FACULTAD ECONOMÍA Y NEGOCIOS UNIVERSIDAD DE CHILE
DEPARTAMENTO DE ECONOMÍA

SERIE DE DOCUMENTOS DE TRABAJO

SDT 455

A Model of Diversification and Growth in Open Developing Economies

Autores:
Manuel Agosín
Yerko Retamal

Santiago, Agosto de 2019

sdt@econ.uchile.cl
econ.uchile.cl/publicaciones

A model of diversification and growth in open developing economies

Manuel Agosin and Yerko Retamal*

Abstract

We build a growth model that resembles the situation of many poor countries with small domestic markets: they are far from the world technological frontier and they have a comparative advantage in one (or a few) primary commodity. Their great challenge is to introduce into the domestic economy goods that are produced elsewhere in the world economy. Starting new sectors from scratch is hampered by two market failures. In the first place, entrepreneurs must be willing to invest in discovering production technologies abroad and adapting them to local conditions. This process has information externalities: the pioneers have to undertake investments in information that cannot be patented and that can easily be copied by others who haven't made the investment (copycats). Second, there is a coordination problem. Success in establishing new industries is dependent on non-traded inputs that serves a variety of sectors ("infrastructure"). A simple model allows us to simulate the conditions under which a planner that balances her budget can succeed in maximizing growth. The solution involves erecting infrastructure and subsidizing information investments of pioneers and taxing both a traditional sector and copycats induced to invest by the discoveries of pioneers.

JEL Codes: O11, O38, O41

Key words: Growth, Development, Growth Models, Development Policies

Introduction

Most models of economic growth do not take into account the basic features of economic structures in developing countries and the challenges that they face in accelerating economic growth. In the first place, following the pioneering papers of Harrod, Domar, and Solow, they generally adhere to the assumption of a one-sector economy (where Y (GDP) is an all-purpose good). In the some of the newer endogenous growth models (e.g., the AK model, a resurrection of the Harrod-Domar model in new garb), technological change is wrapped up in the capital-accumulation process, and this may be why there are constant returns to capital accumulation.

The Solow model assumes an exogenously given rate of technological change toward which the rate of growth of output per worker tends in the long run. This rate, or the growth of "total factor productivity (TFP)", has captured the attention of legions of economists and policymakers. In a world of diminishing returns, in the steady state, the variable that accounts for growth is the rate of change of TFP. Many empirical studies have shown that, paradoxically, TFP, calculated the conventional way (as a residual from a Solow empirical growth equation, assuming a Cobb-Douglas production function) grows at modest (and sometimes even negative) rates in most developing countries. Even in the so-called Asian tigers (Hong Kong, Taiwan, Singapore, and Korea), growth per worker seems to be

* Facultad de Economía y Negocios, Universidad de Chile. We thank Luis Cabezas and Alejandro Bayas for able research assistance, as well as the legions of students in Agosin's development course at FEN who have been exposed to subsequent versions of this model and have made important suggestions for its improvement. We would like to thank participants at the RIDGE Workshop on Macroeconomics and Development, Buenos Aires, December 14-15, 2017, for useful comments on an earlier draft.

accounted for mostly by capital accumulation per worker (Young, 1993), in contrast to the original findings of Solow (1957) for the United States, which found that up to 80% of GDP growth is accounted for by TFP.

One-sector models are not very useful to describe the growth process in economies that depend on diversification as the motor of growth. In the first place, any one-sector model assumes away the diversification issue. Second, in developing economy settings, technological change is the result of factors of production moving from less productive to more productive uses in new sectors that didn't exist previously. In fact, we would venture that much that is measured as technical change in developing countries is related to the introduction of new sectors which involve higher factor productivities and results from the diversification of production. In the view of development offered by Hausmann and Rodrik (2003), growth in developing countries is the result of "self-discovery", which involves the incorporation of sectors that are new to the domestic economy but which exist elsewhere. Since these new sectors have higher factor productivities, technical change as conventionally measured (or "total factor productivity") reflects the shift of resources from lower- to higher-productivity sectors.

Technical change, in the sense of most of the growth literature, has no place in models based on "self-discovery". Even if technical change is zero in each existing sector of the economy, there can be growth fueled by some entrepreneurs investing in sectors that didn't exist before in the local economy. In fact, the key to growth in most developing economies is the process by which goods produced elsewhere in the world economy are incorporated into specific developing country settings. The technology thus acquired is new to the recipient but not new to the world. And it represents technical change for the recipient economy as a whole.

Self-discovery involves copying technologies that cannot be patented rather than adding new products or technologies to the stock of world knowledge. This way of looking at development is a close cousin to Gerschenkron's (1962) "advantages of backwardness". Hausmann and Rodrik (2003) identify two reasons why the amount of self-discovery (i.e., the pace at which goods and technologies extant in the world economy are incorporated into a developing country setting) is sub-optimal. In the first place, the discovery that a product can be produced with comparative advantage in a specific country generates important informational externalities. In other words, the pioneers who make the investment in information may be unable to appropriate the entire return on their investment, because others who have not made the investment can readily copy it. However, copying is key to the social benefits of the investment in information.

Second, there is a coordination externality. Any *de novo* endeavor involves the need to coordinate the activities of many actors, some private, others public. In particular, the production of any new good will require the existence of non-tradable infrastructure. Think of exploiting a new mine. For exports to take place, roads and a port have to be built. Exporting any new agricultural good requires what agronomists call post-crop management: phytosanitary controls to enable exports, transport links from producer to port, cold-storage facilities, knowledge of who the buyers are and the tastes of foreign consumers.

We place particular importance on exports, because most developing countries are small (populations under 20 million inhabitants) and, therefore, it is difficult for them to become competitive internationally solely on the basis of their domestic markets. We will be attempting to disentangle the conditions under which developing countries can begin to produce goods already in existence in the world economy and do so with comparative advantage; (eventually) unaided exports are the best evidence of comparative advantage.

Section I discusses the literature on growth models and their inadequacies to tackle the problems of developing economies. In section II we review selected evidence in favor of the hypotheses developed in this paper, which view successful growth as the joint effect of pioneering the incorporation into the domestic economy of industries that exist elsewhere and the provision of infrastructure (writ large) by a central authority needed for the success of these market-driven efforts. Section III describes the model, while section IV shows the results of simulating it for a large number of periods under different assumptions and the planner's decisions regarding taxes and infrastructure investments. Section V describes some robustness exercises, and section V concludes.

I. Some recent literature

There hasn't been a great volume of literature, either theoretical or empirical, emphasizing the role that diversification of production and exports can play in the economic growth of countries well below the world technological frontier. Mention has been made of the paper by Hausmann and Rodrik (2003). An older contribution is Lucas (1993), which emphasizes learning by doing as a source of growth in developing economies. The gist of his paper is modeling the path of an economy that is not initially competitive but is able to become so through learning by doing. Lucas' mechanism for learning by doing is the accumulation of human capital, which has a kinship to the model we develop below. However, Lucas's is still a one-sector model and, therefore, doesn't capture the basic stylized fact that growth is associated with diversification.

The growth driver in both Rosenstein-Rodan's classic paper of 1943 and its formalization by Murphy, Schleifer, and Vishny (1989) is the amplification of the domestic market through the pecuniary external economies of investment in various sectors jointly. The emphasis on coordination externalities also has a certain resonance in this paper, which, however, has no place for domestic demand. The externalities involved here are those that relate to information useful in producing new goods, and the coordination that is necessary is at the level of supplying non-tradable inputs, not aggregate demand.

A paper by Temple (2005) explores various implications of a two-sector growth model, among which are those that can be derived from a formalization of the Lewis (1954) classic paper quoted above. Its interest, in relation to this paper, is that it goes beyond the one-sector growth model that has dominated the literature.

Other two-sector models, incorporating a goods-producing sector and an ideals-producing sector (or an R&D sector) can be found in Lucas (1988). However, the goods sector continues to be a single composite good. The innovation of this paper is that it is more useful to think of the economy as producing a very large number of goods. A developing economy's sectors are variable and depend both on pioneers' search for transferable technology and the incentives and coordination provided to that process by the planner. This gives policies to diversify production a prime role in the growth process.

One study, by Imbs and Wacziarg (2003), shows that countries that have higher incomes become more diversified in both exports and output, but up to a point in their growth processes, after which concentration begins to rise again. Our interest is the inverse of the relationship explored by

Imbs and Wacziarg: we are interested in whether diversification of output and exports leads to higher growth. This issue is explored empirically by Hesse (2009), who, with the use of panel data and a GMM econometric technology, finds that countries that diversify their exports tend to grow more rapidly than those that do not. Also, with an instrumental variable approach in a cross section for 1980-2003, Agosin (2009) builds an empirical growth model and finds a strong correlation between initial export diversification and subsequent growth. This result is also found by Hausmann and his collaborators (see, for example, Hausmann, Hwang, and Rodrik, 2006; and Hausmann and Klinger, 2006).

II. Recent economic growth success stories

We will develop a highly stylized model in which growth results from additions of new lines of production into an economy that has been producing a single good for export markets. These additions are a stepwise process that depends on the interaction between the supply of public goods and private entrepreneurship to discover new opportunities for introducing goods and technologies that exist elsewhere into the domestic environment. Does the recent record of growth in the world economy support the hypothesis that copying existing technologies outside the boundaries of the national economy has been the major source of growth in poor countries?

Over the past sixty years, this has indeed been the case. Countries such as Korea, Taiwan, Singapore, more recently China, and Chile have followed roughly that path. In Korea and Taiwan, beginning in the 1960s, government incentives and support through the provision of non-tradable services (e.g., education, credit, physical infrastructure) assisted the private sector to move in a stepwise pattern from the production of a few commodities to ever more sophisticated goods (Korea's story is amply documented by Amdsen, 1989, Taiwan's, by Wade, 1990). Copying (legally or illegally) technologies in use abroad was a significant aspect of these experiences, as has been most recently the experience of China since 1979. In the latter case, multinational corporations were invited to set up in Special Economic Zones, thus introducing technologies and knowledge of international markets to the domestic economy, beginning with light manufacturing and now extending to technologically complex products. In Chile, since the 1980s, the assistance of government through incentives to pioneers and the public provision of services for new sectors have been essential in the incorporation of specialized knowledge on how to produce goods in a number of new natural resource sectors that were once new to the domestic economy. The emergence of various industries – such as wood industries, pulp and paper, cultivated salmon, wine, and fruit for export – fit well this description (Agosin, 1999; Meller and Sáez, 1995). To a more limited extent, this was also the case in a number of other Latin American countries (Sabel et al., 2012).

III. The model

The model we develop and simulate in this paper explicitly accounts for the centrality of diversification in economic growth in countries at low levels of initial income.[1] In keeping with the modest capabilities for innovation in most developing countries, we assume that there is no total factor productivity growth and no variable reflecting productivity. Instead, the "growth driver" in the model is the introduction into the economy of production functions from elsewhere. This process has two constraints: (1) the search for information on such production functions is costly for the pioneer and

[1] The expression "low levels of income" includes all countries except those for whom innovation is crucial to their growth prospects.

free for the copycat; and (b) new sectors require "infrastructure", by which we denote a set of non-tradable inputs.[2]

Assume, to start with, an economy producing a single commodity for export ("sugar"), the production of which requires as inputs land and unskilled labor. The output of this sector is entirely exported. For simplicity, we assume that there is no growth in the traditional sector. This economy has "unlimited supplies of unskilled labor" of the Lewis (1954) type, owing to the existence of a large subsistence sector (self-consumption agriculture, informal commerce, or menial personal services). That is, labor can be drawn into non-sugar, emerging modern sectors with no reduction in production in the traditional export sector or in the informal sector. Its opportunity cost is zero.[3]

Growth occurs when new sectors arise. Assume that all production in new sectors requires unskilled and skilled labor, and that all of it is for export.[4] All output is carried out by small firms that produce the same amount, regardless of the sector they are in. The existence of a sector requires a public non-tradable, non-rival, and non-excludable input. The emergence of these new sectors is the result of entrepreneurial activity to explore the possibility of copying technologies extant in other parts of the world but which require adaptation to local settings.

For simplicity, all production is for world markets and all consumption consists of imports. This allows us to ignore domestic demand. The economy's aggregate consumption is limited by its production (all exported). While the terms of trade will normally be an important determinant of aggregate demand, here we also assume, again for simplicity, that the terms of trade are exogenous (fixed, in relation to the model itself). This allows us to concentrate on the conditions required for diversification of the production side of the economy.

We also assume that the government is in fiscal balance and that its expenditures consist only of subsidizing information gathering and erecting new infrastructure. Infrastructure serves a variety of different sectors, and all the sectors using a particular infrastructure can be thought of as a "family" of sectors. There are j different infrastructure projects, each of which supports i sectors, where both j and i are large numbers.

The production side of the economy thus comprises two parts: the traditional sector (whose production function uses land (T) and unskilled labor (L) as inputs, and a series of modern sectors (with production functions G), which may or may not exist, depending on entrepreneurial activity and on the availability of requisite infrastructure. A_{ij} is a binary variable where unity represents the existence of a sector belonging to the family of sectors using infrastructure B_j, also a binary variable equal to one when the infrastructure is built (zero otherwise). The inputs of all of these sectors are unskilled labor (L) and

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[2] A preliminary sketch of this model can be found in Agosin (2009).

[3] The Lewis model has been extremely influential in the thinking of development economists. It is not without logical flaws (Gollin, 2013). Perhaps the main one is that, even if the wage is set at the average product of labor in traditional agriculture, removing workers from it would nevertheless impact total output, since there is less labor to produce the same level of output, and the average product of labor (and hence wages) would have to rise and not remain constant at its "subsistence" level.

[4] The export assumption allows us to ignore domestic demand, which we will assume is satisfied entirely by imports. The difference between this model and those centered on pecuniary external economies of the Rosenstein-Rodan (1943) type (for a formalization of these ideas, see also Murphy, Schleifer, and Vishny, 1989) lies in the fact that here we are dealing with a small open economy in which domestic demand plays no role in its general equilibrium.

skilled labor (H), which we assume arises as unskilled labor receives on-the-job training. Prices in the modern sector (p_{ij}) are expressed in terms of the price for the traditional commodity. For simplicity, we assume that training is generic enough that the worker can take it with her if and when she migrates to another sector. Since both traditional and modern sectors sell into the world market, we assume additionally that our country is a price taker, which allows us to ignore relative prices.

$$(1) \quad Y = F(T, L) + \sum_{i,j} [p_{ij} G_{ij}(L_{ij}, H_{ij})] A_{ij} B_j$$

$$A_{ij}, B_j = 0,1$$
$$i = 1, \dots, n; j = 1, \dots, m$$

The supply of skilled labor is assumed to grow at a rate of μ, and the initial level of skilled-labor supply is designated as H_o.[5] The demand, on the othe hand, will depend on the emergence of modern sectors. If the demand is higher than the supply, the price for skilled labor (s) will rise; the opposite happens if supply exceeds demand.

$$(2) \quad H_t = (1 + \mu) H_{t-1}, \quad H_0 = \bar{H}$$

$$(3) \quad H^D = J\left[\left(\sum\nolimits_{i,j \neq 0} G_{i,j}\right), s\right], \quad \frac{\partial H}{\partial G} > 0, \ \frac{\partial H}{\partial s} < 0$$

Finally, we close the macroeconomic aspects of the model with the condition of public budget balance (i.e., the public sector neither lends nor borrows). Tax rates on profits in the traditional sector (τ_T), on pioneering firms and on copycat firms (τ_p and τ_c) in the modern sector are formally allowed to be different. In all simulations, we set $\tau_T = 0.50$. We consider that the only expenditures of the government are (a) providing subsidies to investments in information (C, assumed to be equal for all sectors) by pioneering firms in modern sectors and (b) those involved in setting up new infrastructure (where $\dot{B}$ represents the number of new projects per period and λ is the cost of each project, assumed to be equal for each project). Formally:

$$(4) \quad \lambda \dot{B} + \delta\left(\sum\nolimits_{ij \neq 0} C_{ij}\right) = \tau_T * \pi_T + \tau_p * \sum\nolimits_{i,j \neq 0} \pi_{ij}^p + \tau_c * \sum\nolimits_{i,j \neq 0} \pi_{ij}^c$$

where δ is the rate of subsidy on C. In other words, we are going to give the planner three choices with regard to subsidizing information investment: not subsidizing them at all (δ=0) or setting the subsidy rate 50 percent (δ=0.5) or 100 percent (δ=1).

Before moving on to specifying the microeconomic aspects of the model, it is worthwhile noting that all of the elements needed for self-discovery are already in place. Undiscovered sectors don't enter into the production function. The addition of a sector will depend on entrepreneurial investment in information (the C's) and on the existence of a complimentary public, non-tradable input (the B's). Tax revenues come from profits from production in the traditional sector and in the modern

[5] There must be a small amount of skilled labor in the economy to begin with, since otherwise there would be no growth in the supply of skilled labor.

sectors. In the latter, in order to fix profit tax rates, the planner can distinguish between those who make investments in information (pioneers) and those who take advantage of such investments made by others (copycats). Subsidies to information investment compete for resources with the costs of creating new infrastructure projects $(\lambda\dot{B})$.

We now add the microeconomics. Think of production and the realization of profits as a two-period process. In the first period, the pioneer makes an investment in information, which takes the form of seeking out the coefficients of production functions *G*. In the second period, production takes place only if it turns out to be profitable (i.e., if profits exceed production costs and the net present value of information investment).

Input-output coefficients are constant. Producers in new sectors maximize profits subject to the constraint that they must be at least equal to the net present value of their investment costs (equation (5)). After a good has been "discovered", the information is available to anyone. Copycats are free to enter, on condition that revenues exceed production costs (equation (6)). For copycats, the conditions for initiating production are less stringent than for pioneers, since the former don't invest in information gathering. Therefore, the copycat has two advantages: she saves on information costs, and she has no uncertainty as to whether the production technology is profitable. If the information obtained by the pioneer in unprofitable, neither the pioneer nor the copycat will invest; if the costly information obtained by the pioneer is profitable, the copycat will also invest, without having made any information investment. Ignoring sector and sector-family subscripts:

$$(5)\ (1-\tau_p)E(\pi) \geq C(1+r) \qquad \text{profitability condition for the pioneer}$$

$$(6)\ (1-\tau_c)\pi \geq 0 \qquad \text{profitability condition for the copycat}$$

where *r* is opportunity cost of capital and *C* is the investment cost in information.

Substituting the expected value of profits for the pioneer and the profits for the copycat, we obtain:

$$(5a)\ \ (1-\tau_p)\big(p-\overline{w}E(l)-sE(h)\big)G \geq C(1+r)$$

$$(6a)\ (1-\tau_c)(p-\overline{w}l-sh)G \geq 0$$

where *w* = unskilled wage (assumed constant), *s* = skilled wage, *l* = coefficient of unskilled labor per unit of output, and *h* = coefficient of skilled labor per unit of output. *E(l)*, *E(h)* refer to the ex-ante expectation of the pioneer.

Discovering the set of feasible input-output coefficients that is profitable can be done by setting the inequality of (5a) to equality. It can be seen that this set is equal to the area under the triangle in the space of feasible *l, s* in Figure 1:

$$(7)\ l = -\frac{s}{\overline{w}} * h + C'/\overline{w}$$

where $C' = \left[p - \frac{C(1+r)}{G(1-\tau_p)}\right]$

Equation (7) describes a straight line with $-s/\bar{w}$ as its slope and intercepts $C'/\bar{w}$ and C'/s in the vertical and horizontal axes, respectively. Thus the area bounded by the axes and the hypotenuse of the triangle represent all the combinations of input coefficients that are profitable. All the combinations that lie on the straight line yield sufficient gross income to pay factors of production and to recover investment costs (i.e., they have zero rents).

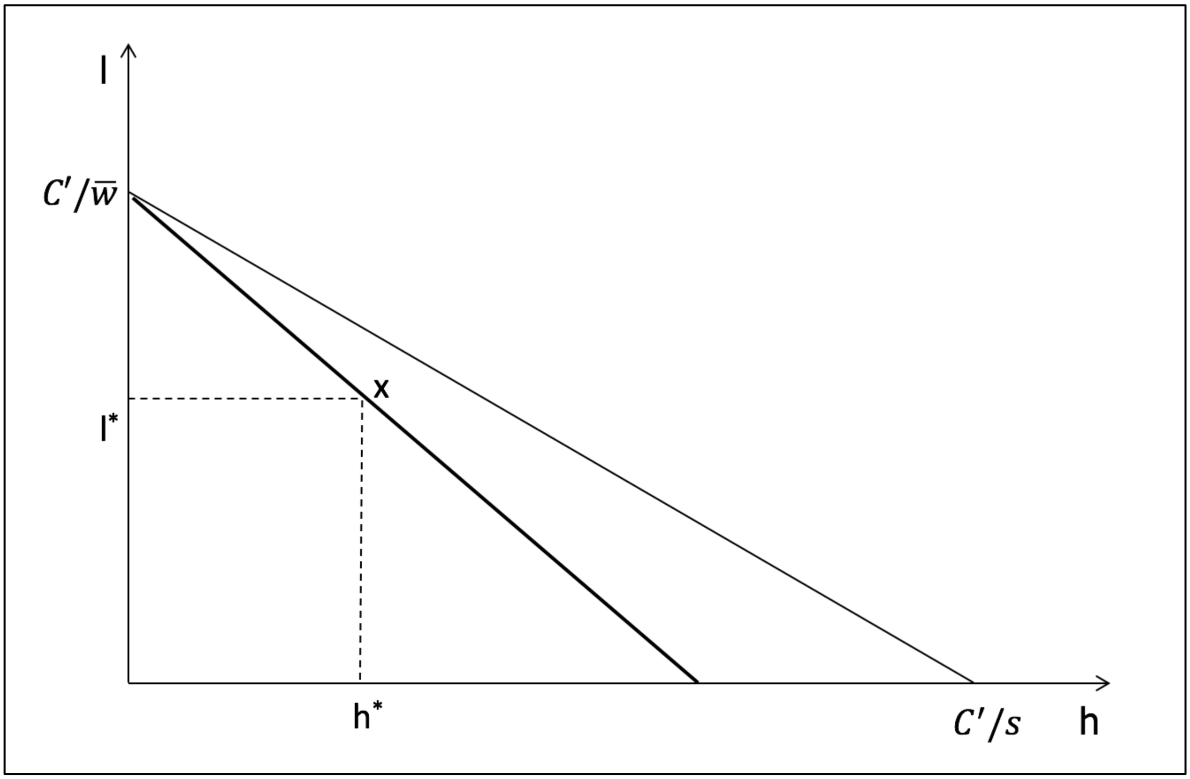


Figure 1: Feasible combinations of *l,h* that yield positive profits for the pioneer

In this model, if the pioneer discovers an *l,h* combination that falls inside the triangle, she will initiate production. However, she will be emulated by copycats that will jump in until all super normal profits are competed away. This will happen when the entry of copycats causes the price of skilled labor (*s*) to rise and the combination of l^*, h^* discovered by the pioneer to lie on the bold line, at which point all quasi rents disappear (as in point x on figure 1). The model thus reproduces one of the distinguishing traits of self-discovery: While the costs of self-discovery are born by pioneers, its private and social benefits tend to be captured by copycats. Any entrepreneur, unless she had a high risk preference, would decide to wait for others to jump into the fray first.

In another version of this model, the unknown factor is not the technology but the price the product can fetch in international market. Say, if the good in question were wine, the production technology might be known, but producers may have to discover the shape of the demand curve in foreign markets (wine being a good subject to monopolistic competition).[6]This case is formally identical

[6] For a study of the Chilean wine industry, see Agosin and Bravo-Ortega, 2012.d

to the one developed above, except that the unknown here is the size of the triangle. Its slope, as before, is the relative price of skilled labor. Once the product price is discovered, and if it is profitable, competition from copycats will cause the price of the good to all and, in figure 1, the hypotenuse of the triangle to shift inward in a parallel fashion.[7] This process will end when and the optimal input coefficients are again on the straight line.

This model, open-ended by design, doesn't have an analytical solution, but it can be simulated giving the parameters some values and running it forward for a large number of periods. Assume the planner's objective function is to maximize growth through the introduction of modern sectors into the economy. The planner has a lower rate of time preference than the private entrepreneurs and is thus willing to subsidize, fully or in part, the investment in information gathering. The planner will also have to decide which infrastructure projects she will invest in. Finally, she can set tax rates on profits. Tax rates can be the same for the modern and traditional sectors, or they can be differentiated. In addition, in the modern sector the tax rate on pioneers can be different from the one that applies to copycats.

As noted above, we assume that the government has no borrowing ability and that the public budget must balance. This setup makes for several interesting possibilities. In the first place, if taxes in the modern sector are set too high, it may not be profitable for pioneers to engage in search activities. Second, if the planner subsidizes search costs, she may not have sufficient resources left to build infrastructure. Third, low taxes on pioneers may encourage search but they may not generate sufficient tax revenue to build new infrastructure projects. Finally, new skill-intensive production may put upward pressure on the skilled-labor wage, but only the emergence of skill-intensive output ensures the future growth in the availability of skilled labor.

IV. The choices facing the planner

The planner has three policy levers. One is to choose the family of sectors for which she will provide infrastructure. Second, she can choose to subsidize part or all of search costs (in the model, C). Third, she can set the level and agents to which profit taxes will apply. The latter can be uniform for all sectors and types of agents. Alternatively, tax rates can be differentiated between pioneers and copycats within each sector, or between the traditional and the modern sector. To simplify, we will vary tax rates between pioneers and copycats and assume a fixed tax rate on the traditional sector (equal to 50 per cent of profits, which are fixed because neither the price nor quantity of the commodity, nor of its factor inputs, vary).

As regards the choice of infrastructure projects, we can distinguish two broad set of possibilities. In the first one, the infrastructure projects are chosen at random. Alternatively, the planner can guess pretty accurately the expected mean level of the coefficients of each family of sectors, but does not know their distribution by specific sector around that mean. In this case, she can use several rules of thumb:

[7] There have been cases in which the entry of a single country's producers into the world market have caused the international price to drop sharply. An example is provided by the Chilean experience with kiwis in the 1980s. An unknown product in Chile until then, the massive planting of kiwis led to a collapse in its international price.

1. Choose projects that serve families of sectors with the highest expected value of the labor coefficient (highest E(l)). This would correspond to a choice based on comparative advantage.
2. Choose projects serving families of sectors with the highest E(h) and lowest E(l). Although somewhat counterintuitive, this choice would give pride of place to sectors with externalities in human capital formation.
3. Choose projects serving potential sectors with the lowest E(h), again on the basis of comparative advantage and for the sake of saving on the scarce factor.

As already noted, the planner must then decide to subsidize search costs (C) and what proportion of such costs, the values of the profit tax rates, and whether she will differentiate as between the traditional sector and pioneers and copycats in the modern sectors. We will simulate the model for three subsidy rates: 0, 50 percent or 100 percent ($\delta = 0, 0.5$, or 1). The model is run for each of these rates. For each subsidy rate, the following sequence is followed:

1. Start with initial values of tax rates, traditional sector output, and the values of the search investment (C);
2. The government then collects tax revenues and builds infrastructure;
3. Determine the sectors that emerge during the next period;
4. This generates supply and demand for skilled labor (*H*) in the next period, and determines the wage for skilled labor (s);
5. The model is run for 50 periods ahead and one obtains a final output level and a final accumulation of skilled labor;
6. The simulations are repeated for all possible choices of tax rates.

As can be seen in table 1, subsidizing search costs is a dominant strategy: no matter what the combination of tax rates used, the strategy with subsidy yields a larger final output and higher final skilled labor. Either a subsidy of 50 percent of search costs or of a subsidy of 100 percent of costs yields the same results. The intuition is that, if the subsidy is kept to 50%, the planner has resources left over to finance additional infrastructure investments. Both are superior to a zero subsidy.

Table 1: Benchmark results of running the model for 50 periods
(growth rates per annum in percentage)

C subsidy	Strategy	Growth rate of output	Growth rate of skilled labor	Tax on pioneers (%)	Tax on copycats (%)
0%	Random	1.5	1.6	0	50
	Highest E(l)	1.0	1.4	0	25
	Highest E(h), lowest E(l)	1.6	1.6	0	50
	Lowest E(l)	1.7	2.7	0	50
50%	Random	2.2	2.6	0	50
	Highest E(l)	1.9	1.9	0	25
	Highest E(h), lowest E(l)	2.5	3.0	5	50
	Lowest E(l)	2.3	2.6	0	50
100%	Random	2.1	2.6	0	50
	Highest E(l)	2.1	2.2	0	40
	Highest E(h), lowest E(l)	2.5	3.0	0	50
	Lowest E(l)	2.3	1.2	0	50

While the choice of subsidizing search costs has an visible impact on output at the end of the simulation period, the choice of infrastructure projects is much less of a determinant in final results. The rates of growth of output fluctuate about half of a percentage point depending on the choice of sector families made. In the absence of information with regard to the expected values of the input-output coefficients, the best choice for infrastructure would be a random one. Taxes don't seem to deter copycats. The optimal tax rate on copycats (that is, the one that maximizes growth) is 50 per cent of profits (which turns out to be equal to the rate assumed on traditional sector profits). On the other hand, the tax on pioneers should be kept low (0-5 per cent). The intuition is that, given the information externalities involved, the planner ought to subsidize the investment in information (either half or the whole investment) and, in addition, tax pioneers lightly, while recouping its investments on information and subsidies with high taxes on the traditional sector and on copycats.

In the following figures, I show some of the simulations that are behind the summary table 1. In all cases, subsidizing information costs leads to higher final output, so that I show only the graphs obtained under that assumption. The three-dimensional graphs show total output in the vertical axis and the tax rates on pioneers and copycats, respectively, on the horizontal axes.

Figure 2
Final output after 50 periods, with government subsidizing 100% of information investment and choosing infrastructure projects with the highest E(h)/lowest E(l)

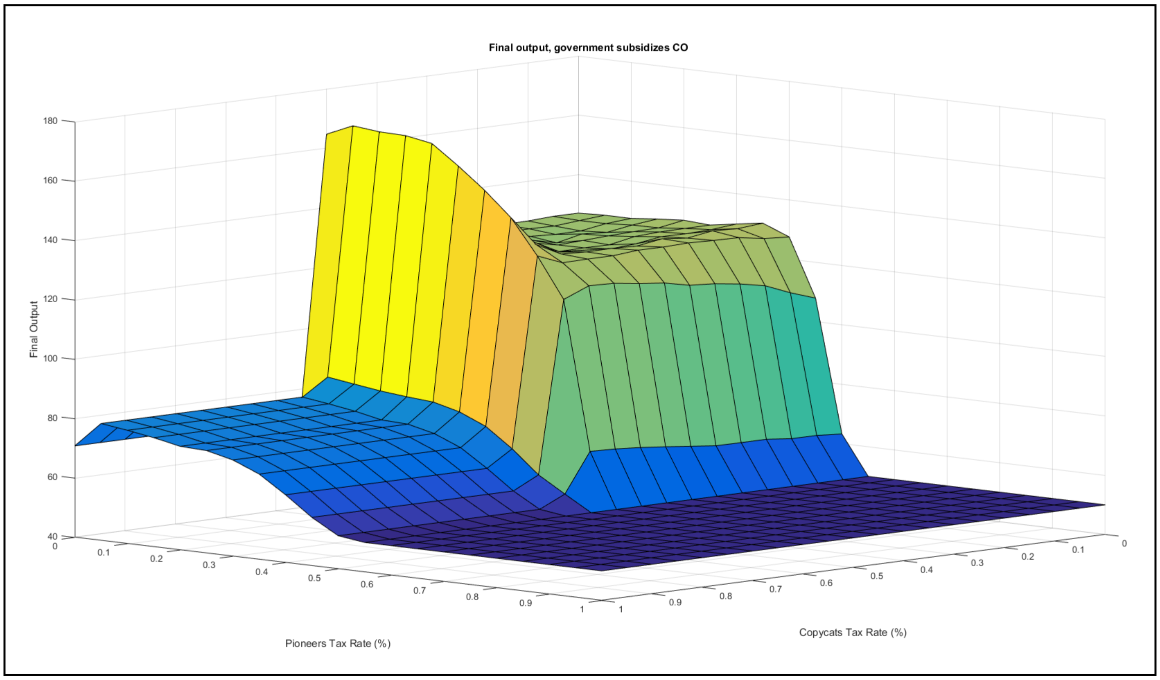


Figure 2 is built on the assumptions that the planner fully subsidizes information investment and chooses infrastructure projects that meet the joint condition of having the highest expected value of the skilled-labor input coefficient and the lowest expected value of the unskilled labor coefficient. In this case, as the profit tax on pioneers rises above 5 percent, final output monotonically decreases and, at tax rates above 40 percent, it goes to zero, regardless of the profit tax on copycats. The latter, which is an important source of revenue to the government, shows interesting properties. As the tax on pioneers falls, the economy's total output increases together with the tax rate on copycats. The combination of tax rates that maximizes output is 5 percent for pioneers and 50 percent for copycats.

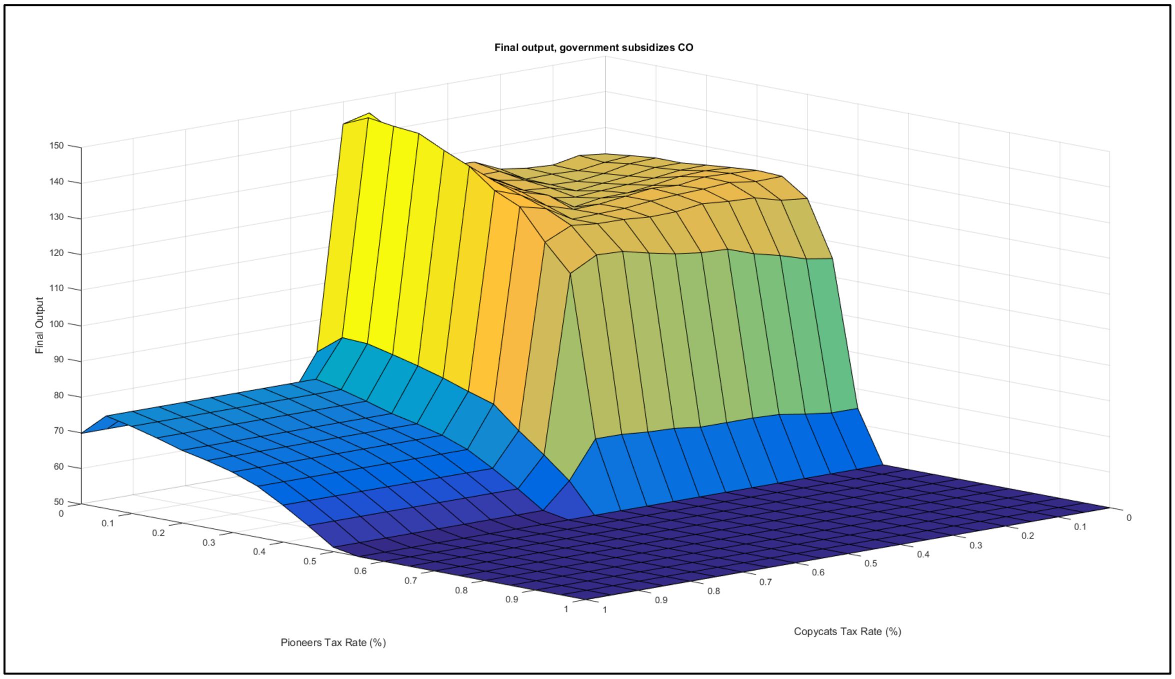
The three-dimensional figure drawn on the assumption of a 50 percent subsidy on information investment is almost identical, except for the fact that final output and human capital stocks are maximized at tax rates of 5 and 50 percent for pioneers and copycats, respectively.

Figure 3 is also very similar, except that the selection of infrastructure projects is random. If one assumes, perhaps more realistically, that governments don't know the input-output coefficients of different families of sectors – and not even their expected value – the strategy of randomly selecting infrastructure projects makes more sense.[8] In fact, the loss in output from this strategy relative to the "best" strategy (in Figure 2) is rather minor. While output peaks in the first case examined at an output

[8] Of course, one has to assume that the planner won't choose projects where the country can't hope to develop comparative advantage. For example, the planner is smart enough not to launch a policy such as Brazil's information technology program in the 1980s, which had absolutely no positive results for the economy. See Crespi, Fernández-Arias, and Stein, 2014, pp. 16-18.

level of 165 (compared to a base level of 50, the output of the traditional sector), adopting a random infrastructure strategy would lead to a maximum output level of 145.

Figure 3
Final output after 50 periods, with government subsidizes information and chooses infrastructure projects randomly



Let us now see what happens with human capital accumulation (the initial level of skilled labor, H_0, having been set arbitrarily at 45) with the two strategies outlined above. If planners, after having subsidized information investment, choose infrastructure projects that maximize E(h) while minimizing E(l), the resulting levels of skilled labor formation will be as shown in Figure 4. On the other hand, the final levels of skilled labor are shown in Figure 5, on the assumption that the choice of infrastructure projects is random.

Figure 4
Final levels of skilled labor when planners subsidize information investment and choose infrastructure projects that maximize E(s) while minimizing E(l)

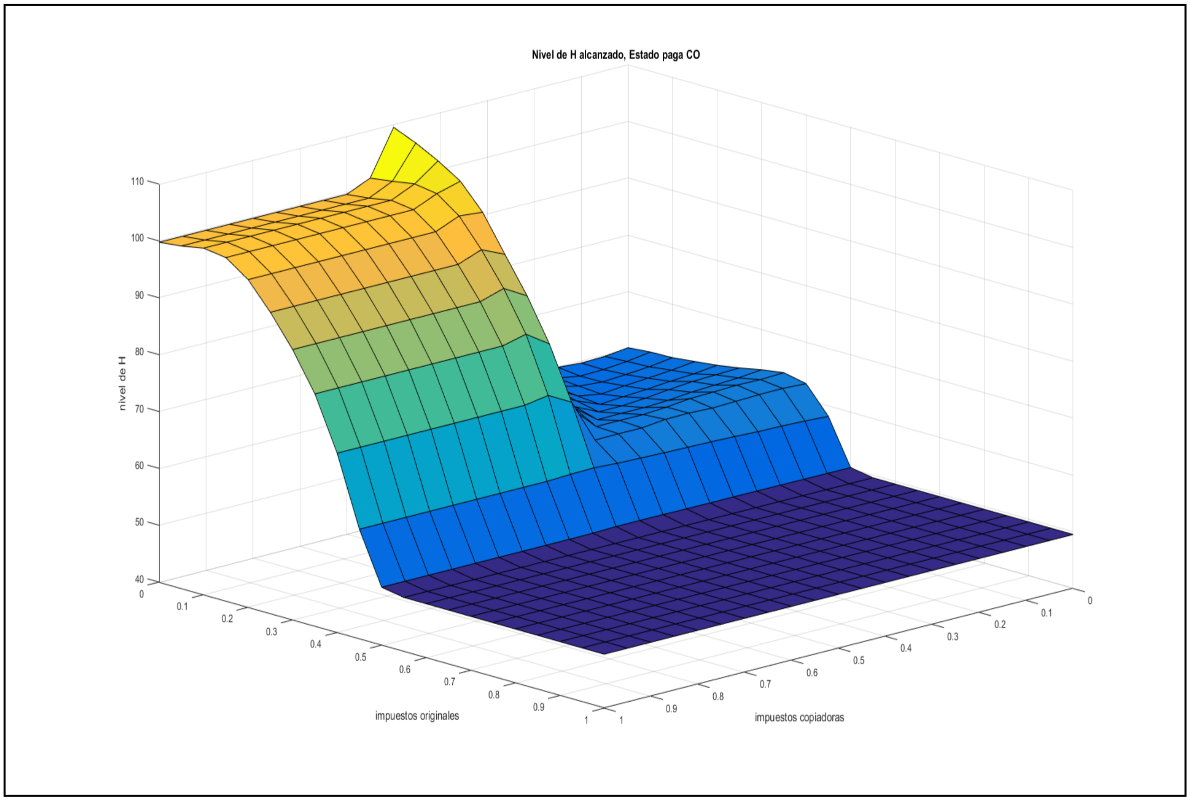
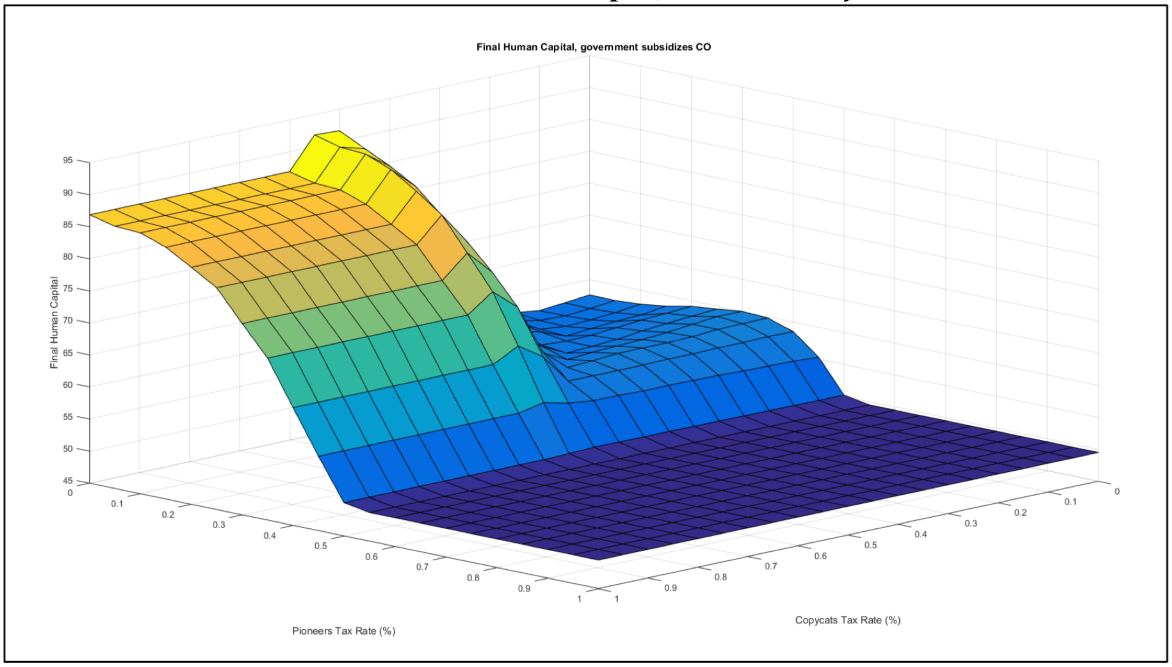


Figure 5
Final levels of skilled labor when planners subsidize information investment and choose infrastructure projects randomly



The results are quite similar to those for output. Human capital formation is maximized when taxes on pioneers are close to zero and taxes on copycats are in the 40-50 percent range.

V. Robustness

We tried a large number of different assumptions on the level of information costs, subsidies on the hiring of skilled labor, and others. Here I report only the results with a level of information cost investment that is 50 percent higher than the one assumed in the first set of exercises. Again, I estimate final outputs and human capital for three situations: zero subsidy of information cost investment, 50 percent subsidy, and 100 percent subsidy. The results are shown in table 2 for two choices of infrastructure investment: a random choice and a choice that maximizes the expected value of the human capital coefficient while minimizing the expected value of the labor coefficient.

In this case, again the two scenarios with 50 percent and 100 percent subsidy on information costs are pretty much of a toss-up. The higher are information costs, the better seems to be the scenario of partial rather than full subsidy. Why should this be the case? In the first place, as information costs rise, so does the commitment of resources by the planner in cases where the subsidy is 100 percent. This clearly competes with the objective of infrastructure investment. Second (and not considered formally in the model), the planner may wish pioneers to have some "skin in the game", for moral hazard reasons.

Table 2: Results, assuming that information costs are 50% higher than those assumed in the first set of runs, and that the planner considers the option of subsidizing 0, 50, and 100% of information investments

C subsidy	Strategy	Growth rate of output	Growth rate of skilled labor	Tax on pioneers (%)	Tax on copycats (%)
0%	Random	1.5	0.4	0	50
	Highest E(h), lowest E(l)	1.6	0.4	0	50
50%	Random	2.2	1.5	0	50
	Highest E(h), lowest E(l)	2.5	1.8	0	50
100%	Random	2.1	1.4	0	50
	Highest E(h), lowest E(l)	2.4	1.8	0	50

The results are quite similar for a random selection of infrastructure projects, except that the final levels of output and human capital are somewhat lower. Tax rates that maximize output are still zero for pioneers and 50 percent for copycats.

We also simulated outcomes considering a subsidy of 50 percent of the wages of skilled labor. The resulting tax rates on profits of pioneers and copycats are still zero and 50%, respectively, but the levels of final output and final human capital are considerably lower.

One question that may arise in the minds of some readers is why the pioneer fails to expand so as to internalize the entire information externality. This may be all the more likely since in the model there are no diminishing factor returns and constant economies of scale. While theoretically possible, in practice this outcome is highly unlikely in a developing country setting characterized by the existence of many small producers. One rationale might be the existence of liquidity constraints that keep firms small. It is duly noted that the model has no capital input, and liquidity considerations are therefore left out. Nonetheless, we leave this explanation as a plausible one for those who might feel inclined to raise what is a valid theoretical point but one that is unlikely to arise in the setting we are considering.

VI. Conclusions

This simple growth model of a small, technologically backward economy, has emphasized the notion that growth in such an economy does not occur from technological change of the conventional type but from copying and adapting to the local environment technologies available in the world economy. We have stressed the interconnections of two key growth constraints: (1) the informational externalities of finding production knowledge that is available in the world economy but not in use in the domestic economy; and (2) the coordination problem that arises in any effort to encourage diversification into new sectors of a typically specialized economy with a scarcity of skilled human resources.

The key constraint on planners is the fiscal budget. If taxes on new sectors, particularly pioneers, are set too high, investment will not be forthcoming, the economy will not diversify, and growth will not take place. On the other hand, the lower the tax rates the greater the difficulty of planners in investing in infrastructure in subsequent periods. Such infrastructure is key to the emergence of new sectors and continued diversification.

We have seen that the dominant strategy is to subsidize investment in information leading to the establishment of new sectors. There is no policy option without the subsidy that is better than any option with the subsidy. This is to be expected from the structure of the model, which emphasizes the incorporation into the economy of hitherto absent (and presumably higher-productivity) lines of production. The difference in growth rates of subsidizing the full costs of obtaining information and only 50 percent of such costs are more or less of the same order of magnitude. However, the higher are information costs the more onerous becomes the subsidy in terms of foregone infrastructure projects. Thus, there is an inverse relationship between the cost of information, on the one hand, and growth and the optimal information subsidy, on the other. Moreover, given the moral hazard involved in full subsidization, it is probably wiser to opt for a partial subsidy regardless of the cost of information.

There is another externality that is worth mentioning. Since the model assumes that skilled labor is of the on-the-job-training type, demand from sectors that are skilled-labor-intensive has a positive spin-off on the economy. By construction, only new sectors demand skilled labor. Once labor is skilled, it is able to skill others. That is the reason that the best strategy for infrastructure selection involves choosing projects that serve skill-intensive families of sectors.

Clearly, this type of model is highly unrealistic. But so are one-sector models, which obscure just as much as they illuminate. I hope that it will encourage others to build models that reflect the basic stylized facts of economic growth in a poor economy: the importance of copying existing technologies and the constraints that process faces.

Appendix: Initial values of the main variables, coefficients, and simulation procedure

Initial values and coefficients

C = 1 and 1.5; the values of search costs are equal for all sectors
λ = 75, equal for all projects
p_{ij} = 1.4 times the price of the good in the traditional sector; equal for all new sectors
Y_T = 50 (units of output, and value, of the traditional sector output, held constant)
τ_T = 0.50 (for all runs of the model)
H_0 = 25 (initial levels of human capital)
μ = 0.25 (increase in human capital per period)
r = 0.10 (discount rate)
$\beta = \frac{1}{1+r}$ (impatience factor of pioneers)
= 1/1.10 = 0.90, when the planner subsidizes partly or wholly information investment, and
= 1/1.17 = 0.85, when there are no subsidies on information investment

The model was programmed in Matlab following a certain sequence:

During the first stage the aggregate output of the economy is calculated, and the skilled-labor wage is determined endogenously. Remember that in the first period only the traditional sector exists. Demand for unskilled and skilled labor in the modern sector is determined with a random uniform function. The supply of skilled labor in period one is determined by equation $H_1 = (1+\mu)H_0$.

In the second stage, the planner collects tax revenues from the traditional sector (and in later periods, from those modern sectors that arise). The calculations also allow for transferring to the period t+1 whatever tax revenue is left over from period t.

In the third stage, the planner determines the infrastructure projects to be built. This is essential to the workings of the dynamic model, because subsectors can arise only if they belong to the family of sectors for which the infrastructure is built. These two latter stages determine the variables in the following period.

The full model is run for 50 periods (each one of which is repeated 50 times). Growth rates are estimated for Y and H in the tables of results. The surfaces shown in figures 2 through 7 are expressed in final outputs and human capital relative to their initial values.

In greater detail, the code is built with the following logic:

- We first define a random function using a "twister", which we use every time we create a normalized variable such as the levels of h and l for each sector. These take values in the continuum of zero to unity.
- We also fix the number of repetitions of the model at 50 and take averages of the values of each variable.
- We create the matrices that store the levels of aggregate output Y, H, the number of firms, the salary of skilled labor s, and the quantity of infrastructure projects built per period, for each of the

50 repetitions, for each possible combination of tax rates for pioneers and copycats. These are stored in 21x21 matrices. Each coordinate of the matrix is a pair of pioneer and copycat profit tax rates and rates and its level of output: 441 cells.

- We assume that there are 10 families of sectors and 10 sectors in each family; the parameters *h* and *l* are created as normalized variables derived from the random uniform functions.
- Since we need to obtain the outputs of interest for each combination of tax rates that can be applied to pioneers and copycats, two rounds of iterations are nested, with the objective of filling in each ordered pair of the result matrices (containing Y, H, s, and l). This network of iterations contains 21 potential tax rates for pioneers and copycats per round, which is equivalent to testing the results of applying tax rate combinations by increasing them by 5 percentage points at a time.
- Then we estimate the vectors indicating the coefficients *h,l* per unit of output required by each sector (and each family of sectors) in each repetition.
- In the following step, we build the equations by which the planner orders families of sectors according to her infrastructure strategy. The planner has an idea of the expected values of the input coefficients of families of sectors, but she does not have the full information of those values for each sector within each family. She ranks the sectors according to the size of the *h* and *l* coefficients. In most cases, the optimal result is obtained when the planner maximizes the expected value of *h* (the skilled-labor coefficient per unit of output) while at the same time minimizing the expected value of *l* (the unskilled-labor coefficient per unit of output).
- Vectors are created for each combination of tax rates that store the aggregate value of output and outputs of each sector and family of sectors. Other vectors that are created for each tax rate combinations are: (1) the government budget for infrastructure and subsidies to information investment; (2) firm profits; (3) the values of *s* that firms are willing to pay.
- The quantity demanded of *H* and the skilled-wage salary (*s*) are jointly determined by ordering firms according to their willingness to pay, until all available supply of *H* is exhausted (market clearing assumption). Willingness to pay is determined by the following equation: $s_{ij} = \frac{(p_{ij} - \bar{w} l_{ij})}{h_{ij}}$ (remembering that all *Gi,j* are set equal to 1). The supply of H is distributed to the firms that make the cut and the model determines the family of sectors and, within them, the sectors that are active.
- Each pioneer produces one unit of output. For every pioneer there are 10 copycats, also producing one unit each. The output of pioneers is added to that of copycats, and to this the output of the traditional sector (50) is added to obtain aggregate output.
- The planner collects taxes on the basis of profits made by the three types of producers.
- After deciding whether she will subsidize part or all of the costs of information investments, the planner allocates her remaining budget to infrastructure projects, ranked according to various sets of criteria (see text).
- In the next round, the available *H* is brought up to date by adding up the *H* created in each sector.
- The planner needs to know whether the firms will be profitable during the next period. This will depend on whether she has been willing to subsidize (fully or partially) the cost of information investment.
- The matrices mentioned above are filled and the planner determines which combination of tax rates on pioneers and copycats result in the largest output after 50 periods.

References

Agosin, M. R. (1999), "Trade and Growth in Chile", *CEPAL Review* 68: 79-100.

Agosin, M. R. (2009), "Export Diversification and Growth in Emerging Economies", *CEPAL Review* 97: 115-131.

Agosin, M. R., and C. Bravo-Ortega (2012), "The Emergence and Consolidation of the Chilean Wine Industry", in Sabel et al (editors), *Export Pioneers in Latin America*, Harvard University and Inter-American Development Bank, Cambridge, MA.

Amsden, A. (1989), *Asia's Next Giant – South Korea and Late Industrialization*, Oxford University Press, Oxford.

Crespi, G., E. Fernández-Arias, and E. Stein, editors (2014), *Rethinking Productive Development: Sound Policies and Institutions for Economic Transformation*, Inter-American Development Bank, Washington, D.C.

Gerschenkron, A (1962), *Economic Backwardness in Historical Perspective*, Harvard University Press, Cambridge, MA.

Gollin, D. (2014), "The Lewis Model: A 60-Year Retrospective", *Journal of Economic Perspectives* 28: 71-88.

Hausmann, R. and D. Rodrik (2003), "Economic Development as Self-Discovery", *Journal of Development Economics* 72: 603-633.

Hausmann, R., J. Hwang, and D. Rodrik (2006), "What You Export Matters," Working Paper, Center for International Development, Harvard University.

Hausmann, R., and B. Klinger (2006), "Structural Transformation and Patterns of Comparative Advantage in the Product Space," Working Paper No. 128, Center for International Development, Harvard University.

Hesse, E. "Export Diversification and Economic Growth", Commission on Growth and Development Working Paper No.21, World Bank, Washington, D.C., 2009.

Imbs, J. and R. Wacziarg (2003), "Stages of Diversification", American Economic Review 93: 63-86.

Lewis, W. A. (1954), "Economic Development with Unlimited Supplies of Labour", *Manchester School*, May: 400-449.

Lucas Jr., R. E. (1988), "On the Mechanics of Economic Development, *Journal of Monetary Economics* 22 (1): 3-42.

Lucas Jr., R. E. (1993), "Making a Miracle", *Econometrica* Vol. 61: 251-72.

Meller, P., and R. E. Sáez, editors (1995), *Auge Exportador Chileno – Lecciones y Desafíos Futuros*, Dolmen, Santiago.

Murphy, K., A. Schleifer, and R. Vishny (1989), "Industrialization and the Big Push", *Journal of Political Economy* 97: 1003-1026.

Rosenstein-Rodan, P. N. (1943), "Problems of Industrialization of Eastern and South-Eastern Europe", *The Economic Journal* 53: 202-211.

Sabel, C., E. Fernández-Arias, R. Hausmann, A. Rodríguez-Clare, and E. Stein, editors (2012), *Export Pioneers in Latin America,* Harvard University and Inter-American Development Bank, Cambridge, MA.

Temple, J. (2005), "Dual Economy Models: A Primer for Growth Economists", *The Manchester School*, 73 (4): 435-478.

Wade, R., (1990), *Governing the Market – Economic Theory and the Role of Government in East Asian Industrialization*, Princeton University Press, Princeton, NJ.

Young, A. (1993), "Lessons from the East Asian NICs: A Contrarian View", NBER Working Papers No. 4482, Cambridge, MA.