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# Endogenous Growth in a Spatial Economy: The Impact of Globalization on Innovations and Convergence

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**Abstract**

In this article we explore the claim that spatial interactions among cities are significant drivers of their growth. We assert that reallocation of ideas among cities is a source of improved allocation of resources. We propose a closed economy, agent-based model that is in constant flux. It is populated by autonomous agents that compete and adjust constantly their behavior in reaction to the conditions they perceive. The economy is a dynamic, self-organizing system. We focus on the intensity of globalization as the critical economic process that explains differences in convergence and divergence in the system. The means by which the extent of globalization affects the long-run performance of economies is the geographic reach of new ideas and their conversion into innovations. The question that plays out in our model is the relative influence of globalization and the localized entrepreneurial ecology on innovation. When the globalization is weak, new firms are limited by the market value of their own city. As the globalization strengthens, more and more new firms belong to the global playground. We demonstrate that in line with empirical literature, the gross domestic product of our urban system increases greatly with the increase in globalization level.

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Based on the analyses in the first half of the twentieth century, Kaldor (1961) suggested some stylized facts that framed much of the consequent research into growth processes. According to Kaldor, labor productivity and capital per worker display a sustained growth rate. The ratio of capital to output is stable, and capital and labor capture stable shares of national income. Yet, there is a significant variation, of the order of 2–5 percent per year, in growth rates among the fast-growing economies of the world. Some fifty years after Kaldor, Jones and Romer (2010) modified Kaldor's list to include a significant increase in the flows of goods, ideas, and finance that characterize globalization and urbanization and increase the rates of growth and of variation in gross domestic product (GDP) per capita. While human capital has been rising, it did not result in changes in relative wage rates of skilled and unskilled workers. Most significantly, the measured inputs can explain less than half of the differences in per capita GDP of countries (Jones 2016).

The failure of the vast literature to explain consistently persistent differences in GDP per capita is coupled with contradictory empirical evidence concerning convergence across economies at various spatial resolutions. In one of the early studies, Quah (1996) reported a stable and uniform rate of convergence among economies of 2 percent per year. He suggested that the convergence may be unrelated to growth. Furthermore, he wrote that "usual empirical analyses—cross-section (conditional) convergence regressions, time series modelling, panel data analysis—can be misleading for understanding convergence . . . ." (1353) Quah suggested that there is a need for an improved theoretical infrastructure. In a later study, Barro and Sala-i-Martin (1992) analyzed forty-eight US states between 1840 and 1963 and found evidence for convergence. According to Ganong and Shoag (2017), on the other hand, per capita income inequality among US metropolitan areas increased by 30 percent between 1980 and 2016.

A critical determinant of the results concerning economic convergence is the choice of spatial and temporal resolution. Generally, time series of various measures of urban economies displays irregular patterns. They are characterized by fluctuations with sharp declines and increases at various time scales. The common approach to studying nonlinear dynamics in such situations is to use a "model-free" method to identify a minimal set of parameters that can resurrect the entire phenomenon based on a sample of data. The most common method uses delay-coordinate embedding (Yagasaki and Uozumi 1998). It hints at the ergodic characteristics of the system. Moreover, characterization of the long-term dynamics of urban systems is based on short series of aggregated data. To understand the ergodic properties of processes that are produced by our meager data, there is a need for models with robust first-principles theoretical underpinning that suggest how the data were produced.

Generally, the models that we have are too restricted to yield the entire spectrum of dynamics of an urban system. Contrary to the expectation based on a general equilibrium model, the Lucas (1990) paradox points out that capital does not flow from rich to poor countries. It is our view that the self-organizing nature of modern economies leads to prolonged far-from-equilibrium conditions that are not conducive to the Lucas expectation. Urban systems are not linear and are subject to a variety of positive and negative feedbacks. Local positive feedbacks that are inherent in urban dynamic systems tend to possess a multiplicity of possible emergent structures. Initial conditions combined with random events push the urban system into the domain of attraction of one of these states.

In this article, we aim at exploring further the assumption, central to Pumain's (1997) evolutive urban theory, that spatial interactions among cities are significant drivers of their growth. We assert that reallocation of ideas among cities can be the main source of improved allocation of resources and economic growth. Therefore, we study growth/decline processes that arise endogenously within a system of cities. Our workhorse is an agent-based model that was previously used in order to study the dynamics of urban systems, including life cycles for individual cities and power law distribution for the system as a whole (Broitman, Benenson, and Czamanski forthcoming). The results obtained in that paper suggested that the model could also be used to explore the influence of globalization on convergence or divergence: in this study, we specifically focus on this type of processes.

The rest of this article includes three sections. In the first section, we describe our far-from-equilibrium growth model. In the second section, we present an analysis of the critical parameters of the model and the results of selected simulations. In the third section, we propose some conclusions and suggestions for future research.

## Far-from-equilibrium Growth in a Spatial Context

The traditional neoclassical growth paradigm, as exemplified by the Solow–Swan model (Mankiw, Romer, and Weil 1992), is characterized by perfectly competitive markets and constant-returns-to-scale technologies. The typical model is populated by identical agents enabling simple aggregation of representative individuals. Agents are assumed to be fully rational, and competition among them is price related only. Models of the Solow–Swan genre predict that market forces will lead to economic convergence in living standards across space. The empirical observations are assumed to reflect equilibria.

In neoclassical models, growth in per capita output is the result of capital accumulation and/or technological progress. After convergence is achieved, growth is possible through reduced current consumption and saving that enables investments and by the introduction of exogenous injection of resources. A third source of growth is possible if there are obstacles to the operation of a perfectly competitive economy. In such cases, rearrangement of the resources will lead to growth. Thus, there are three sources of growth in a closed economy:

- injection of resources,
- reduced current consumption in favor of investments, and
- rearrangement of existing resources.

In our model, we focus on the third source of growth, the spatial rearrangement of resources. The rearrangement mechanism generates endogenous growth dynamics. In contradistinction to traditional growth models, we do not assume equilibrium as an inevitable end condition of urban dynamics. It can occur. However, the economy can persist in a far-from-equilibrium state for indefinite periods of time. Empirical observations, therefore, do not necessarily reflect equilibria. The choice of spatio-temporal prism for testing model outcomes is critical. Furthermore, the model is populated by adaptive agents that at times are subject to bounded rationality. They compete and adjust constantly their behavior in reaction to the conditions they perceive. The economy is a dynamic, self-organizing system. Therefore, the choice of the specific time for examining the outcomes of the model is critical as well. Within an agent-based framework, the model reflects ideas from our rudimentary previous models (Czamanski and Broitman 2017, 2018).

In addition, the model accommodates the possibility of two stylized facts associated with cities. Individual cities experience life cycles. Because cities' dynamics may have very long characteristic time, we can fail to observe all stages of the cycle in existing data. But cities grow at a slow and at a fast rate. Later their growth ceases and they may shrink (Brezis and Krugman 1997; Czamanski and Broitman 2018). In Europe, for example, the phenomenon of shrinking of some cities has become an issue (Iammarino, Rodríguez-Pose, and Storper 2019). The second stylized fact concerns systems of cities. At times, they display rank–size (power) law for various city characteristics (Masucci et al. 2015; Benguigui and Blumenfeld-Lieberthal 2007; Black and Henderson 2003; Ioannides and Overman 2003).

In our model, the spatial economy is comprised of cities that are populated by workers and firms. The economy is closed. Firms do not migrate among cities. Some firms may cease to exist. New firms may be born. Workers can migrate among firms and cities. As they migrate, they are a critical source of new ideas that spawn new products and technologies. In a city with a static population, the source of new ideas that can generate new products and new technologies is limited. Immigrants are a significant source of new ideas. They generate innovations that firms adopt and convert into inventions. Thus, a city with significant immigration is blessed with increasing source of inventions and innovations. Recently, Kauffman's (2000) idea of adjacent possible (de Vladar, Santos, and Szathmáry 2017) has been an inspiration for thinking about the emergence of novelties (Loreto et al. 2016).

The model reflects the following story. There is a fixed number of cities. They are separated by distances that are sufficiently large so that commuting is made impossible. A fixed number of workers are initially equally distributed among the cities. An initial number of firms are allocated equally in each city. New firms are created during the model's run. Since firms do not migrate, all new firms remain in the city of their birth. Each one of the workers works in a firm located in the city where he or she lives. There is no interurban commuting, and there is full employment. On a larger geographic scale, workers are partially mobile: every time step, a worker has a chance to consider the possibility to migrate to another firm, in the same city or elsewhere. In that case, the prospective worker chooses a random firm and compares his or her salary in the actual firm compared with the possible salary in alternate firms while taking into account relocation costs. If the relocation is worthwhile, he or she moves to another firm in the same or in a different city. Although the workers' population is constant, the cities' sizes change in time, as workers migrate by choosing where to live and work.

The main characteristic of each firm is its market value. It is associated with the firms' product mix, and its initial value is assigned at a moment of the firm's birth. The initial market value represents the quality of the products produced by the firm and the technologies utilized in the production processes. As more production process innovations are adopted by the firm, its market value increases. The invention of new products and services gives rise to new firms, specialized in serving new markets, that old firms cannot serve.

Workers are the innovative force that determines the system's economic development. A worker can propose innovation in the firm's production *process*. If it is adopted, it increases the firm's market value only marginally. Alternatively, he or she can propose a new *product*. *Product* innovation implies a qualitative leap into a new market, generating a fundamental upgrade in the firm's business that can only be implemented by means of a subsidiary firm managed by the innovator. Firms compete for workers, and they remain active until the last worker leaves to work elsewhere. They constantly search for better opportunities in an increasingly advanced technological environment. The extant technology is driven by worker's innovations and the firm's willingness to implement them.

The following figure describes the main decisions taken by workers and firms in the model. A detailed description of each one of the model's components and their mutual dynamics can be found in Broitman, Benenson, and Czamanski (forthcoming). For the purpose of the present article, we present a brief summary of the model.

The upper loop of Figure 1 describes the workers' choices. In each time step, 10 percent of the workers can consider migration to a new firm. They pick a random firm (located in the same city or elsewhere), compare salaries and relocation costs (if needed, as explained previously), and decide whether to move or not. If the worker decides to move, he or she has a chance to become a product innovator or a process innovator, but this happens randomly. The difference between both types of innovators is their persistence: a process innovator desists if the innovation is not

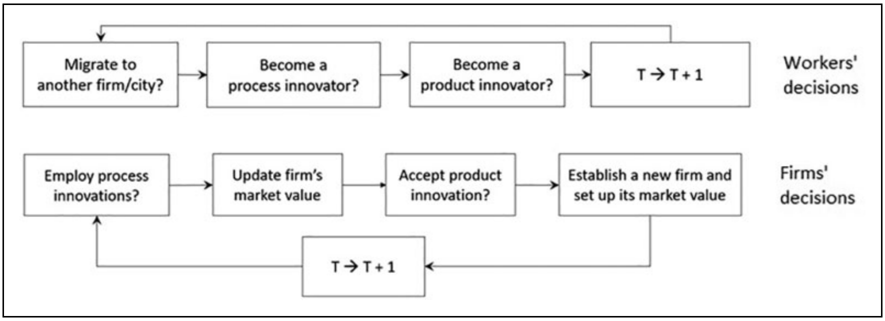


**Figure 1.** Decisions of workers and firms in the model.

implemented after a period of time and forget it. Conversely, a worker who suggests a product innovation becomes an entrepreneur. If after a certain period, a product innovator cannot implement its idea, he or she will try to do so in another firm. From the point of view of firms (lower loop in Figure 1), the innovations suggested by the workers (if any) can be taken into consideration, but the chances of their acceptance and implementation are also random. If a process innovation suggested by a worker is adopted, the firm's market value is updated. However, if a product innovation suggested by a worker is adopted, the consequences are different: a new dedicated firm is created with the purpose to develop and commercialize the new product. Therefore, the market value of this new firm will be significantly higher.

## The Model's Critical Parameters and Simulation Results

Globalization is characterized by extensive flows of goods, ideas, and finance among economies. It, together with urbanization, increases the rate of economic growth and of variation in GDP per capita. Thus, following Jones and Romer (2010), we focus on the intensity of globalization, called herein "globalization strength," as the critical economic process that explains differences in convergence and divergence. The means by which the extent of globalization affects the long-run performance of economies is the geographic reach of new ideas and their conversion into innovations. The question that plays out in our model is the relative influence of globalization and the localized entrepreneurial ecology on innovation (Audretsch and Belitski 2017; Audretsch et al. 2019). In other words, if local entrepreneurial ecosystems aim to increase the probabilities of successful new ventures, what will be the impact of an increasing or decreasing level of globalization on their functioning, and how these entrepreneurial ecosystems manage to adapt to changes.

Given an innovative environment in a city and the presence of workers that are inclined to innovate, the adoption of a *product innovation* proposed by a worker leads to dramatic consequences. The worker's innovation is implemented within a newly established subsidiary firm. In our model, it is considered a new independent firm. The new firm will be technologically more advanced than its mother firm, meaning that its market value is larger than the market value of the mother firm.

We assume that technological development level that has been already achieved inspires further technological developments and defines the range of future technological innovations that is expressed by the metaphor of the "adjacent possible" (Kauffman 2000; Loreto et al. 2016; de Vladar, Santos, and Szathmáry 2017). At the center is the commonsense notion that a new thing leads to another new thing. It is the set of ideas that are one step away from what actually exists and generate incremental modifications and recombinations of the existing ideas. The "adjacent possible" concept is manifested in the model by enlarging the current maximal market value that can be assigned to a new firm, by a certain percentage, beyond the observed maximum. This means that, when a firm adopts a product innovation suggested by a worker and a new dedicated firm is created, the market value of this new firm has a chance to be higher than that of any other firm. By technological innovations, the horizon of possibilities expands continuously.

There are two possible market values. The global maximal market value pertains to all the firms active in the world regardless of their location. The local maximal market value is associated with all the firms that are active in the city. The market value of the new firm is always bounded from below by the market value of the mother firm but can be drawn from the segment limited from above by the global maximal market value. The alternative is to draw the new firm's market value from a segment limited from above by the local maximum market value. The *globalization strength g* is a share of new firms that reflect the global market. It is equal to 1 if the maximal market value of reference is always the global one. If the *globalization strength g* is, for example, 0.3, around 30 percent of the new firms will receive a market value in the range between their mother's firm and the maximal global market value. The other 70 percent will be bounded by the local maximum market value of the firms in the same city at their birth time.

In our model, it is the reallocation of ideas among cities that causes an improved allocation of resources and economic growth of the system of cities. The basic simulation result of the model is the monotonic economic growth of the system of cities caused by the continuous emergence of innovations and enlargement of the segment of initial market values for new firms. Within the system, cities display a variety of dynamics including partial and complete life cycles. At the same time, some cities degenerate to "villages" and even disappear. Furthermore, our model indicates convergence only under very specific conditions. In most of the scenarios, differences in the economic performance of cities persist.

A fundamental question that we address is to what extent the assumed globalization strength generates different growth patterns. The model includes 50,000 workers distributed among an initial number of 1,000 firms, located in 100 cities. Therefore, initially, each firm employs 50 workers, and each city is home of 500 workers. To analyze the impact of the globalization strength, we consider eleven values, from 0 percent (all new firms receive their market value according to the

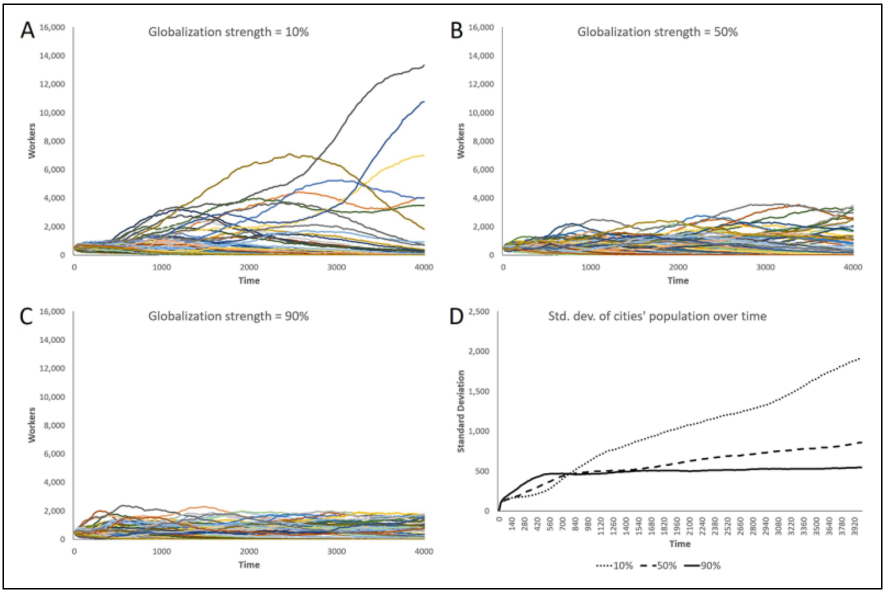


**Figure 2.** Evolution of the urban system as function of the globalization strength $g$. Cities' size for (A) $g = 10$ percent, (B) $g = 50$ percent, (C) $g = 90$ percent, and (D) standard deviation of the city size distribution as measure of city size divergence.

local conditions) to 100 percent (the contrasting case in which all new firms draw their market value from the global rank), varying $g$ by 10 percent. Figure 2 illustrates the evolution of the system of cities during a period of 4,000 steps for very low (10 percent), medium (50 percent), and very high (90 percent) globalization strength.

When the globalization strength is low (panel A in Figure 2), innovations remain locked in the places where they emerge initially, despite migration of workers between firms and cities. Places that do not manage to thrive in the early stages of their development have a high chance to decline and even to disappear. These are the cities that remain close to the horizontal axis. In some cities, there are significant technological developments that drive a virtuous cycle of innovation-migration-innovation during certain periods of time, until other, more advanced innovations emerge in other places. This is the case of several inverse U-shaped cycles clearly discernible in the upper panel. Only few cities achieve a more sustainable growth cycle, reaching populations of more than 10,000 workers. The urban system in this case is composed of large, medium, and small cities during all stages of development.

When the globalization strength is high (panel C in Figure 2), the dynamics of the urban system are completely different and stand in stark contrast with the previous scenario. In this case, *because of the globalization*, any momentaneous preponderance of a firm, or a small group of firms, in a single city is soon contested by firms in other cities. The competition for technological dominance is made possible by the

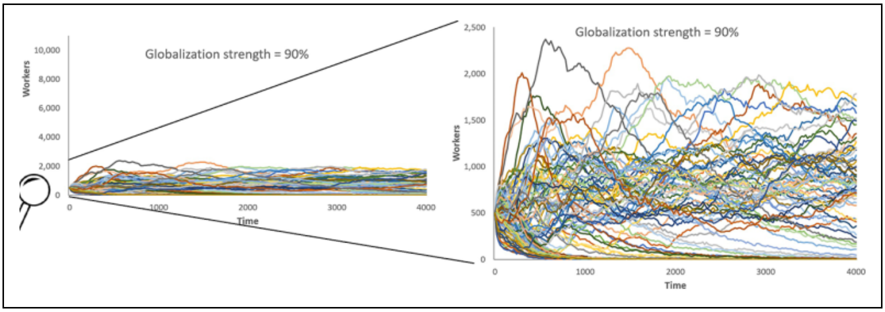


**Figure 3.** Evolution of the urban system when the globalization strength is 90 percent.

free flow of ideas among cities. As a result, a city cannot preserve its advantage for long. This phenomenon is evident also when the globalization strength is moderate (panel B in Figure 2). This intermediate scenario shows mixed results, a combination of two opposite forces. On the one hand, local innovations that give birth to virtuous growth cycles, creating medium-size cities of around 4,000 workers, and on the other marked fluctuations caused by globalization forces that are available everywhere. As a rule of thumb, there is an opposite relation between globalization strength and the divergence of the urban system with time (panel D in Figure 2). Figure 3 shows the reason for the lower divergence of the urban system when the globalization strength is high, zooming in on panel C of Figure 2.

In the scenario shown by Figure 3, large cities cannot emerge. Every time an innovation emerges somewhere, it accelerates the city growth, but the innovation is global in the sense that any other firm located elsewhere can also take advantage of it. This is the meaning of the high globalization strength. Most of the time, new firms, regardless where they were born, draw their market value from the global values. As a consequence, the largest cities remain relatively small (around 2,000 workers) and their life cycles are fast (see the right panel in Figure 3). Some cities decline and die, but most of them struggle to survive with fluctuating populations, according to their relative innovation levels.

The final distribution of city sizes (at time 4,000 according to the performed runs) is shown in Figure 4 as a function of $g$ (the globalization strength).

As the globalization strength grows, there are fewer large cities (of more than 2,000 workers, in black color) and more medium-size ones (between 100 and 2,000 workers, in dark gray). The number of cities that decline and disappear tend to grow as the globalization strength increases (the white columns from left to right). It is noteworthy that in the absence of globalization, among the large cities, there are also super-sized cities. Thus, for example, with globalization strength of 10 percent, there are two primate cities with a population of around 11,000 and 13,000 workers. These primate cities are the largest of a group of six cities that have more than 2,000 workers (included in the black upper part of the left column).

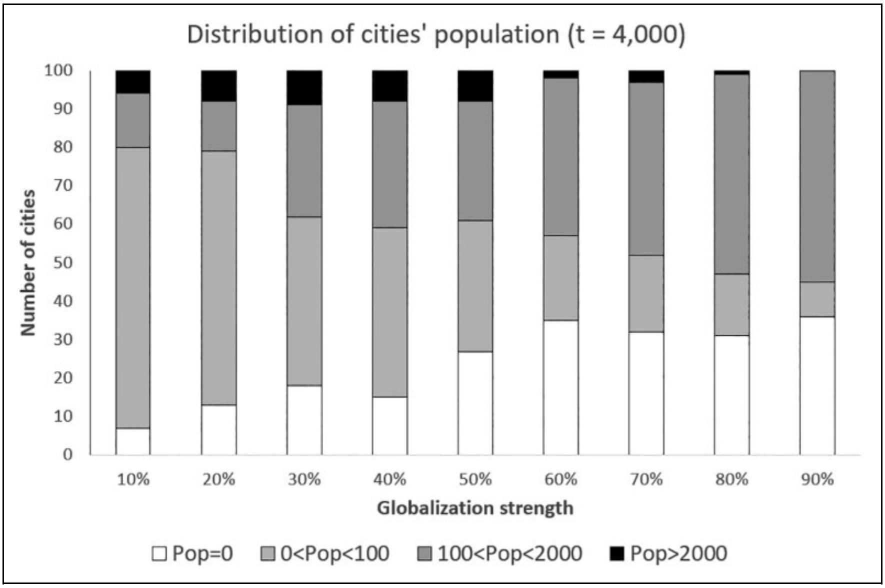


**Figure 4.** Size distribution of cities for different globalization strengths (*g*).

Besides the distribution of city sizes as an aggregated parameter, the underlying distribution of firms among the cities that comprise the urban system according to different globalization values is interesting. With low globalization strength, there are few cities that host the most advanced firms, firms with the highest market values in the whole urban system. As a consequence, the difference between the firms' composition of the largest cities and smaller ones will be remarkable. In contrast, when the globalization strength is high, the differences between the firms' composition of the large cities should be moderate. Since in this case a new firm born anywhere has almost the same chances to acquire a high market value, the distribution of market values should be more balanced. The contrast between both scenarios is evident in Figure 5, that shows the market values of firms located in the four largest cities of the urban system, for the scenarios with a globalization strength of 10 percent and 90 percent, respectively.

The upper chart of Figure 5 shows the case of low globalization strength. The largest city (in black) has a disproportionate share of firms (455) compared with the second city (325 firms, in gray). The firms located in the largest cities have a higher market value of their counterparts in the second city. The largest city has many more firms in absolute terms than the second, and these firms are more advanced. The same can be said about the second city compared with the third, and so on. This chart reflects the features of Figure 2A, through a different focus: the size of the most populated city is explained by the large number of firms located in the city and their

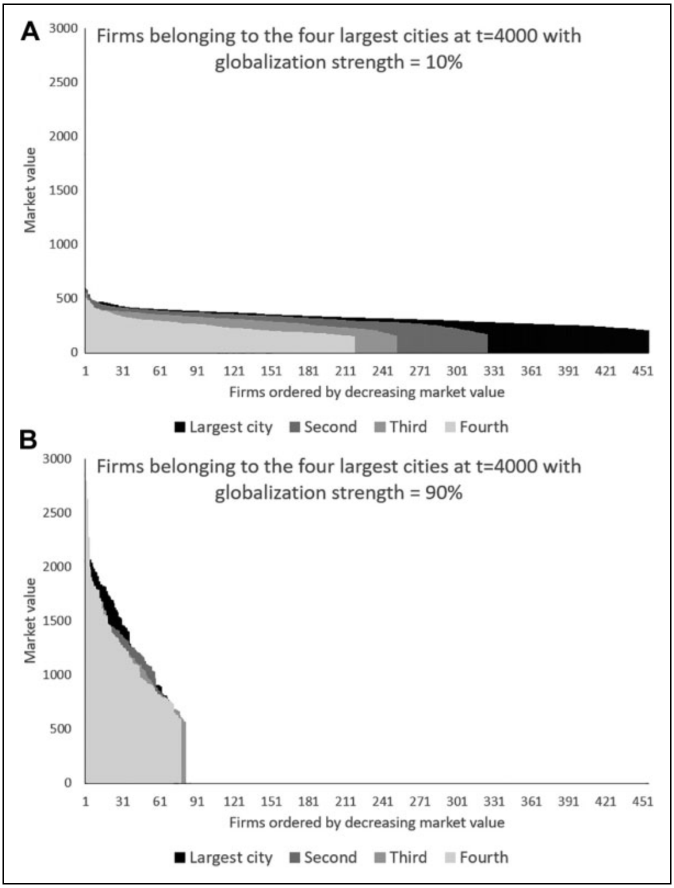


**Figure 5.** Firms ordered by decreasing market values in the four largest cities of the urban system. (A) Firms belonging to the four largest cities at $t = 4{,}000$ with globalization strength $=$ 10 percent. (B) Firms belonging to the four largest cities at $t = 4{,}000$ with globalization strength $=$ 90 percent.

high market value that attract migrants. However, the *y*-axis shows that even the highest market value in the urban system (less than 600) is dwarfed by the values obtained by firms when the globalization strength is 90 percent (lower chart in Figure 5). In this case, the four largest cities are almost superposed and is difficult to discern them. There are less firms per city (around 75), but their market values are high (the most advanced ones reach market values of almost 3,000). The most remarkable feature is the almost egalitarian distribution of firms among the cities (in terms of both numbers of firms and their market values). This explains why the population of the cities oscillates continuously (as shown in Figure 3), but no city is able to predominate: the high globalization strength prevents it.

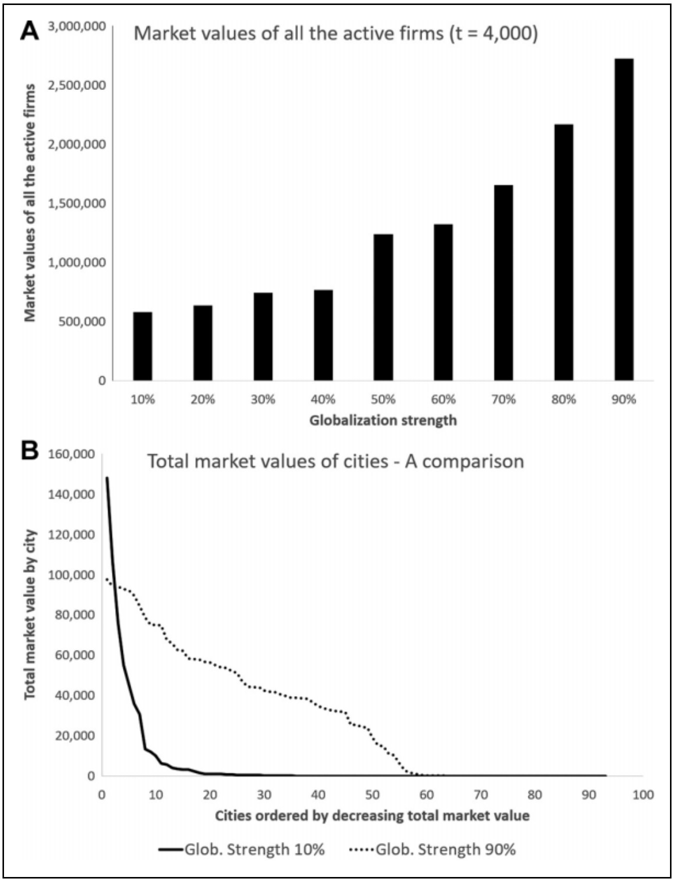


**Figure 6.** Aggregated market values of firms as function of different globalization strengths. (A) Market values of all the active firms ($t = 4{,}000$). (B) Total market values of cities—a comparison.

The market values of all the firms active at any point of time can be interpreted as the GDP of the urban system. Figure 6 shows the results of each scenario at time 4,000 as a function of the globalization strength.

The GDP of the urban system increases greatly with the globalization level. This is consistent with the empirical literature (see, e.g., Hasan 2019). When the globalization is weak (the left size of the upper chart), new firms are limited by the market value of their own city. Therefore, the aggregation of their revenues is a sum of relatively low values. As the globalization strengthens, more and more new firms belong to the global playground. The global market values are always larger than their local counterpart since any new firm born anywhere, regardless of the local market limitation, can draw its market value from "the great world." This is the reason why the GDP is the largest when the globalization is more established (right column in the upper chart). The impact of the globalization strength on the GDP is more evident in the lower chart in Figure 6. This chart shows the aggregate market value of each city, by decreasing order in time $t = 4{,}000$ for globalization strength 10 percent (continuous line) and 90 percent (dotted line). The area below the functions is represented in the leftmost and rightmost column, respectively, of the upper chart. With globalization strength of 10 percent, there is a significant inequality among the cities (the continuous line declines very fast), but the integral below the function is small. When the globalization strength is 90 percent, a large share of the cities has comparable aggregated market values, and hence the dotted line declines moderately with a much large integral beneath it.

## Discussion

The model and the simulations presented above give credence to the notion that economic growth is driven by interactions among cities. By means of interurban migration and the resulting reallocation of ideas among cities, we generate improvements in the allocation of resources. As Bloom, Van Reenen, and Williams (2019) suggest, we view innovation as a driving force in the economy. In our closed economy model, we witness endogenous growth. At the same time, the model described in this article is intended to study processes of convergence and divergence in an urban system fueled by the spatial rearrangement of resources. This rearrangement mechanism generates endogenous growth dynamics that depend strongly on the location in which it takes place. There is a force in the model that can resist the "location tyranny." This is what we call the globalization strength. When the system is more global, the comparative advantage of specific places is weaker since any economic activity can be performed efficiently almost everywhere. In that case, even if a new technology is invented in city A, it can be soon replicated in city B and a bit later overpassed by an even more advanced one in city C. This is reflected in the life-cycle dynamics of the cities, giving rise to a fairly egalitarian urban system.

Therefore, according to the model's results, in a globalized setting, each single city has almost the same chances to grow all the time. However, empirically, this is not what is observed when urban systems are analyzed. The opposite is generally true. As the rank–size rule predicts, there are few disproportionately large cities along with lots of smaller ones. Only scenarios with low globalization strength fit the empirical observations. This means that technological advances cannot be implemented easily everywhere since they depend in some fundamental way on the specific local conditions that give them birth in the first place. The same unique combination of local factors that make a technical innovation possible is the same ones that maintain it over time. At some stage, all cities will be able to implement and take advantage of the new technologies, but this will take time, and probably even new technologies will emerge till then, with high chances that this will happen in the same city that leaded the last innovation. In other words, within an urban system, location still matters. This observation has important policy implications regarding attempts to achieve a more balanced model of growth among cities. Future research based on the model will focus on the impact of different policies (migration policy, infrastructures development, business promotion, etc.) on the urban structure and dynamics. By now, the model's results suggest that creating the required background for the implementation of new technologies is a necessary condition for balanced urban development.

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