of the parameter of the arrival rate of product innovation, we make emulation very easy by considering the parameter of the rate of arrival of product emulation as ten times the rate of arrival of product innovation, and then increase the level of difficulty in equal intervals until product emulation becomes as difficult as product innovation ($\lambda_k^{emulation} = \lambda_k^{product}$). The rate of arrival of product innovation takes the values of {1/100, 1/125, 3/500, 1/250, 1/500}. The scenario in which $\lambda_k^{product} = 1/100$ indicates that a researcher is expected to find a new product on average every 100 units of time, while the scenario in which $\lambda_k^{product} = 1/500$ a new product is expected to be discovered by one researcher every 500 units of times. During the simulations, we consider that process innovation is as difficult as product innovation, and process emulation as difficult as product emulation:

$$\lambda_k^{process} = \lambda_k^{product}$$

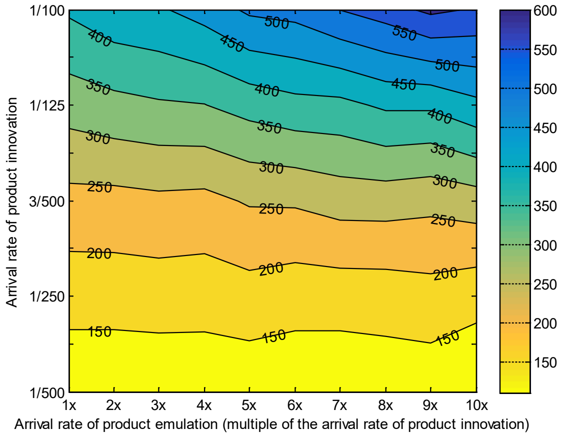
$$\lambda_k^{process\_emulation} = \lambda_k^{emulation}$$

Figure 2 shows the average global GDP of 100 runs for each set of parameters. The figure shows the arrival rate of product innovation in the vertical axis, which increases from the bottom (arrival rate of 1/500) to the top (arrival rate of 1/100). In the horizontal axis, the figure shows the rate of arrival of product emulation represented as a multiple of the rate of arrival of product innovation. It increases from the left (1x) to the right (10x). Thus, the left side of the graph represents the scenarios of the most stringent international protection of IPR. The contour lines in the graph connect points representing combinations of product innovation and emulation rates that result in the same values of global GDP. Different colours in the figure represent different values of global GDP. Although the graph shows eleven colours, it represents a continuous set of results highlighted by the legend on the right side of the graph.

The figure shows that the level of global GDP is associated with product innovation. For lower rates of product innovation, this association is mainly independent of the level of product emulation. Intuitively it makes sense because although emulation reduces the output of the country/sector that was the original product innovator, an equivalent level of output is created by the country/sector that emulates the production. If it is very easy to emulate, many countries may be able to emulate the production of the original product innovator, in which case the competition will drive the price of the product down. This increases consumption of the whole basket of products in most countries, increasing the total output. The figure shows that for higher rates of innovation, the easier emulation (low international IPR protection) results in a higher level of global GDP. That effect of emulation on total GDP is small when technological change is slower (lower part of the graph). Still, it becomes evident for faster emulation and product innovation (top right corner of the graph).

Emulation (international IPR protection) also has a large effect on the distribution of output between countries. To illustrate that, Figures 2, 3 and 4 show how the value of GDP of the poorest (low-income), median (middle-income) and richest (high-income) countries at the end of each run vary with the different parameters for product innovation and emulation. The GDP values are shown as a percentage of the global GDP.

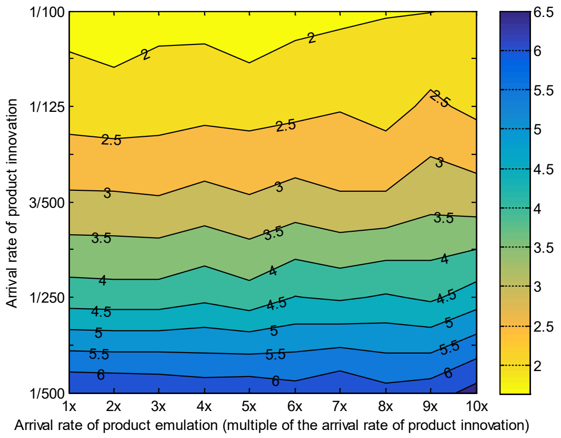
Figure 2. Global GDP, ($)



Source: Author.

In Figure 3, the results vary mainly in the vertical dimension, increasing from the top to the bottom. That suggests that the faster the product innovation (rapid technological change), the lower the relative GDP of the low-income country. Intuitively, these countries were not successful in innovating, therefore, when product innovation is faster, other countries benefit the most, and the poorer countries lag further behind. The figure also shows that the level of international protection of IPR (emulation) has a small effect on low-income countries.

Figure 3. Low-income country, percentage of Global GDP

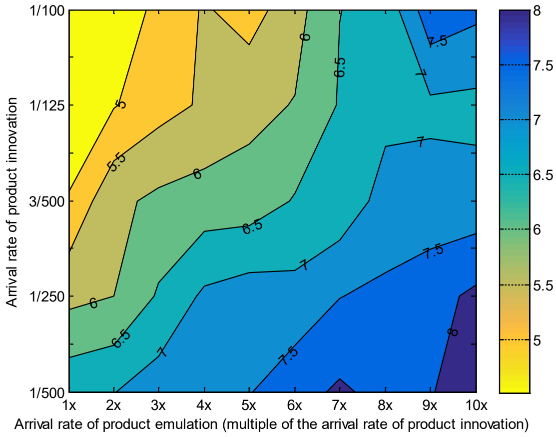


Source: Author.

Figures 3 and 4 are fundamentally different from the previous one because now the GDP value varies mainly horizontally instead of vertically. That means that product emulation (international IPR protection) has a larger effect than product innovation (the pace of technological change) in the relative value of GDP of the middle- and high-income countries. Figure 4 shows that the easier the emulation for the same level of product innovation, the higher is the relative level of GDP for the middle-income country. Figure 5, on the other hand, shows that the high-income country is better off the faster the product innovation and the more difficult the emulation process (more stringent international IPR protection).

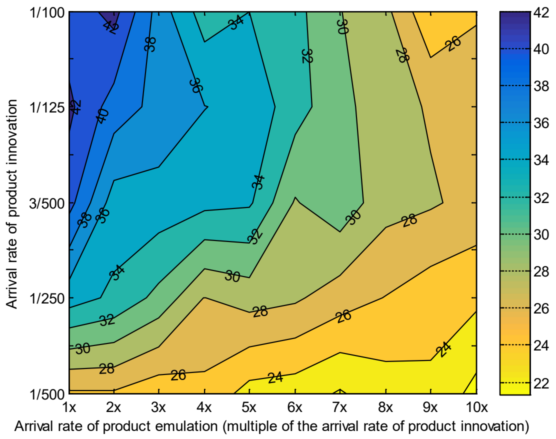
Intuitively, the countries that would tend to benefit first and the most when emulation is facilitated (international IPR protection is relaxed) are the ones that are already somewhat successful in innovating and have accumulated the set of technologies required to emulate the production of the original innovator. That explains why the level of GDP for the low-income country is essentially independent of the level of emulation, while emulation has a large effect on the shares of total GDP of the middle- and high-income countries.

Figure 4. Midde-income country, percentage of Global GDP



Source: Author.

Figure 5. High-income country, percentage of Global GDP



Source: Author.

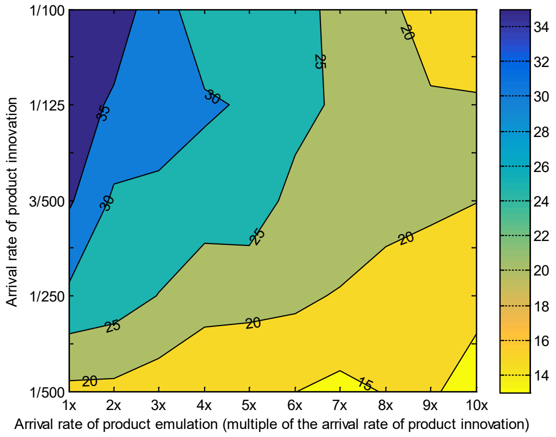
If emulation is facilitated (international IPR protection relaxed) to the degree that even low-income countries can quickly emulate the production of other countries, then the majority of countries are able to also benefit from technological progress, which is reflected in higher shares of total GDP. The effect is strong for the middle-income country (left side of Figure 4) but also noticeable on a smaller scale in Figure 3 for the case of the low-income country.

Figures 6 and 7 summarize the effect of the different rates of product innovation and emulation on the income inequality between countries. The figures show that faster product innovation (rapid technological change) is associated with higher levels of inequality across countries, but that tendency could be counteracted by facilitating emulation (relaxing international IPR protection).

The positive association between product innovation and inequality across countries could be explained by the combinatorial nature of the innovation process, in which the combination of existing technologies creates new products. Not all possible combinations generate useful products; nevertheless, that process creates increasing returns that make successful innovators distance themselves in terms of GDP from relatively less innovative countries.

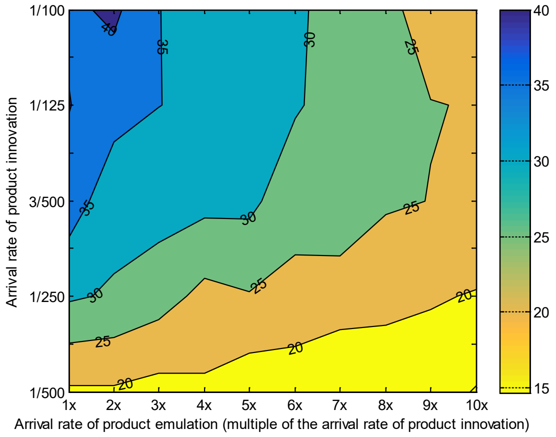
However, for a given level of product innovation, easier emulation gives countries more chance to catch up. First movers still benefit from being more successful in product innovation and having a larger set of technologies to create even newer products. Still, faster emulation reduces the first-mover advantage. When a product is emulated, market share and the associated production to attend that demand shift from the original innovator to the emulator. That process reduces inequality across countries.

Figure 6. Income inequality (Difference between high- and middle-income countries as a percentage of Global GDP)



Source: Author.

Figure 7. Income inequality (Difference between high- and low-income countries as a percentage of Global GDP)



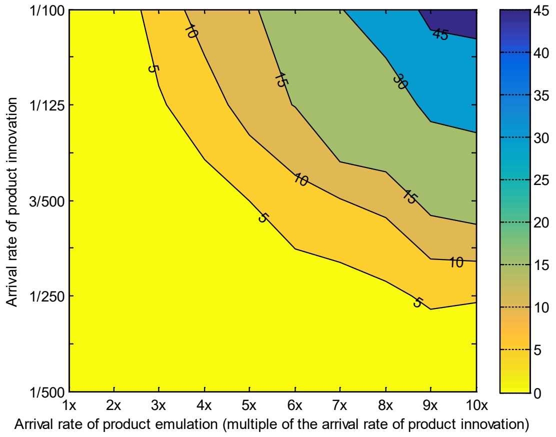
Source: Author.

In an initial approximation, people in low- and middle-income countries would prefer to live in a world where there is fast product innovation and emulation (rapid technological change combined with low international protection of IPR). In that world, they would have higher GDP per capita, and the inequality across countries is lower. People living in high-income countries, in their turn, would be better off in a world with fast innovation but in which emulation is difficult (rapid technological change combined with stringent international IPR protection). That is a narrative consistent with the prevalent view that more developed countries prefer institutions that provide strong protection to their original innovation efforts. In contrast, developing countries prefer more policy space in which emulation is facilitated.

However, it is important to note that although emulation affects distribution, reducing the share of total GDP of richer countries, the effect on the absolute level of GDP of these countries is less dramatic. The reason is that, as shown in Figure 2, global GDP increases with faster emulation for a given level of product innovation, which somewhat compensates for the reduction in the share of total GDP. Moreover, even in a scenario of faster emulation, high-income countries' share of global GDP is still several times higher than middle-income countries. Therefore, faster innovation and emulation make people from low and middle-income countries better off without a large negative effect on the GDP per capita of people in high-income countries.

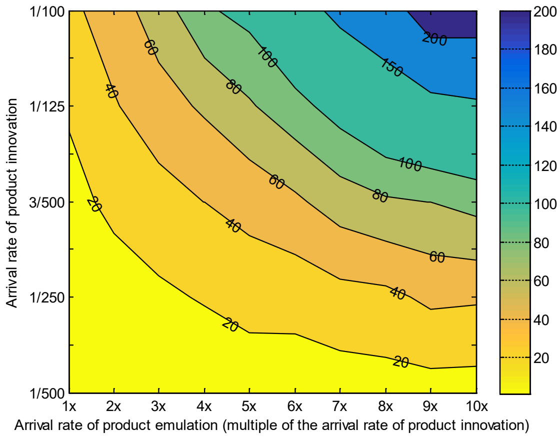
Faster emulation has an additional positive effect that is stronger in high-income countries. It increases diversification, the total number of products used to fulfil a larger set of human needs. Figures 8, 9 and 10 illustrate that by showing how diversification in the low-, middle- and high-income countries, respectively, is affected by product innovation and emulation.

Figure 8. Low-income country (additional diversification as a percentage of the initial level of diversification)



Source: Author.

Figure 9. Middle-income country (additional diversification as a percentage of the initial level of diversification)

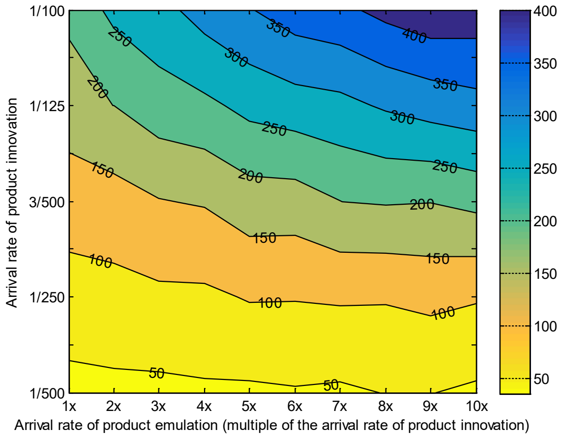


Source: Author.

These figures suggest that diversification increases in all countries in the scenario of faster product innovation and emulation. Not only the low- and middle-income countries benefit, but the result is more significant for the high-income country. Easier emulation can increase the level of diversification of this country by over four-fold. These figures also show that even if great effort is placed in product innovation, the level of diversification of low-income countries will not improve if technology transfer mechanisms are not in place to assist the emulation of production.

The stronger positive effect of faster emulation on the diversification of the high-income country could be seen as counterintuitive given that it results in shorter periods during which the original innovator benefit from Schumpeterian rents - the higher markups due to the advantage of being the only producer of the good. Given that markups finance R&D, that dynamic could lower innovation in the countries at the top. However, that narrative misses the point that when emulation is facilitated, high-income countries also benefit by emulating other original innovators. When this happens, they tap into shares of new markets and expand the set of technologies available to them to generate new product innovation and emulations. That process compensates for the shorter periods of Schumpeterian rents.

Figure 10. High-income country (additional diversification as a percentage of the initial level of diversification)



Source: Author.

In summary, the model simulations suggest that rapid technological change is associated with higher global GDP and higher GDP for high and middle-income countries but lower GDP for low-income countries. High-income countries also increase their share in global GDP, compared with scenarios of slower innovation, but low- and middle-income countries have their shares of global GDP reduced. Therefore, income inequality between high- and middle-income countries and high- and low-income countries increases. On the other hand, faster emulation (lower international IPR protection) serves as a mechanism to reduce global inequalities and also increases the global GDP when innovation is faster. Middle-income countries benefit the most, with higher GDP and shares in global GDP. Low-income countries experience little gains, and only when emulation is very fast. High-income countries have their GDP and share of global GDP reduced compared to a slower emulation scenario. Global inequality reduces. Faster innovation and emulation are associated with higher diversification in all countries, which increases welfare by creating more products that satisfy human needs.

4. Discussion and policy implications

What are the policy implications of the results of the analysis? Faster product innovation is associated with higher global GDP, which confirms the policy recommendation for higher investments in R&D in all countries. Still, the value is higher when the emulation of production is facilitated. That leads to higher global GDP, lower income inequality across countries, and a higher number of new products to satisfy human needs. Middle-income countries will have the higher gains in GDP, lower-income countries will experience some gain, and the higher-income countries will still have very high GDP levels, although lower than in the scenario of slower emulation. Therefore, in the context of rapid technological change (fast innovation), global welfare will increase if emulation is facilitated.

How to increase the rate of emulation? The model considers two mechanisms: (1) improving the capacity of people and firms to emulate and (2) increasing the set of technologies available for combination in the economy. The model simulations reported in this paper assess the effects of exogenous changes (e.g., through public policies and international agreements) in the first mechanism. In an economy, this change can be promoted through four channels.

The first channel is through the IPR regime. This is basically the mechanism replicated in the model, in which emulation is facilitated or hindered for all countries simultaneously. More stringent international protection of IPRs reduces the emulation rate because it reduces the opportunity for firms to reverse engineer and copy the products they try to emulate. Countries that were able to build their productive and innovative capacities after the Industrial revolution and catch up with Britain were able to do so through a good amount of copy, and the same was done in Asian countries that catch up in the past century, such as Japan and the Republic of Korea (Chang, 2002; Reinert, 2008; Lee, 2019). Only after way into the catching up process, they increased their levels of intellectual protection. However, with TRIPS, the IPR regime at the international level was set at a higher bar (Cimoli et al., 2009). A less stringent IPR regime at the global level (which is unlikely) would increase the opportunities for emulation for all countries at the same time.

The other channels for facilitating emulation are country-specific. The policies in each country will determine how they are implemented. The model assumes that all countries in the simulation have the same levels of capacity and outcome in the three channels that follow.

The second channel is building the capacity of firms to emulate, which is the act of creating product innovations that are new to the country. Many times, it is assumed that firms know how to innovate (and emulate), but they do not emulate because of market failures. Firms face a risk in emulating, but if they are successful, others will follow their steps and increase competition, driving profits down; thus, private benefits are lower than the social benefits. Under this assumption, solutions to increase emulation will focus on market-based instruments such as providing R&D subsidies to incentivize firms to innovate. Other times, particularly in countries with already some level of innovation capacity, the culprit is system failures – missing or weak actors in the national innovation system, including universities, research institutes, financial institutions, certification and metrology institutes, and regulators. Another problem could be the weak linkages between them. Therefore, the solution focus on creating and strengthening actors and interlinkages. However, as discussed in Lee (2013, 2019), in many low-income developing countries, firms usually do not know how to innovate. There is a failure of capabilities. In this case, governments should use policy instruments that teach firms how to emulate. Some of these policy instruments are public-private R&D, innovation hubs, extension services, and industrial institutes. It is also critical to train people on entrepreneurial skills to leverage the system to create a new business that produces and provides "new to the country" goods and services. This will include specific skills that go beyond the setting up of a business and have at its core the capabilities required to identify opportunities for emulation based on work that people already perform.

The third channel is increasing the opportunities of firms for emulation. Innovation comes from intuition and ideas that emerge from the materials people work with, the skills already in use during work, or problems people see while doing the work (Jacobs, 1970; Arthur, 2011). But jobs are usually missing in developing countries, so people have fewer opportunities to innovate. Jacobs (1970) describes how the opportunities to emulate usually happen through four mechanisms. In the first, a shop repairs a product and starts to produce some of the parts that are easier to create and in higher demand. Another channel is when firms making parts begin to assemble them (together with parts made by others) to produce a product. The other way around can also happen; a firm that only assembles parts into a product starts to produce some of the parts. Yet another channel is when a retailer of a product starts to also manufacture it, usually by bringing together different suppliers and assembling the parts. In all these channels, people and firms are already engaged with an existing product. A government can create opportunities if, for example, it promotes the use of local firms as suppliers of FDI factories established in the country.

The fourth channel is to facilitate trial and error in the process of emulation. Failure is common and expected when a firm is trying to emulate. Trial and error are the way that firms will progress towards emulation. But there are just so many trials and errors that a company can endure without exhausting its resources. For MSMEs, which do not usually have extra resources for innovation, it is a risk to fail in the emulation process. Access to financing instruments designed to promote economic diversification, for example the financing provided by development banks, can facilitate emulation. Bankruptcy laws that allow firms to fail without dragging the company's owners into massive debt create a more conducive environment for the trial and error required for emulation.

Governments should act in all these channels to increase the capacity of firms to emulate and, therefore, increase the rate of emulation.

The model also shows that low-income countries do not benefit as much as middle-income countries from faster emulation. Low-income countries are exactly those that were not able to benefit from innovation and emulation; thus, the lower the rate of innovation and emulation, the lower the output gaps between these countries and the others. Therefore, the model simulation shows that a common international level of emulation is not conducive to reducing global inequality across countries because it leaves low-income countries (less technologically capable) behind. However, the homogenization of minimum standards for IPR regimes is exactly what was accomplished by the TRIPS agreement. TRIPS has no provisions to differential IP regimes for countries at different levels of technological capabilities - the special and differential treatment provisions only relate to time lags in the implementation of the agreement, which are not linked to any objective measures of technological or productive capacities.

A stringent TRIPS that treats equally all countries fails itself in at least two ways. First, it fails its Article 7, which says: "The protection and enforcement of intellectual property rights should contribute to the promotion of technological innovation and to the transfer and dissemination of technology, to the mutual advantage of producers and users of the technological knowledge and in a manner conducive to social and economic welfare, and to a balance of rights and obligations." As shown in the results of the model, more stringent international protection of IPR results in lower diversification (product innovation) and higher income inequality between countries; thus, it fails Article 7 by not promoting technological innovation and not being conducive to social and economic welfare. Second, stringent and homogenous TRIPS reduces global GDP and trade, thus fails to be consistent with the "GATT-style" objective of lowering barriers to trade.

A revamp of the international protection of IPRs, considering the technological gaps between countries, is needed to reduce global income inequalities and increase trade. This paper does not presume to propose a formula for how this could be accomplished, but it instead raises the issue for the attention of policymakers. Nevertheless, we can highlight two principles that should be observed in a redesign of the system. First, it should follow the principle of asymmetric protectionism as proposed by Chang (2020) in the sense that firms in technologically weak and less diversified countries should be allowed to imitate the production of more technologically advanced economies. Secondly, a renewed international IPR system should allow for tailored IP regimes in which governments manage their IP systems in support of their industrial and technological development strategies, balancing IP regimes to address the needs of different sectors and different stages of development, as suggested in Cimoli et al. (2009).

However, this option of an overhaul of the international protection of IPR is unlikely under the current international institutional framework on trade, investment and technology. In practical terms, for low-income countries to benefit from emulation, they must become more like middle-income countries regarding the set of technologies available in their economies. This is the second way to increase emulation mentioned at the beginning of this section - increasing the set of technologies available for combination in the economy. Such an increase in the set of technologies can happen endogenously, by creating new technologies by combining existing technologies available in the economy, or exogenously through the importation of technologies in the form of capital goods or FDI, for example. The analysis in this paper does not consider exogenous changes in the set of technologies available to each country, but this change can be facilitated through public policies via four channels: facilitating technology transfer, direct provision of the technology by the government, increasing the absorptive capacity of the firms in the economy, and promoting the diversification of the economy.

The facilitation of technology transfer is the usual mechanism to improve the level of technology in an economy. There are several ways through which technology transfer can be facilitated, including exports or imports of final goods (trade), licenses, purchase of foreign firm (M&A), strategic alliance or joint venture, migration of people for work or education, open sources of knowledge, contract with research entity, collaborative R&D, inter-university collaborations on technology transfer, bi-lateral or multi-lateral technology agreements (United Nations, 2019). Technology transfer from developed to developing countries should be encouraged. In the United Nations, the Technology Bank for Least Developed Countries was created to facilitate technology transfer to that group of countries. The online platform of the Technology Facilitation Mechanism also contributes to this work by providing information regarding available technologies for the SDGs. Setting up a central open source technology database supporting the SDGs could facilitate technology transfer to developing countries to promote sustainable development. Critical in this regard is the transfer of non-tradeable technologies – know-how, tacit knowledge, methods, and procedures that are learned by doing. That is only possible to be transferred through training and usually through on-the-job training. Transfer of technology in which new technology is licensed to a firm in a developing country, but foreigners carry out all the work, does not fully complete the technology transfer in this sense - the non-tradeable technology is not in the economy for others to use. There should have people working with the new technology and mechanisms for the knowledge generated in this process to be passed to others in the local workforce- allowing the technology to be used in future combinations.

Another way to promote emulation by increasing the set of technologies is by the direct provision by the government of critical technology. This includes electricity, water and sanitation, and digital infrastructure. This also includes education and technical training in areas that are important for the emulation into new sectors. Governments usually have the role of providing such infrastructure, but there needs to have a direction in their provision. Infrastructure is not neutral, and given the limited resources, a government may have to face thought decision to further invest in the roads and railway to benefit the commodities industry or the new digital infrastructure for the new digital sectors, for example (Chang, 2009). The directionality in the new sectors will guide these decisions. Given the emergence of the Industry 4.0 paradigm and the deployment of digitalization in developing countries, the digital infrastructure has great importance in the possibilities to catch up in the next decades (UNCTAD, 2021).

We come to the third channel for that to happen, building the absorptive capacities of people and firms in the economy. That would allow for people to learn new technologies by observing and doing the work. This includes training engineers who can work with the new machines, technicians who can engage in the new processes, etc. It is critical to increasing the number of people trained in areas related to the new sectors that the country is promoting.

The fourth channel promotes the diversification of the economy by setting up incentives for creating new firms in new sectors. The policy instruments in this regard are different from the ones discussed in this section previously because they do not focus on building the capacity of firms on how to innovate (emulate) but on creating incentives for firms to do so. The critical is that the incentives are targeted to innovation that is new to the country. Crucial in this regard is the decision on the sectors to promote (Freire, 2017).

The model assumes that the innovation capacity of each worker engaged in emulation is the same in each country. What is different is the number of people engaged in emulation in each country and for each potential new product, and the set of technologies available for combinations, which are all determined endogenously in the model. However, this assumption can be relaxed if we consider that firms in developed countries are more likely to engage in organized R&D than firms from developing countries and that those working in R&D departments are more likely to have specific training that increases their productivity in innovation. Therefore, the impact of relaxing that assumption will increase emulation capacity in more technologically advanced countries, which will increase the emulation rate in those countries compared to less technologically advanced countries. In this scenario, we should expect that increasing emulation will be less detrimental to richer countries and less beneficial to middle-income countries, and even less beneficial for low-income countries. Similarly, innovation in high-income countries will increase if we relax the assumption that all people engaged in innovation has the same capacity and consider that workers in high-income countries may have more innovation capabilities due to more specific training. Overall, the relaxation of these assumptions will result in higher inequalities. The policy implication is that it is even more important to increase the emulation in low- and middle-income countries to reduce the income gap to high-income countries.

5. Conclusions

This paper examines the effects of rapid technological change and international protection of IPR in the inequalities between countries (through product innovation and emulation). It differs from the work in the literature of product cycles, which also examines the same topic, by using a different methodology that considers multiple countries engaging in product and process innovation and emulation. That analysis is carried out through computer simulations of a multi-country multi-sector evolutionary economic model with endogenous technological change, change in consumption patterns and diversification, proposed by Freire (2019).

The results suggest a complex and non-linear relation between innovation and emulation and their impact on income inequality between countries. The paper shows that rapid technological change results in higher global GDP but also higher inequalities between countries. In this context, faster emulation further increases global GDP and serves as an equalizing force, reducing the inequalities between countries. However, low-income countries do not benefit much from mechanisms that facilitate emulation in all countries equally. They require special interventions that foster their innovation and emulation capacities and increase the set of technologies available in their economies, so they are not left behind.

These results are highly significant and relevant in the current context of rapid technological change with digital transformation and the installation period of Industry 4.0. The current homogenous level of international protection of IPRs enforced by the TRIPS agreement, even with the time lags in implementing the agreement by the least developed countries, hinders any progress in building the technological capacities of low income and least developed countries. Governments and the international community have to foster emulation in developing countries, and particularly in low-income countries, to ensure that the next wave of technological change will not further increase the gap between developed and developing countries.

Appendix

Table 1. List of variables

Exogenous	
N_k	total population in country *k*
L_k	total labour available for production sectors in country *k*
State variables	
$l_{j,k}$	labour coefficient (labour input per unit of output) to produce commodity *j* in country *k*
$c_{j,k}$	coefficient of consumption per capita of commodity *j* in country *k*
$MK_{j,h,k}$	proportional markup added to the price of commodity *j* produced in country *k* and consumed in country *h*
w_k	nominal wage rate in country *k*
Endogenous	
$p_{j,h,k}$	price of commodity *j* produced in country *k* and consumed in country *h*
$c_{j,h,k}$	coefficient of consumption per capita in country *h* of commodity *j* produced in country *k*
$Q_{j,k}$	quantity of commodity *j* produced in country *k*
$E_{j,k}$	employment in sector *j* in country *k*
E_k	total employment in country *k*
$Y_{j,k}$	output of sector *j* in country *k*
Y_k	total output in country *k*
y_k	output per capita in country *k*
$Exp_{j,k}$	household expenditure in sector *j* in country *k*
Exp_k	total household expenditure in country *k*
exp_k	per-capita household expenditure in country *k*

Table 2. The model (Freire, 2019)

Short-run: Economic variables calculated based on exogenous and state variables	
Prices: Prices reflect labour costs and markups	$p_{j,h,k} = l_{j,k} w_k \, MK_{j,h,k}$
Quantities:	
Quantity of commodity *j* produced domestically in country *k* is equal to the domestic and foreign demands	$Q_{j,k} = \sum_{h=1}^{R} c_{j,h,k} N_h$
Calculate domestic and foreign demand using the following linear programming	
Minimises expenditure given consumer preferences (under the following constraints)	Minimise $\sum_{k=1}^{R}(\sum_{j=1}^{m}(\sum_{h=1}^{R} c_{j,k,h} \; N_k \, p_{j,k,h}))$ $c_{j,k,h} \geq 0$
Constraint: The consumption per capita of a commodity *j* in country *k* is the sum of the domestic consumption of commodity *j* that is locally produced and of commodity *j* that is imported	$c_{j,k} = \sum_{h=1}^{R} c_{j,k,h}$

Constraint: The sum of quantity produced of a commodity *j* in all countries is the same as the sum of the quantity consumed of that commodity in all countries	$\sum_{h=1}^{R}\left(\sum_{k=1}^{R} c_{j,k,h}N_k\right) = \sum_{k=1}^{R} c_{j,k}N_k$
Constraint: The maximum total labour employed in each country is lower or equal than the total labour available in that country	$\sum_{j=1}^{m} l_{j,k}\left(\sum_{h=1}^{R} c_{j,h,k}N_h\right) \leq L_k$
Endogenous macroeconomic variables	
For each country *k*, employment in each sector *j* is equal to the labour required to produce the quantity of commodity *j* produced domestically	$E_{j,k} = l_{j,k}Q_{j,k}$
Total employment is the sum of employment in each sector of the economy	$E_k = \sum_{j=1}^{m} E_{j,k}$
The output by sector ($Y_{j,k}$) is given by the price of the commodity multiplied by the quantity produced	$Y_{j,k} = \sum_{h=1}^{R} c_{j,h,k}N_h\ p_{j,h,k}$
Total output of the economy *k* is the sum of the outputs of the individual sectors	$Y_k = \sum_{j=1}^{m} Y_{j,k}$
Dynamics	
Nominal wage rates endogenously reflect the average productivity of the economy. At each period, the wage rates in other countries are given by the wage rate of country 1 multiplied by the ratio of average labour coefficients in both countries weighted by the employment shares.	$w_k = w_1 \frac{\left(\sum_{j=1}^{m} l_{j,1}E_{j,1} \big/ E_1\right)}{\left(\sum_{j=1}^{m} l_{j,k}E_{j,k} \big/ E_k\right)}$
Change in markup prices: The mechanism of setting markups is implemented in the model through the following algorithm:	Initial markups are given for each market. We consider that markup of exports are higher than for selling in the domestic market: $MK_{j,k,k}(0) < MK_{j,h,k}(0)$ *j=1,..,m; h,k=1,…,R; h≠k* At the start of a period, sectors initially set their tentative markup for each market as the same as in the previous period: $MK_{j,h,k}(t) = MK_{j,h,k}(t-1)$ *j=1,..,m; h,k=1,…,R* Sectors calculate their tentative prices (the labour component of the price may have decreased due to changes in the exchange rate, which affect the relative wage rates, or due to changes in the labour coefficient as a consequence of, for example, process innovation). Sectors of different countries compare prices and try to match the lowest tentative price by reducing their markups: $MK_{j,h,k}(t) = \min(p_{j,h,g}) \big/ l_{j,k}w_k$ *j=1,..,m; g,h,k=1,…,R; g≠k*

	Sectors for which the labour costs are higher than the lower price are forced out of the market.
Technological change	
Adjacent possible: The possible new products and processes that can be introduced through innovation have to be part of the set of possible combinations of existing technologies in the economy (the adjacent possible). The algorithm used to determine the adjacent possible for each country *k* at the start of each period is the following:	Generate full adjacent possible (AD_k); For each potential new product in the adjacent possible, add it to the effective adjacent possible if that potential product is in List 1; If, on the other hand, that potential product is in List 2 discard it; If the product is not yet in either list, then it will be assigned to List 1 or List 2 (stochastically), and the algorithm returns to step 2 above.
Calculation of share of labour dedicated to innovation	
Share of labour engaged in R&D	$$\epsilon_k(t) = \frac{min\ (SP_k(t), LA_k(t))}{L_k(t)}$$ $$LA_k(t) = L_k(t) - E_k(t)$$ $$SP_k(t) = \sum_{h=1}^{R}\sum_{j=1}^{m}\big(l_{j,k}(t)(MK_{j,h,k}(t) - 1)Q_{j,k}(t)\big)$$
Out of the group of people engaged in R&D, a share of them is devoted to research towards a new product ($\partial_k^{product}$) (either to the country or to the world) and another share is devoted to finding a new and more productive way to produce an existing product ($\partial_k^{process}$)	$$\partial_k^{product}(t) + \partial_k^{process}(t) = 1$$ $$0 \le \partial_k^{product}(t) \le 1;\ 0 \le \partial_k^{process}(t) \le 1$$
Shares of research dedicated to finding a new product or a new process are endogenous to the model and a function of the share of the labour force that is employed	$$\partial_k^{process}(t) = E_k(t)/L_k(t)$$ $$\partial_k^{product}(t) = 1 -\ E_k(t)/L_k(t)$$
Out of the group of people engaged in finding a new product, a share of them is devoted to research towards product innovation ($\sigma_k^{product}$) and another share is devoted to emulation ($\sigma_k^{product\_emulation}$)	$$\sigma_k^{product}(t) + \sigma_k^{product_{emulation}}(t) = 1$$ $$0 \le \sigma_k^{product}(t) \le 1$$ $$0 \le \sigma_k^{product\_emulation}(t) \le 1$$
Shares of research dedicated to product innovation and emulation are endogenous to the model	$$\sigma_k^{product}(t) = \frac{m_k(t)}{m(t)}$$ $$\sigma_k^{product_{emulation}}(t) = 1 - \frac{m_k(t)}{m(t)}$$ m_k is the number of types of commodities produced in country *k* and *m* is the combined number of different types of commodities traded by all countries
Out of the researchers working to discover a more productive process of production, a share is devoted to	$$\sigma_k^{process}(t) + \sigma_k^{process_{emulation}}(t) = 1$$ $$0 \le \sigma_k^{process}(t) \le 1$$ $$0 \le \sigma_k^{process\_emulation}(t) \le 1$$

research towards process innovation ($\sigma_k^{process}$) and another share is devoted to process emulation ($\sigma_k^{process\_emulation}$)	
Shares of research dedicated to process innovation and process emulation are assumed to be endogenous	$\sigma_k^{process}(t) = TF_k(t)/m_k(t)$ $\sigma_k^{process\_emulation}(t) = 1 - TF_k(t)/m_k(t)$ TF_k is the number of sectors in production in country *k* that are operating at the technological frontier, meaning that they have the highest productivity when compared with similar sectors in other countries
Product and process innovation and emulation	
Process innovation: In each country *k* the outcome of the work of one person engaged towards process innovation takes the form of a Poisson process with the arrival rate of the new process given by $\lambda_k^{process}$	$X_{j,k} \sim P(\epsilon_k \partial_k^{process}\ \sigma_k^{process} N_k(E_{j,k}/E_k)\ \lambda_k^{process})$ $l_{j,k}(t) = rdc_{j,k}\ l_{j,k}(t-1)$ $0 < rdc_{j,k} < 1$ $rdc_{j,k} \sim U(\beta_1, 1)$ $0 < \beta_1 < 1$ Where β_1 is a parameter of the model
Process emulation: One person engaged towards process emulation in country *k* would find a new process at an arrival rate of $\lambda_k^{process\_emulation}$ that takes the form of a Poisson process. A sector will only undergo process emulation if the sector is lagging behind the technological frontier. When process emulation happens in a sector *j*, we consider that the sector adopts the technologies of the frontier country	$X_{j,k} \sim P(\epsilon_k \partial_k^{process}\ \sigma_k^{process\_emulation} N_k(E_{j,k}/E_k)\ \lambda_k^{process\_emulation})$ $l_{j,k}(t) = l_{j,h}(t)$
Product innovation: In each country *k* the outcome of the work of one person engaged towards product innovation takes the form of a Poisson process with the arrival rate of the new sector given by $\lambda_k^{product}$. Labour coefficient of the new sector (l_{new}) is given by the average of the labour coefficients of the production sectors in activity in the economy in the previous period	$X_k \sim P\left(\epsilon_k\ \partial_k^{product} \sigma_k^{product} N_k \lambda_k^{product}\right)$ $l_{new,k}(t) = \frac{\sum_{j=1}^{m_k} l_{j,k}(t-1)}{m_k(t-1)}$
Product emulation: In each country *k* the outcome of the work of one person engaged towards emulation takes the form of a Poisson process with the arrival rate of the new sector given by $\lambda_k^{emulation}$. For the process of emulation, it is necessary that a new product has emerged in another country. labour coefficient at the time of the emulation (t'') is the same as the labour coefficient of that sector at the time that it was created (t') in the	$\varphi_{j,c}(t) = \frac{\sum_{k=1}^{R} Y_{j,k}(t-1) - \sum_{k=1}^{R} Y_{j,k}(t-2)}{\sum_{i=1}^{m}\sum_{k\neq c}^{R} Y_{i,k}(t-1) - \sum_{i=1}^{m}\sum_{k\neq c}^{R} Y_{i,k}(t-2)}$ $X_k \sim P\left(\epsilon_k \partial_k^{product}\ \sigma_k^{emulation} N_k \varphi_{j,c} \lambda_k^{emulation}\right)$ $l_{j,k}(t'') = l_{j,h}(t')$

economy of country *h* that initially introduced the commodity	
Change in consumption patterns	
Commodities' order from those that satisfy the most to those that satisfy the least essential needs: We enforce a decreasing order on the rate of consumption changes ($r_{j,k}$) in each country in each period	$r_{1,k} \geq r_{2,k} \geq \cdots \geq r_{m_k,k}$
Saturation of demand: For each commodity *j* there is a maximum amount for the consumption per capita of that commodity given by $maxc_j$	$\forall j \; \exists \; maxc_j, c_{j,k}(t) = \min\left(c_{j,k}(t-1)e^{r_{j,k}}, maxc_j\right)$ $maxc_j > MAX_j$ $MAX_j = \max\left(c_{j,1}(1), c_{j,2}(1), \ldots, c_{j,m_k}(1)\right)$ $maxc_j \sim U(MAX_j, \beta\, MAX_j)$
Dual-decision hypothesis: Households receive their income and, based on the current prices of products, decide on consumer preferences for the next period. If the income received is lower than the latest expenditure, people will have a lower expectation related to the extent to which their incomes will be able to fulfil their consumption in the next period, and they would decide to consume less. If, the income received is higher than the latest expenditure, people would decide to consume more. When households actually consume in the following period, firms decide on the level of employment to fulfil that demand, which determines income in the next period.	$\begin{cases} r_{j,k}(t) > 0, if\, exp_k(t-1) < y_k(t-1) \\ r_{j,k}(t) < 0, if\, exp_k(t-1) > y_k(t-1) \end{cases}$ $\begin{cases} r_{j,k} \sim U(0, \max(r)), if\, exp_k(t-1) < y_k(t-1) \\ r_{j,k} \sim U(-\max(r), 0), if\, exp_k(t-1) > y_k(t-1) \\ r_{j,k} = 0, \quad if\, exp_k(t-1) = y_k(t-1) \end{cases}$
Variation in the composition of consumption may occur as a consequence of the introduction of new products. $s_{i,j}$ is the substitution and complementarity effect of the emergence of the new product *i* on the consumption of an existing commodity *j*	$c_{j,k}(t'') \quad \begin{cases} > 0, if\; y_k(t''-1) \geq \alpha \\ = 0, \; otherwise \end{cases}$ $s_{i,j} \sim U(1-\kappa, 1+\kappa)$
In each country *k*, by the time of the introduction of the new product *i*, the coefficient of consumption of existing product *j* is affected in the following one-time change	$c_{j,k}(t) = \min\left(s_{i,j}\, c_{j,k}(t-1)e^{r_{j,k}}, maxc_j\right)$ $maxc_j(t) = s_{i,j}\, maxc_j(t-1)$

Table 3. Initial parameters for the simulation

Labour coefficient $l_1 = l_2 = \cdots = l_{10} = \{0.5, 0.5, 0.5, 0.5, 0.5, 0.5\}$;
Coefficient of consumption per capita $c_1 = c_2 = \cdots = c_{10} = \{0.01, 0.01, 0.01, 0.01, 0.01, 0.01\}$;
$u = 0.4$; Meaning that 4 out of 10 potential new products as combination of existing technologies are useful;
Wage rate in country 1 $w_1 = \$\,1$;
$\beta = 2$; Saturation of consumption not higher than 100% above the initial consumption per capita.

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