UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT

JULY 2021

UNCTAD Research Paper No. 68
UNCTAD/SER.RP/2021/11

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

Clovis Freire
Economic Affairs Officer
Division on Technology and Logistics, UNCTAD
freire@un.org

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.

The findings, interpretations, and conclusions expressed herein are those of the author(s) and do not necessarily reflect the views of the United Nations or its officials Member States. The designations employed and the presentation of material on any map in this work do not imply the expression of any opinion whatsoever on the part of the United Nations concerning the legal status of any country, territory, city, or area or of its authorities, or concerning the delimitation of its frontiers and boundaries.

This paper represents the personal views of the author(s) only, not the views of the UNCTAD secretariat or member States. The author(s) accept sole responsibility for any errors. Any citation should refer to the author(s) and not the publisher. This paper has not been formally edited.

UNITED NATIONS

© 2021 United Nations

Contents

Acknowledgements

This paper builds on computer-based model simulations conducted by the author that were part of his dissertation to obtain the degree of Doctor at Maastricht University (Freire, 2017). Comments provided by Liping Zhang and Xiran Yan (UNCTAD) on a previous version of the paper are gratefully acknowledged.

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).

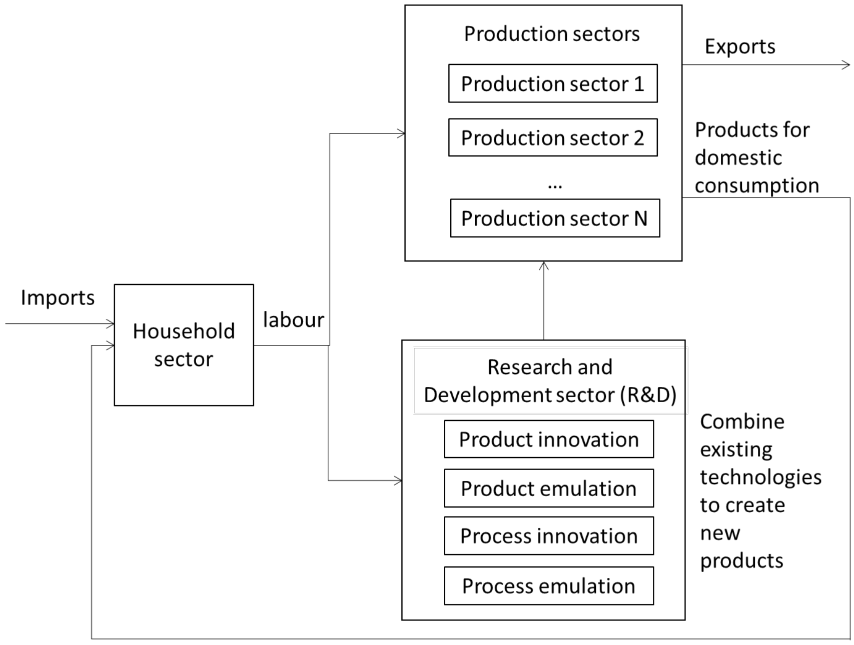
The household sector comprises the country's population, provides labour to other sectors, and consumes products (domestic or imports). Consumption coefficients give the consumption per capita of each commodity. Labour is uniform in quality so that each unit of labour is equivalent as a means of production 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:

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

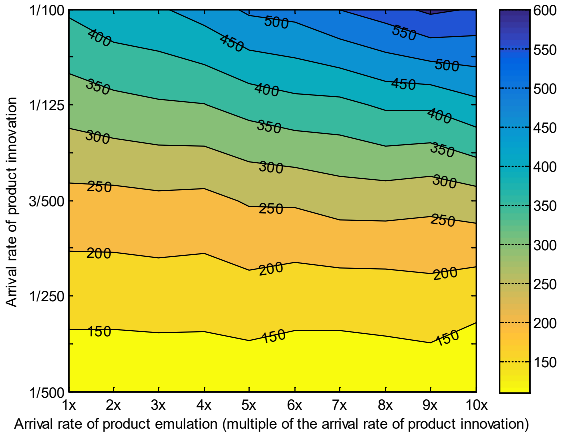
$$\lambda_k^{process\_emulation} = \lambda_k^{emulation}$$

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.

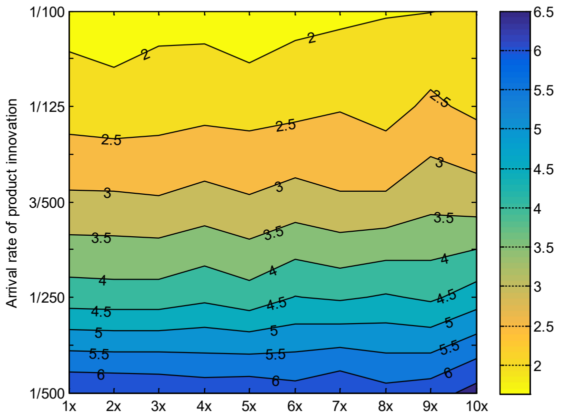
Figure 2. Global GDP, ($)



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



预览已结束，完整报告链接和二维码如下：
https://www.yunbaogao.cn/report/index/report?reportId=5_8582