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An evolutionary model of international competition and growth

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Abstract

The paper attempts to interpret a few stylized facts of international economic growth by means of an open economy evolutionary model. The idea is that growth models that incorporate a richer representation of the properties and effects of technological change can give a better explanation of the differentials in the growth performance and development patterns of countries worldwide.

In the proposed multi-country model, growth is endogenously generated by the R&D activities performed by firms constantly searching for technological improvements. Both innovation and imitation processes are modelled and technological diffusion involves local spillovers. Firms are selected in all markets worldwide via an evolutionary replicator equation in terms of their 'competitiveness'. The predictions of the model are studied under different regimes of technological change. The model generates persistent differentiation of levels of per capita income and growth rates across countries.

Keywords: Growth, technological change, trade
JEL-Codes: O30, O41

1 Introduction

The paper proposes a new multi-country growth model that tries to account for the persistent differentials in per capita incomes and in the growth performance observed across countries worldwide (see the evidence in Dosi *et al.*(16) and Durlauf and Quah (19)). We choose to micro-found the growth variables of each country on the dynamics of the firms that are located in it. We allow for a richer representation of the activities of

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R&D that are undertaken by firms to increase their technological level. It is argued that technological asymmetries together with the dynamics of international competition, can help in understanding convergence and divergence in cross-country growth patterns.[1]

An evolutionary perspective is taken, as the model finds its antecedents in some of the evolutionary models of economic growth developed in the last years (for a review, Silverberg and Verspagen (35)). The primary reference is the model in Nelson and Winter (29). The two authors first claimed that it was possible to capture the properties of macro time series without giving up the challenge of incorporating in the model a richer understanding of the patterns of technological change. Firms are assumed to follow "routines" when choosing their levels of investment and when setting their prices. In fact bounded rational agents may use simplified decision rules and these rules can prove to be realistic solutions when agents cope with strongly uncertain environments. We include this assumption in our model.

The model in Dosi, Fabiani, Aversi and Meacci (15) extends the Nelson and Winter model to a set of open economies. The main idea put forward is that 'international competitiveness' is the key to operationalize the link between technology and growth (see also the model in Verspagen (37)). Indeed, our model shares with this work many features of the representation of the activities of innovation and imitation.

The cited models have in common with the model presented in this paper at least three basic assumptions. First, all models are micro-founded on the activities of firms. Second, they allow for capital-disembodied process innovation. Third, they include a replicator dynamics based on competitiveness of the different techniques.

The system of open economies is regarded as an evolving complex system, much in the spirit of the Santa Fe research program (see Arthur, Durlauf and Lane, (4)). The focus is on dynamics and the interest lies in out-of-equilibrium patterns. Moreover, micro-foundations are not based on any representative agent, but on multiple and heterogenous ones, characterized by bounded rationality.

From a methodological point of view, we develop an agent based model and we use simulation techniques to study the predictions of the model. The option of using simulation techniques allows to study the aggregate dynamic properties even when no closed form solution exists. We want to study the predictions of the model under different regimes of technological change and market competition and compare them with the historically observed growth patterns. The conjecture is that incorporating a more refined representation of technological change can better help in the explanation of the differentials in the growth performance and development patterns of countries

[1] As discussed in Nelson (28) a new growth theory should incorporate a theory of the firm in which firm capabilities and differences across firms are central elements.

worldwide.

Section 2 presents the baseline model, sets out its structure and relates it to the evidence coming from the empirical literature. Section 3 analyzes a first benchmark setting and reports the results of a series of simulations. Finally, in section 4 we draw some conclusions and suggest directions of further analysis.

2 The baseline model

Let us first briefly outline how the model is structured. We consider a system of open economies. A finite set of N firms is represented. Firms are localized homogeneously in all the countries. Each firm $i = 1, ..., N$ is characterized by the country $x(i) = 1, ..., C$ where its production is located. Labor is the only input in production, therefore labor productivity indicates the efficiency of the technology used by each firm.

Firms systematically engage in R&D activities, to which they devote a fixed percentage of income. At the beginning of each period they draw the outcome of their search activities, depending in turn on the level of current and lagged investment. At the same time, they also devote resources to imitation and have a probability of imitating a better technique being used by other firms worldwide. The probability of imitation depends upon a technological distance, adjusted by a geographical parameter.

Once all firms have updated their productivities, they set their prices. The effective price in a specific country of the good produced by a certain firm depends also by costs related to trade. Price and trade costs together determine the "competitiveness" of each firm. An evolutionary market selection mechanism establishes the market shares of all firms.

Demand comes from the wages earned in each country and is allocated to firms in relation to their market shares. Firms then set their production levels. At the end of each period wages are updated in the labor market and aggregate variables can be calculated for each country.

2.1 The activities of firms and the micro-economics of technological change

A set of micro stylized facts that we choose to build upon, stems from the economics of innovation and the processes of technological change at the firm level (see Dosi (14)).

A first evidence is that technological improvements are eventually achieved after costly and risky R&D activities, whose qualitative properties depend on the specificities of the sector of production (see the taxonomy in Pavitt (30)). Each regime is defined by the degree of appropriability of technological knowledge and the properties of the specific learning process. In our model, firms produce a homogenous output using labor as the only input. The technology used is thus characterized by the labor productivity measure. Technological change is endogenously determined and firms engage in R&D in order to innovate or imitate existing techniques, the ultimate goal being an improvement in their productivity.

Search is uncertain and thus modelled as a stochastic process. It is also costly because the probability of success crucially depends on the level of R&D investment[2] undertaken by the individual firm. In this sense R&D activities at the firm level benefit from economies of scale, because the more is invested in search the higher the probability of the search turning out successful.

For each firm $i = 1, ..., N$ the amount of labor SL_i to be invested in the two complementary search activities is decided at the beginning of each period $t = 1, ..., T$, based on the following rules:

$$RD_{i,t} = r_1 * Y_{i,t-1}$$

$$SL_{i,t} = \frac{RD_i}{w_{x(i),t-1}}$$

where RD_i is the total investment in search activities, $Y_{i,t-1}$ is the income obtained in the previous period and $w_{x(i),t}$ is the wage rate valid in the country $x(i)$ where firm i operates. The division of resources between innovation and imitation is set by the parameter r_2 for all firms $i = 1, ..., N$:

$$LINN_{i,t} = (1 - r_2) * SL_i;$$

$$LIM_{i,t} = r_2 * SL_i;$$

where $LINN_{i,t}$ and $LIM_{i,t}$ are the numbers of workers employed in innovation and imitation activities respectively.

We assume that firms invest a fixed and constant percentage of income in search activities. There is empirical evidence that firms follow this type of strategy. We can justify it with the idea that firms are required to keep investing in search because of the threat of advances by rival firms. Both innovation and imitation need investment for each period. Basically, firms need to keep up with the average level of the knowledge

[2] In the case of developing countries, we take R&D expenditure to be investment in training and equipment

base to be able to recognize and discriminate alternative techniques (see Chiaromonte and Dosi (9)).

Innovation and imitation search are modeled as two stages stochastic processes, where the first stage defines the probability of innovation (imitation) and the second stage sets the actual random realization of innovation (imitation) itself.

As for innovation, each firm draws its own success with a probability that depends both on the current and past labor investment in innovation search:

$$1 - \exp(-\alpha * (LINN_{it} + LINN_{i,t-1}) \tag{1}$$

where the parameter α governs in probability the 'innovative productivity' of R&D investment[3]. Then the actual size of innovation s_i is drawn from a $Poisson\,(\lambda)$ and the resulting new productivity $\pi\_INN_{i,t}$ for firm i is determined by:

$$\pi\_INN_{i,t} = \pi_{i,t-1} * (1 + \frac{s_i}{100})$$

It should also be noted that in this model innovation is in fact mainly incremental, but we allow for particularly "big" jumps when letting the size of innovation be randomly chosen from a Poisson distribution.

Similarly, for imitation each firm draws a binary success variable with probability given by:

$$1 - \exp(-\beta * (LIMM_{i,t} + LIMM_{i,t-1})) \tag{2}$$

If success is drawn, the firm will have the chance to imitate one of the existing techniques. A distance between technologies π'_{j_1} and π''_{j_2} located respectively in countries j_1 and j_2, is defined as the following:

$$d\left(\pi'_{j_1}, \pi''_{j_2}\right) = \begin{cases} max\left\{0, \pi'_{j_2} - \pi''_{j_1}\right\} & \text{if } j_1 = j_2 \\ \xi_{j_1,j_2} max\left\{0, \pi'_{j_2} - \pi''_{j_1}\right\} & \text{if } j_1 \neq j_2 \end{cases}$$

where $\xi_{j_1,j_2} \geq 1$, for each $j_1, j_2 = 1, ..., C$. Each firm will imitate the closest firm for which the distance is strictly positive. Call $\pi\_IMI_{i,t}$ the imitated technique. The new production technique $\pi_{i,t}$ for firm i at time t is then chosen as the best alternative between the old one and the ones eventually found through search.

$$\pi_{i,t} = \max\left\{\pi_{i,t-1}, \pi\_INN_{i,t}, \pi\_IMI_{i,t}\right\}$$

We should now stress that the whole R&D search crucially draws on accumulated knowledge, so that dynamic increasing returns in production generally arise.

[3]Later on, we can let α_j depend on the country to account for the efficiency of different national innovation systems.

For a knowledge-driven progress, processes of learning play a key role. We follow Chiaromonte and Dosi (9) in distinguishing two types of learning.

First, a 'private' learning arises, that is mainly a learning-by-doing and attains to the single firm. Experience cumulates with time as well with the volume of investment, so that the probability of both imitating and innovating depends on the current and lagged efforts (as in Eq.(1) and (2)). Engaging in R&D activities in every period allows firms to acquire competences and skills. This positive feedback creates a sort of path dependence, so that a firm that has consistently been successful in search activities in the previous periods enjoys a relatively higher probability of success in both innovation and imitation in the present.

Second, there is a 'public' learning due to the technological spillovers that are granted to the other firms because of information diffusion, personnel mobility and more. The latter effect ends up producing an enlargement of the public knowledge base. The extent of this public learning may vary and the effect may work at a sectoral level and/or at a local (in the geographical sense) level. In this model the public learning is represented by the knowledge spillovers that form the basis for technological diffusion and crucially enable imitation. In fact, imitation is feasible when technological knowledge is only partially appropriable by the firm that first developed it. The size of spillovers depends upon the technological efficiency level achieved by firms.

We model the imitation process so that the probability of imitating a technique decreases in the technological distance. Here the idea is that there are stronger information flows between firms with similar level of efficiency in production. This assumption is reasonably supported in the real world if we think that similar firms may indeed access the same type of labor force, undertake technological alliances, and more.

The defined distance also includes the parameters ξs. They adjust for the distance of countries and are meant to take into account the geographical location of firms. A firm has a higher probability of imitating a better technique used in the same country, because the distance measure implied by the parameters ξ_{j_1,j_2} will make it harder to imitate techniques employed abroad. This formulation acknowledges the positive effect of spatial proximity in knowledge diffusion and the local nature of spillovers. Indeed, technological diffusion clearly depends on the properties of those micro-interactions likely to yield knowledge spillovers. There are costs, difficulties and delays associated with the transfer of information and here the tacit component of technological knowledge is the one that limitates a frictionless spread of technological knowledge. Spatial proximity has been used to support increasing returns in production in many models (see for example Arthur in (4) and David (13)) that deal with agglomeration economies and stress the localized nature of knowledge spillovers. It should also be noted that economies of agglomeration are very much related to innovation being cumulative. Innovative activity builds upon knowledge generated by previous research, so that the accumulation of innovative activity in a certain country/region facilitates in a positive feedback the creation of new technological knowledge.

2.2 Market dynamics

Firms set the price for their goods with the simple rule:

$$price_{i,t} = \frac{w_{x(i),t-1}}{\pi_t}(1+m)$$

where m is a constant mark up. The profits generated by the mark up margins are set to be equal to the investment in R&D actually undertaken by all firms[4]. It should also be noted that the productivity is the (eventually) new one, while the wage is the one given at the time that R&D investment decisions were taken. So, a one lag adjustment in the wage is assumed, which can be related to a weak idea of stickiness of prices.

Let us consider the evolutionary mechanism governing selection. The selection environment is the worldwide market and the 'fitness' of each firm is captured by its 'competitiveness'. In turn, competitiveness of firm $i = 1, ..., N$ in country $j = 1, ..., C$ is defined as the inverse of the set price. The lower the price, the more competitive the firm. But the effective price $p_{i,j,t}$ valid for goods produced by i and sold in country j at time t, is given by:

$$p_{i,j,t} = price_{i,t} * d_{x(i),j}$$

where $d_{j_1,j_2} \geq 1$ for $j_1, j_2 = 1, ..., C$, are weights that account for barriers in trade (fees and/or transportation costs) between countries j_1 and j_2[5]. Thus competitiveness is given by:

$$E_{ij,t} = \frac{1}{price_{i,t} * d_{x(i),j}}$$

Therefore, thanks to the d parameters, the competitiveness is also determined by how open the market in j is to the products coming from country i.
The evolution of market shares of firms is governed by a replicator dynamics equation which has the following form:

[4]For this accounting equality to hold, we simply set the corresponding parameters r_1 and m equal to each other.

[5]We neglect exchange rates adjustments and we implicitly assume an 'absorption approach' to the balance of trade.

$$ms_{ij,t} = ms_{ij,t-1} * (1 + c * (\frac{E_{ij,t} - EE_{j,t}}{EE_{j,t}})) \quad (3)$$

where $EE_{j,t}$ is the average competitiveness of all firms operating in country j, calculated as a weighted mean with weights provided by current market shares. We set $c = 1$ as the baseline value. The basic intuition behind Eq.(3) is that firms with above average competitiveness will expand in their relative importance and those below will shrink.

It should be clear that two assumptions are made. First, product is homogenous. Second, the country of origin of the products does not affect their competitiveness, which is in turn the only relevant variable. The reason for the assumed mechanism to apply is an assumption of imperfect markets. In perfectly competitive markets the firm setting the lowest price would have a market share of one and all the demand would eventually be satisfied by that same company. But if information costs are accounted for, then it is reasonable to assume that a range of firms satisfies the market demand according to their relative competitiveness, so that a replicator dynamics mechanism can model the dynamics of shares in the product markets (more in Silverberg *et al.* (34)). This means embracing a Schumpeterian view of competition, where market competition "...entails rivalry and a struggle for market share; it is perpetual condition of disequilibrium and change, not a state of balance between forces of equal marginal significance" (Metcalfe (27)).

Market dynamics crucially interact with the processes of technological change. In fact, the ultimate outcome of successful R&D activities concerns the ability of the firm to gain or maintain its advantage in market competition. This is determined through the market shares dynamics governed by the replicator equation (Eq.3). This mechanism awards those firms able to improve relatively to the average performance of all the other actors present in the worldwide market.

Once market shares are determined, they provide the percentages of total demand that each firm satisfies. Domestic demand for goods in each country $j = 1, ..., C$ is equal to the total income of workers employed in domestic firms:

$$D_{j,t} = \sum_{\text{i st x(i)=j}} w_{x(i),t} * L_{i,t}$$

The production level of firm i at t, $Y_{i,t}$, is determined by the share of demand that the firm satisfies both in the domestic and in the foreign markets:

$$Y_{i,t} = \sum_{j=1:C} ms_{ij,t} * D_{j,t}$$

After determining their production levels firms set their demand for labor $L_{i,t}$:

$$L_{i,t} = \frac{1}{\pi_{i,t}} \sum_{j=1:C} \frac{ms_{ij,t} * D_{j,t}}{p_{ij,t}}$$

We assume that labor can move freely across firms within a country, but does not move across countries. For simplicity we assume that labor employed in production and in R&D activities is the same. Therefore, we can consider a single labor market where a common wage is determined. The wage rate changes according to the dynamics of domestic average productivity,the price index and demand for labor:

$$w_{j,t} = w_{j,t-1}(1 + \Delta w_j)$$

where $\Delta w_j = e\Delta\pi_j + f\Delta p_j + g\Delta L_j$. $\Delta\pi_j$ is the percentage change in the average productivity of firms producing in country j, Δp_j represents the percentage change of a weighted index of prices available in country j, and ΔL_j is the percentage change in labor demand. By tuning the parameters e, f and g, we are able to specify a wide range of different labor market regimes. When $e = 1$, wage is indexed directly on labor productivity. At another extreme ($g = 1$), the market is competitive and the wage rate responds to changes in labor demand.

All aggregate country variables are obtained by summing up values at firm level as in national accounts statistics. Let the national real income of country j at time t, $YY_{j,t}$, be:

$$YY_{j,t} = \sum_{\text{i st x(i)=j}} \frac{Y_{i,t}}{p_{i,j,t}}$$

while the level of per capita income is given by:

$$Z_{j,t} = \frac{YY_{j,t}}{L_{j,t}}$$

where $L_{j,t}$ is the total amount of labor force employed in firms of country j.

Exports $X_{j,t}$ and imports $M_{j,t}$ are given by:

$$X_{j,t} = \sum_{\text{i st x(i)=j}} \sum_{\text{jj}\neq\text{j}} ms_{i,jj,t} * D_{jj,t}$$

$$M_{j,t} = D_{j,t} - X_{j,t}$$

The growth rate of GDP is calculated as the percentage change in national income:

$$g_{j,t} = \frac{YY_{j,t}}{YY_{j,t-1}} - 1$$

2.2.1 Interaction patterns

Different levels of interaction are recognizable.

1. Imitation is mediated by the technological distance and controlled by the parameters β and ξ. It should be noted that this process does not come from a maximization rule, as firms simply select the closest productivity. When able to imitate, firms are not generally able to select the highest productivity available in the world, so that there is imperfection in the diffusion process. The parameter β adjusts the probability of drawing a success in the imitation search and can be used to control for the effectiveness of the search activity. ξ is the parameter used to discriminate domestic vs foreign firms in terms of imitability.

2. Competition in the commodities market works on the competitiveness variable and is tuned by the parameter c.

3. Trade relationships are represented by the 'distance' parameters d, which in turn affect prices.

It is indeed critical to identify the relevant parameters in the model and then study the causal relation between parameters and outcome. Then, as long as the relevant trade-offs are singled out, with their associated parameters, the model can be used for interesting predictions.

3 A first benchmark setting

3.1 Preliminary analysis

We want to start analyzing a very extreme special case of our model. Let us begin from a perfect initial symmetry of all countries and firms with parameters ds and ξs set equal to 1. Suppose the market competition parameter c also equals 1, so that the market perfectly awards those firms succeeding in raising their productivity above average. As for innovation and imitation, they work as described in the previous section, but we first consider a fixed and constant innovation size: $s_i = s$ for $i = 1, ..., N$.

At the initial time, all firms are endowed with the same opportunities for technological change. Some of them, say $F_1 = \{i : INN_{i,1} = 1\}$, where $INN_{i,1}$ is the binary variable representing success in innovation for firm i at time 1, will be able to have their initial productivity π_INI jump to $\pi\_INN_{i,t} = \pi\_INI * (1 + \frac{s}{100})$. The other firms will keep their initial productivity.

In the following period, firms in F_1 will maintain their technological superiority regardless of what happens to the remaining firms. We can see this as an inertia effect due to the assumption of fixed and constant innovation size. In the extreme case, firms in F_1 do not increment again their productivities while all other firms do. This complete "catching up" will cause market shares to stay the same and will prompt all firms to start again from a situation where they all have the same labor productivity. The only changed element is that now the probabilities of innovation differ across firms. The path dependence effect will in general work against future complete catching up situations, given that the parameter α tuning the path dependence effect is high enough.

Thus, in this symmetric, highly artificial case with fixed and constant innovation size, initial events almost totally determine the future technological distribution across firms. Now, if we also assume that wages are indexed perfectly on productivity changes ($e = 1$) then the distribution of technological capabilities will be reflected directly in the cross-country distribution of growth performance. The only delicate issue is the aggregation of firms production levels to calculate the country's growth rate. That is, we need to study whether the catching up in technological capabilities corresponds to a catching up in the growth performance. It should be noted that the remark holds even when the market competition parameter c is not equal to 1, because the competition mechanism with constant c affects all firms in the same fashion. It also holds when we set asymmetric d and ξ. This would only affect the likelihood of the emergence and the timing of partial or complete technological catching up phenomena, but not the general dynamics.

3.2 The effect of distance

The formulation of the model entails two ways in which firms can be distant. First, firms have a distance in the technological space. Second, countries can be more or less close when trading with each other in the international market. We start by investigating the role of geographical barriers as related to the first notion of distance.

A 'technological distance' appears when probabilities of imitation depend on the differential in efficiency between firms. The parameter ξ accounts for positive feedbacks in the process of innovation diffusion for firms located in the same country. After an innovation has been developed by a firm it is more likely that it diffuses in the same geographical area. Different sorts of barriers to the flow of knowledge act like impediments against a perfect and smooth diffusion of new technologies to all countries in the economy. Information spillovers have a local nature and are stronger when there is geographical proximity. Recent work (see Eaton and Kortum (20), Keller (24) and Caniels and Verspagen (7) among others), has in fact analyzed the relevance of

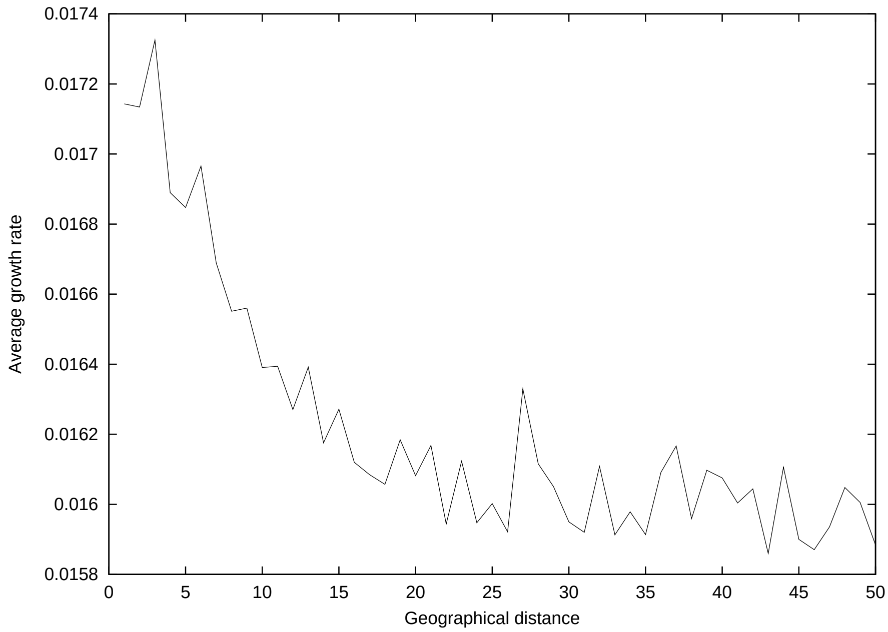

Figure 1: Effect of the ξ parameter on the average growth performance

geographical barriers in the process of technological diffusion.

In a first run of simulations, we take the ξ parameters to be homogenous across countries, so that the only differentiation is between home and rest of the world. We want to use the model to study the effect of the ξ parameter on the growth performance of the system. The conjecture is that a higher distance parameter will negatively affect the average growth performance of the system.

Thus, let the average growth performance of country j in the T time steps, AGR_j, be measured by:

$$AGR_j = \frac{logYY_{j,T} - logYY_{j,1}}{T-1}$$

where $YY_{j,T}$ is the level of real GDP for country j at the final time T. The overall growth performance of the system is then estimated in terms of the mean of all AGR_js, averaged on $M = 500$ runs of Monte Carlo simulations.

As it appears for the specific baseline parameterization[6] shown in Figure 1, the average growth performance increases with the value of the parameter, supporting the previous discussion on the negative effect of distances between countries. The case $\xi = 1$ corresponds to the situation where firms communicate between each other without bearing the costs associated with any sort of 'distance'. We can view this as a 'no gravity' model in which there are no constraints to a smooth diffusion process regime.

[6]The parameterization used sets the values: $N = 100$, $C = 10$, $Y_{i,1} = 1000$, $\pi_{i,1} = 0.5$, $T = 100$, $r_1 = 0.05$, $r_2 = 0.5$, $\alpha = 0.05$, $\beta = 0.05$, $d = 10$, $c = 1$

As soon as $\xi > 1$, country specific externalities are inserted in the system. When ξ is large, countries tend to be isolated and are very unlikely to imitate technologies developed by foreign firms. In this case an innovation designed in a given country is hardly imitated outside the borders so that the only source of productivity increments for firms are the self-produced innovation and the imitation of competing firms in the same country. This sharply reduces the chances of technological improvements for firms and, not surprisingly, negatively affects the overall performance of the system.

3.3 Patterns of divergence

We want to check whether the model accounts for patterns of divergence in economic growth performance across countries. We refer to the historical evidence (see Bairoch (6), Dosi *et al.* (16), Durlauf and Quah (19) and Temple (36)) of persistent variance in the levels of per capita incomes and in the growth rates of countries worldwide . Traditionally, divergence has received more attention from economic historians (Abramovitz (2), Landes (23)). However, several models, like Cimoli (11), Dosi, Pavitt and Soete (18), Metcalfe (27) and Verspagen (37), have moved towards endogenizing growth asymmetries by means of accounting for differences in technological regimes. Technological asymmetries are associated with differences in production efficiency and with gaps in innovative and imitative abilities. In this view developed countries are the ones which have historically gained the competences and resources for a greater success in innovation, while developing countries mainly engage in imitation. Innovation is normally taken as a force towards divergence and imitation is instead one towards convergence.

In our model, technological change is the main force at work in determing national income. The diffusion process that we insert can be thought of as a mechanism promoting convergence between firms and thus between economies. In fact imitation involves knowledge transfers in the form of spillovers from technologically superior firms to inferior ones. Clearly, firms that are positioned at the technological frontier are not profiting from spillovers because there are no better techniques for them to imitate. In this sense, imitation is a 'catch-up process' moving the system towards convergence. We explore the evolution in time of a measure of cross-country variability of the two economic variables of interest, namely the level of per capita income $Z_{j,t}$ and the growth rate of national income $g_{j,t}$. At each time step t we calculate the coefficient of variation, i.e. the ratio between standard deviation and average value in absolute terms.

Figure 2 shows that the variability of growth rates between countries is persistent and significant over time. A similar result is valid for the dynamics of the cross-country

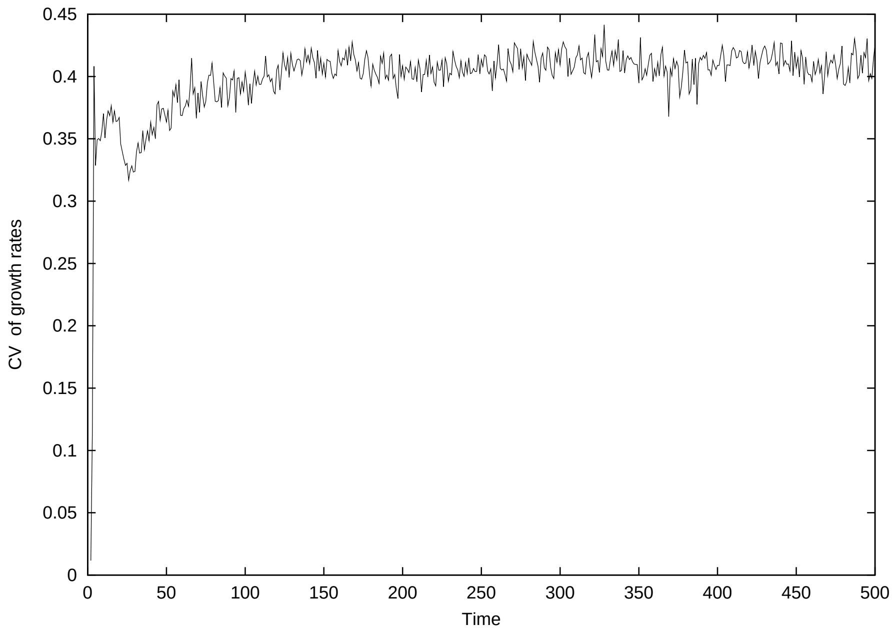

Figure 2: Cross-country variability of growth rates

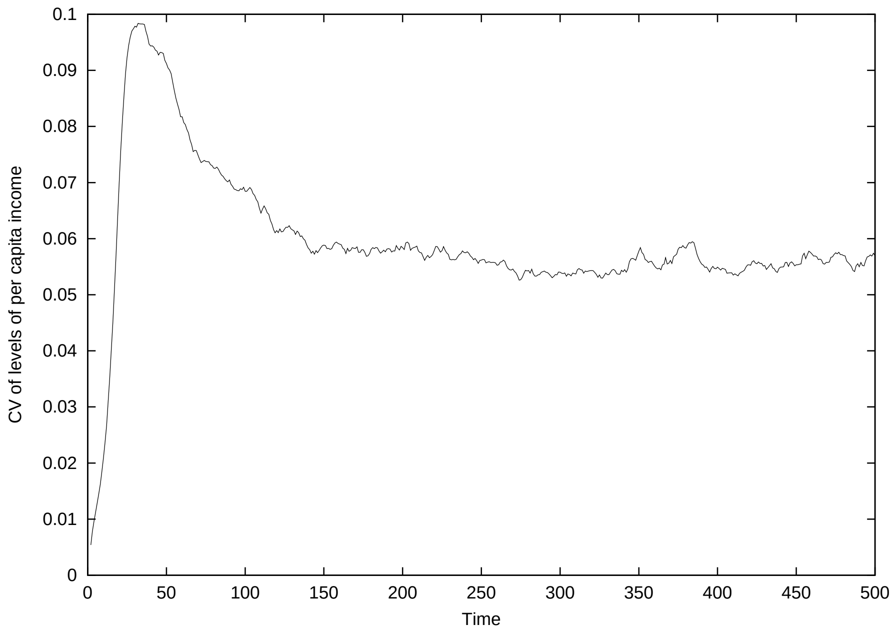

Figure 3: Cross-country variability of levels of per capita income

dispersion of per capita incomes (Figure 3). After an initial phase of transition, the coefficient of variation settles to a steady value that proves persistent differentiation of income level.

So, even when including a significant process of international technological diffusion, the model generates steady differentiation in the distribution of income across countries. This result seems to be a generic property attainable from evolutionary models. As Pavitt (31) points out, a value added of 'Nelson and Winter-type models' is indeed the emphasis on technological regimes and the acknowledgement that firms in different countries experience different patterns of technological change. An interesting direction of further research would be the exploration of the joint impact of technological and market asymmetries.

4 Some conclusions and further analysis

We have presented a model of endogenous growth for a system of open economies. We have developed an agent-based simulation platform that allowed the study of the effect of a combination of key parameters. We directed our interest to the micro activities of technological change performed at firm level. Moreover, we investigated the properties of international technological diffusion. A technological distance between firms was defined and we found that average growth performance of the system was negatively affected by increasing geographical barriers. Despite the effectiveness of the process of technological diffusion, the model could generate persistent differentiation in the level of per capita income and in the growth rates of countries in the system. This property captured one important stylized fact in the empirical literature on growth.

The presented results are the insights coming from preliminary simulation runs of our model. We want to explore in more detail the relation between international trade and growth. An important addiction to our model would be the specification of a mechanism that adjust exchange rates. Conventional models explain trade using a static concept of comparative advantage, where countries technologies are given. New trade models (see Grossman and Helpman (22), Krugman and Obstfeld (25)), have been advocating the shift to a dynamic comparative advantage, with the idea of combining the key properties of endogenous technical change of Romer-type models with the comparative advantage mechanisms. Several models have been concerned with endogenizing comparative advantage (see for example Cimoli *et al.*(12)). By including the Schumpeterian assumptions of imperfect markets and increasing returns in production, the main forces at work in the causal relation between trade and growth are two opposite ones. On one side international trade is beneficial to the extent that it increases the size of the market. Also, trade expands the scope for knowledge spillovers. On the other side, there is a negative competition effect that consists in a fiercer market competition. From a preliminary analysis, it seems that the latter effect is predominant in the specification of our model. We wish to investigate the relevance of the distance in trade for the growth perfomance of the system and the cross-country variance of growth rates. We may find scale effects that justify the relative inefficiency of one single global market vs several isolated domestic markets.

We also want to perform more tests on the simulation results to study the cross-country distribution of growth rates generated by our model. We aim at analyzing the conditions for the emergence of divergence and polarization patterns similar to the ones historically observed. In fact, spatial spillovers and patterns of cross-country trade have already been used by Quah (32) to explain the emergence in time of twin peaks in the cross-sectional distribution of growth rates.

Finally, we want to expand the model to a multi-sector setting. The assumption of the existence of one sector of production only is indeed quite restrictive. Many of the features of the model are quite sector specific. For instance, the properties of technological change in terms of opportunities and appropriability depend on the specific sector of production. Even more critically in a multi-country setting, national economic performances are determined by the sectors in which countries specialize.

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