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Technology adoption, innovation policy and catching-up.

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Abstract

A model is proposed where economic growth is driven by innovation along the diffusion and adoption of technology from the frontier. Business innovation investments are related to households savings, which generates equilibria with low levels of, and equilibria with high levels of, innovation. Low-level equilibria are unstable. Starting from a position with low levels of investment and innovation, increasing investments are associated with high but decreasing dependence on international technology diffusion. A major objective of policy-making is to increase investment sufficiently in the lower end to reach the high level steady state. An economic rationale is provided for the existence of productivity improving equilibria, where distance to frontier countries is reduced owing to a tax and subsidy mechanism designed to boost innovation.

Keywords— Dynamic Optimization, Equilibrium Analysis, Technology Diffusion, Innovation Policy, Economic Growth.

JEL— C62, O33, O38, O40

1 Introduction

The recent literature on innovation has reignited the debate about the relationship between technology progress and economic growth over the long run. In particular, it has spurred controversy about: (a) the relative importance of technology diffusion from abroad over (local) innovation in explaining convergence

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across countries (Romer 1993; Keller 2004); and (b) the merits of fiscal policy mechanisms designed to boost business innovation (OECD 2007; Hall & Lerner 2010; Kerr & Nanda 2015; Nanda, Younge & Fleming 2015; Mazzucato & Penna 2015). However, in spite of being a frequent topic of empirical research, little to no attention has been given in this literature to study the theoretical basis to justify the use of fiscal instruments in order to boost innovation and long run economic growth.

The need for such a theoretical model seems evident. The large tradition of research in the empirical front (Reppy 1977; Lichtenberg 1988; Lerner 1999; Pagés 2010, Nanda, Younge & Fleming 2015; Kerr & Nanda 2015, Howell 2017; Denes et al., 2020; Hu 2020) has led to strong justification for the use of fiscal mechanisms to boost business innovation. But, to the best of our knowledge, less has been advanced about the economic reasoning and theoretical logic giving support to this argument. In this paper we are set to fill the gap. We endeavor to construct a model where growth hinges on local business innovation taking place along the diffusion of foreign technology. Innovation is boosted by a fiscal strategy that we refer hereafter as a *"tax and subsidy mechanism"* designed to ensure a high level of diffusion and innovation.

In our formal approach, the government sets a *consumption-tax* on households and uses the revenue to grant an *innovation-subsidy* that enlarge business investments in this activity. It is assumed, for simplicity, that households and business are separated entities, and tax revenues equal the subsidy funds so that the public budget is permanently in balance. The production function that relates output per-capita to the stock of innovation exhibits decreasing returns to scale. Different from most models of its kind, foreign technology influences the production of final output only indirectly through its relationship with the dynamics of innovation.

We recognize that innovation and diffusion are closely intertwined and also that succeeding innovation is greatly enhanced by technology diffusion. Tracking patterns of international technology diffusion and distinguishing them from local innovation has proved to be a difficult task on both theoretical and empirical grounds (Nelson 1993, OECD 2005, 2007, Nelson, Earle, Howard-Grenville, Haack & Young 2014). Therefore, we use a broad definition of innovation as has become customary in the literature on this subject (OECD 2005, 2007).

While we do not claim a clear-cut distinction between them, we assume a framework where the economy engages in two different—not mutually exclusive—growth strategies: the *"diffusion / adoption"* strategy, which is part of the standard *know–how* on methods, techniques of production and technology developments that improve productive efficiency, hence, the ability to produce more, faster and cheaper; and the *"innovation"* strategy, which refers to the distinct production and commercial applications of technology, hence, the ability to improve the production process and/or to produce novel products to lure consumers (OECD 2005, Jorgenson 2009).

Although they are related, in our model we do not explicitly deal with capital market imperfections that have been discussed in the literature to constraint innovation and growth (Bernanke & Gertler 1990, Aghion, Fally & Scarpetta

2007, Benfratelloa Schiantarellic & Sembenelli 2008, Hall & Lerner 2010). We introduce the tax-subsidy policy as an exogenous innovation-policy intended to get the economy closer to the productivity frontier.

The paper proceeds as follows, in Section 2 we provide a brief discussion of the literature on technology and economic growth and the relationship between government´s policy, business innovation and economic growth. In Section 3, we present the setup of the model. In Section 4 we give formal intuition about the *"tax and subsidy mechanism"* and its influence on innovation and economic growth over the long-run. In Section 5, we discuss the optimization problem and the shifting nature of steady-state trajectories induced by the tax and subsidy mechanism. Finally, Section 6 provides some concluding remarks.

2 Related literature

The model that we develop relates to various strands of the literature on technology and economic growth. A major theme of the received theory is the belief that in less developed countries economic growth is driven primarily by the diffusion of foreign R&D–based flows of technology, which boost productivity as long as the economy is open and well integrated into the world economy (Barro & Sala-i-Martin 1997, Damsgaard & Krusell 2010, Stokey 2015, Benhabib, Perla & Tonetti 2014, 2017, Perla et al., 2015).[1]

Models that incorporate issues of technology diffusion from abroad and local innovation tend to emphasize a sequential process whereby countries at low levels of development first follow an *"investment strategy"* in order to acquire foreign *state-of-the-art* technologies, and switch to an *"innovation strategy"* as they approach the technology frontier (Acemoglu, Aghion & Zilibotti 2006). The model developed here builds also on the interplay between technology diffusion / adoption and innovation. But, ours is primarily a model of *innovation based economic growth*, namely, we set an environment where final output depends directly on local innovation and only indirectly on international technology diffusion.

Our analytical framework is based on distinct strands of the literature that focus on innovation as the deeper determinant of long-run growth (Pack & Nelson 1999, OECD 2007, Jones 2005, Jorgenson 2009, Pagés 2010, Mazzucato & Penna 2015), and the findings of a much recent strand of the research that distinguishes between the growth enhancing effects of *low-tech* innovations and *high-tech* technological activities (Hirsch-Kreinsen 2015; Som & Kimer 2016).

Our paper relates also to the modern debate about the appropriate policy/institutional measures to support innovation (Nelson 1993, Romer 2000, Breznitz 2007, Breznitz et al., 2018, Lin et al., 2011, Spence 2011, Mazzucato 2013, 2018, Stiglitz 2014a, 2014b, Kerr & Nanda 2015). The idea that public intervention is needed to encourage business innovation is at the heart of this debate.

[1] On the empirical approach to these line of research, see Coe & Helpman 1995, Hall & Jones 1999, Keller 2002, 2004, Caselli 2005.

Unlike the conventional wisdom related to *"infant industry"* or specific *techniques* arguments, the *tax and subsidy mechanism* in our analytical framework is meant to be a frequently adopted strategy to boost innovation. This strategy holds as long as the present value of social gains offset the cost of providing the incentive.

3 Model setup

Consider a framework where productivity differences between country "i" and the frontier are proportional to differences in technology.

$$y_i(t)/\bar{y}(t) \approx A_i(t)/\bar{A}(t)$$

where $y_i(t) = Y_i(t)/L_i(t)$, and $\bar{y}_i(t) = \bar{Y}_i(t)/\bar{L}_i(t)$. The frontier technology, $\bar{A}(t)$, consists of high-tech developments that are common to all countries; and $A_i(t)$, consists of innovations broadly defined as commercial applications of technology encompassing new ideas, production methods, processes and inputs. Thus, from the viewpoint of country "i", $\bar{A}(t)$ is exogenous whereas $A_i(t)$ is endogenous, determined by the ability to find new uses for the received technology.[2]

Country i's final output relies on the following production function

$$Y_i(t) = f\left\{A_i(t), L_i(t)\right\}$$

where L is labor, which equals the country's population. This feature frees us from discussing differences in productivity and welfare considerations. Furthermore, for simplicity, we assume that all the population works and all workers are allocated to the production of final output. Finally, we assume linearity in L. Thus, production per-worker is

$$y_i(t) = f\left\{A_i(t)\right\} \tag{1}$$

where $f\left\{0\right\} = 0$, $f^{'} > 0$, $f^{''} < 0$. Final output is denoted in per-worker units, and innovation is defined in levels which implies that productivity depends on the absolute stock of technology rather than on technology per-worker (Jones 2005). Notice that frontier technology, $\overline{A}$, does not show up in Eq. (1) as we assume that it influences the production of final output only indirectly through its impact on the dynamics of innovation—see below.

3.1 The problem of the representative agent

Consider a representative agent in the private sector who wants to maximize the value of some utility function $U(C)$. In an economy without government and with balanced trade, the real value of consumption is given by the value

[2] We assume that there are no absorptive constraints in terms of human capital, institutional infrastructure or political conditions.

of gross income minus total savings (hereafter, we suppress subscripts to avoid over-notation).

$$C^{pt} = Y - S \tag{2}$$

where $Y = yL$, $C^{pt} = c^{pt}L$ and $S = sL$ describe the aggregate levels of output, pre-tax consumption and savings, and "y", "c^{pt}" and "s" are per-worker quantities.

We assume that investment is subject to *adjustment costs* (Turnovsky 1996). In particular, consider the cost function $S = b\{I\}$ with properties $b\{0\} = 0$, $b' > 0$, and $b'' > 0$, which implies that the marginal cost of innovation is positive and increases with the investment intensity. The following so-called *convex adjustment investment cost function* satisfies the above conditions:

$$S = I + \kappa I^2 L^{-1}, \qquad 0 < \kappa \tag{3}$$

we refer to the first term on the right hand side as *"effective investments"* and the second term is the adjustment, e.g., installation costs, which we measure per-worker.

In per-worker terms savings, $s = S/L$, and investments, $\imath = I/L$. Hence the investment adjustment constraint may be written in per-worker terms as

$$s = b\{\imath\} = \imath + \kappa\imath^2, \qquad 0 < \kappa \tag{4}$$

Writing also Eq. (2) per-worker, and using Eq. (1) and Eq. (4) yields

$$\begin{aligned} c^{pt} &= y - s \\ &= f\{A\} - \left(\imath + \kappa\imath^2\right) \end{aligned} \tag{5}$$

Technology diffusion is described by a logistic function that combines the dynamic interaction between the level of investment, (local) innovation and foreign technology (Barro & Sala-i-Martin 1997, Stokey 2015, Benhabib et al., 2014, Luttmer 2015, Perla, Tonetti & Waugh 2015),

$$\frac{\dot{A}^{pt}}{A^{pt}} = \imath\left[1 - \left(\frac{A^{pt}}{\overline{A}}\right)^{\upsilon}\right] - \delta - \varphi, \qquad 0 < \upsilon, \delta, \varphi < 1 \tag{6}$$

where A^{pt} is used to denote the level of *pre-tax and subsidy* innovation, υ, δ and φ capture the rate of technology diffusion from abroad, the rate of obsolescence and the expansion of the technology frontier, respectively. By assumption all these are positive constants. The dynamics of innovation is determined by $\imath$ and $\overline{A}$. Technology diffusion is modulated by the parameter υ, the closer it is to 1 (0), the slower (higher) the spread of technology—i.e., frontier technology does not fully nor instantly spread to other countries. Notice that Eq. (6) is negative whenever $A^{pt} = \overline{A}$. If $0 < A^{pt} < \overline{A}$, A^{pt} heads asymptotically towards $\overline{A}$.

3.2 The role of government

We assume an environment where households and business sectors are separated entities. In this context, the government sets taxes and uses the revenue to grant subsidies that boost business innovation. The government budget position (G_D) is made of taxes minus government expenditures (G_C) minus subsidy payments (TR)

$$G_D = T - G_C - TR$$

Let's assume that the government sets a flat, time invariant, *ad-valorem* tax rate ($\bar{\tau}$) on income allowing for the exemption of savings associated to *effective investments*, e.g., $S - \kappa I^2 L^{-1} = I$ (the adjustment cost is unknown to all parties and, therefore, not exempted from taxation). Let us write the tax bill as

$$T = \bar{\tau}\,(Y - I)\,, \qquad 0 \leq \bar{\tau} < 1 \tag{7}$$

For simplicity, we assume that the government balances subsidy payments with tax revenues, $TR = T$ and $G_C = 0$. Thus, a net balanced budget prevails

$$0 = T - TR \tag{8}$$

From the household and the business sector view point, the *tax-and-subsidy mechanism* above influences consumption and investment decisions in two ways. First, it reduces the value of consumption as households now pay taxes

$$C = Y - S - T \tag{9}$$

Using Eq. (3) and Eq. (7) and rearranging terms, we get

$$\begin{aligned} C &= Y - S - \bar{\tau}\,(Y - I) \\ &= Y - I - \kappa I^2 L^{-1} - \bar{\tau}\,(Y - I) \\ &= (1 - \bar{\tau})\,(Y - I) - \kappa I^2 L^{-1} \end{aligned} \tag{10}$$

Writing the last equation in per-worker terms and using Eq. (1) and Eq. (4) we obtain

$$c = (1 - \bar{\tau}) \left(f\,\{A\} - \mathbf{I} \right) - \kappa \mathbf{I}^2 \tag{11}$$

Taxation redefines the maximization problem as households are set to maximizing the utility of what is left for consumption after taxes and savings, i.e., investment costs, are subtracted (notice that setting $\bar{\tau} = 0$, we obtain $c^{pt} = c$, e.g., Eq. (11) and Eq. (5) are the same).

The second way the government influences private agents decision making is by increasing their resources for innovation. In the next section we analyze the likely implications of this policy approach.

4 The subsidy mechanism

A noteworthy feature of the *tax and subsidy mechanism* in our model is that it is a *discretionary policy* aimed to boost business innovation. We assume away *arbitrage* opportunities. While households pay taxes and firms receive subsidies, in practice they are distinct entities and, therefore, at least partially unable of fully assessing the cost and benefits of fiscal management policies. This may be true in a context of agents with bounded rationality or whenever one allows for surprise fiscal policies to boost innovation.

We assume that the government's policy is to fully grant the tax revenues as subsidies to support innovation in the private sector.

$$\begin{aligned} T &= TR \\ \bar{\tau}(Y - I) &= I\tau_A, \qquad 0 \le \tau_A < 1 \end{aligned}$$

where τ_A denotes the subsidy rate:

$$\tau_A = \frac{\bar{\tau}(Y - I)}{I}$$

This subsidy rate may be written in per worker terms as

$$\tau_A = \bar{\tau}\left(\left(\frac{\mathrm{I}}{y}\right)^{-1} - 1\right) \tag{12}$$

where $(\mathrm{I}/y)^{-1}$ denotes the inverse of the investment output ratio. Notice that only *effective investments* are considered for the subsidy.

For empirically reasonable rates of investment to output such that $\mathrm{I}/y < 1/2$, the subsidy rate is proportionally larger than the tax rate and depends positively (negatively) on the income (investment) behavior. That is, $\partial\tau_A/\partial y > 0$, and $\partial\tau_A/\partial\mathrm{I} < 0$.[3]

Under the *tax and subsidy* environment, investment resources per-worker are

$$\begin{aligned} \mathrm{I}(1+\tau_A) &= \mathrm{I}\left(1 + \bar{\tau}\left(\left(\frac{\mathrm{I}}{y}\right)^{-1} - 1\right)\right) \\ &= \mathrm{I} + \bar{\tau}(y - \mathrm{I}) \end{aligned} \tag{13}$$

Where the first part of Eq. (13) is the business effective investment and the second part is the subsidy. Using this result to modify Eq. (6) we have

$$\begin{aligned} \frac{\dot{A}}{A} &= \mathrm{I}(1+\tau_A) \left[1 - \left(\frac{A}{\bar{\bar{A}}}\right)^{\upsilon}\right] - \delta - \varphi \\ &= \left(\mathrm{I} + \bar{\tau}(y - \mathrm{I})\right)\left[1 - \left(\frac{A}{\bar{\bar{A}}}\right)^{\upsilon}\right] - \delta - \varphi, \qquad 0 < \upsilon, \delta, \varphi, \bar{\tau} < 1 \end{aligned} \tag{14}$$

Notice that Eq. (6) and Eq. (14) are the same provided $\bar{\tau} = \tau_A = 0$.

There are three points worth mentioning when analyzing the macroeconomic implications of Eq. (14). Firstly, as we have noticed earlier, from the point of view of investors, the *tax and subsidy mechanism* is exogenously given. This is

[3]With $\bar{\tau} = 10\%$ and $\mathrm{I}/y = 20\%$, $\tau_A = 40\%$. But with the same tax rate and $\mathrm{I}/y = 30\%$, $\tau_A = 23\%$, which is explained because increasing investments narrows the tax base.

a key assumption. If investors are aware that they are entitled to an innovation investment subsidy on the basis of the households tax bill, they would probably adjust their consumption/savings behavior accordingly leaving investments, hence innovation, unchanged. The exogeneity of the *subsidy mechanism*, and the assumption that households and business are separated entities, precludes this kind of *arbitrage*.

Secondly, the *tax and subsidy mechanism* implicitly reflects the normative idea that the government is interested to boost a process of innovation-based growth. This is in contrast to cases where taxation precludes innovation and growth (Parente & Prescott 1999, 2002).

Finally, welfare effects matter. The effectiveness of the *tax and subsidy mechanism* hinges on its potential to increase the present net value of after tax consumption more than proportionately compared to the no tax and no subsidy scenario. Formally, one would need to show that

$$\frac{\int_0^T e^{-rt}\Big[\Big(1-\bar{\tau}\Big)\Big(f\{A\}-\mathbf{I}\Big)-\kappa\mathbf{I}^2|_{\tau_A>\bar{\tau}>0}\Big]dt}{\int_0^T e^{-rt}\Big[f\{A\}-\mathbf{I}-\kappa\mathbf{I}^2|_{\tau_A=\bar{\tau}=0}\Big]dt}\geq 1 \tag{15}$$

Providing this condition is fulfilled, resources available for consumption and investment are at least as high in the new scenario as they were in the old one. Unfortunately, we will not be able to evaluate the integrals numerically. However, we will indicate conditions under which the condition (15) holds.

5 Solving the optimization problem

The objective of the representative agent is to maximize the discounted sum of Eq. (11) subject to the dynamics of innovation established in Eq. (14). To simplify matters, we assume $\upsilon = 1$ and $\varphi = 0$. Using Eq. (1), the law of motion of innovation is

$$\frac{\dot{A}}{A}=\left(\mathbf{I}+\bar{\tau}\Big(f\{A\}-\mathbf{I}\Big)\right)\left[1-\frac{A}{\bar{A}}\right]-\delta, \qquad 0<\delta,\bar{\tau}<1 \tag{14´}$$

The optimization problem, in per-worker terms and with future values discounted at rate r, is[4]

$$max\int_0^T e^{-rt}\Big[\Big(1-\bar{\tau}\Big)\Big(f\{A\}-\mathbf{I}\Big)-\kappa\mathbf{I}^2\Big]dt$$

$$s.t. \quad \dot{A} \quad = \quad A\left(\mathbf{I}+\bar{\tau}\Big(f\{A\}-\mathbf{I}\Big)\right)\left[1-\frac{A}{\bar{A}}\right]-\delta A$$

[4]This formulation is based on the Stigler-Ozga model of diffusion in advertising theory (see Gould 1976 and Kamien & Schwartz 1991 Section II.9).

$$A\{0\} = \ A_0 > 0, \quad \mathbf{I}\{0\} = \mathbf{I}_0 > 0, \qquad 0 < \delta, \bar{\tau} < 1$$

Assuming $\kappa = 1/2$, the current value Hamiltonian H_c is

$$H_c(\mathbf{I}, A, \lambda) = \Big(1 - \bar{\tau}\Big)\Big(f\,\{A\} - \mathbf{I}\Big) - \tfrac{\mathbf{I}^2}{2} + \lambda\Bigg(A\Bigg(\mathbf{I} + \bar{\tau}\Big(f\,\{A\} - \mathbf{I}\Big)\Bigg)\left[1 - \tfrac{A}{\bar{A}}\right] - \delta A\Bigg)$$

Investment influences the objective function twice, directly, through its own value in the objective function, and, indirectly, through its impact on the evolution of the state equation. The state variable (A) evolves according to the logistic diffusion mechanism. The technology of the frontier, $\bar{A}$ influences the objective only indirectly through the state equation. Finally, the exogeneity of the *tax and subsidy mechanism*, $\mathit{I}(1 + \tau_A) = \mathit{I} + \bar{\tau}\,(y - \mathit{I})$, implies that the optimizing agent has no choices to make about optimal taxation/subsidy policy.

We aim to find an expression that reflects the dynamics of investments in innovation. The first order conditions (FOC) for optimization are Eq. (14´) and

$$\frac{\partial H_c}{\partial \mathbf{I}} = \lambda(1 - \bar{\tau})A\left(1 - \frac{A}{\bar{A}}\right) - (1 - \bar{\tau}) - \mathbf{I} = 0 \tag{16}$$

$$\begin{aligned}\dot{\lambda} - r\lambda = -\frac{\partial H_c}{\partial A} = \; & \lambda\Bigg[-\Bigg(\mathbf{I} + \bar{\tau}\Big(f\,\{A\} - \mathbf{I}\Big)\Bigg)\left(1 - \frac{A}{\bar{A}}\right) \\ & + \Bigg(\mathbf{I} + \bar{\tau}\Big(f\,\{A\} - \mathbf{I}\Big)\Bigg)\frac{A}{\bar{A}} + \delta \\ & - \bar{\tau} f' A\left(1 - \frac{A}{\bar{A}}\right)\Bigg] - (1 - \bar{\tau})\,f' \end{aligned} \tag{17}$$

plus the usual transversality conditions, assuming $T \to \infty$

$$\underset{t\to+\infty}{Lim}\; e^{-rt}\lambda(t) \geq 0, \qquad \underset{t\to+\infty}{Lim}\; e^{-rt}\lambda(t)A(t) = 0$$

Eq. (16) equates the marginal increase in innovation with the current increase in the investment cost. Eq. (17) determines the shadow value of innovation.[5]

By log-transforming Eq. (16) we have

$$ln(1 - \bar{\tau} + \mathbf{I}) = ln\,(\lambda) + ln\,(A) + ln\left(1 - \frac{A}{\bar{A}}\right) \tag{16´}$$

[5]Second order conditions for optimality are satisfied also; *sufficiency* is established by checking that the conditions of the *Mangasarian's theorem* are fulfilled (Kamien & Schwartz 1991 pp. 221 ff). Notice that the production function has properties $f^{'} > 0$, $f^{''} \leq 0$ and, from Eq. (16) we have

$$\frac{\partial^2 H_c}{\partial \mathbf{I}^2} = -1$$

Note, also from Eq. (16), that $\lambda > 0$. Hence, the Hamiltonian is concave in A and $\mathbf{I}$.

Differencing this equation with respect to time yields

$$\frac{1}{1-\bar{\tau}+\mathbf{\imath}}\dot{\mathbf{\imath}} = \frac{\dot{\lambda}}{\lambda} + \frac{\dot{A}}{A} - \frac{\dot{A}}{\bar{A}-A} \tag{18}$$

After some algebra, we obtain[6]

$$\frac{1}{1-\bar{\tau}+\mathbf{\imath}}\dot{\mathbf{\imath}} = r + \delta\frac{A}{\bar{A}-A} - \frac{1-\bar{\tau}+\mathbf{\imath}\bar{\tau}}{1-\bar{\tau}+\mathbf{\imath}}f'A\left(1-\frac{A}{\bar{A}}\right) \tag{19}$$

Over a BGP, with $\dot{\mathbf{\imath}} = 0$, we find that

$$\left(r+\delta\frac{A}{\bar{A}-A}\right)\left(1-\bar{\tau}+\mathbf{\imath}\right) = \left(1-\bar{\tau}+\mathbf{\imath}\bar{\tau}\right)f'A\left(1-\frac{A}{\bar{A}}\right)$$

The last expression may be written as

$$\left(r+\delta\tfrac{A}{\bar{A}-A}\right)\left(1-\bar{\tau}\right) + \left(r+\delta\tfrac{A}{\bar{A}-A}\right)\mathbf{\imath} = f'A\left(1-\tfrac{A}{\bar{A}}\right)\left(1-\bar{\tau}\right) + f'A\left(1-\tfrac{A}{\bar{A}}\right)\mathbf{\imath}\bar{\tau}$$

Solving for $\mathbf{\imath}$, we obtain

$$\mathbf{\imath} = \frac{\left[f'A\left(1-\frac{A}{\bar{A}}\right) - \left(r+\delta\frac{A}{\bar{A}-A}\right)\right]\left(1-\bar{\tau}\right)}{\left(r+\delta\frac{A}{\bar{A}-A}\right) - f'A\left(1-\frac{A}{\bar{A}}\right)\bar{\tau}} \tag{20}$$

From the state Eq. (14´), an equilibrium path satisfying $\dot{A} = 0$ implies

$$A = \bar{A}\left[1 - \frac{\delta}{\mathbf{\imath}+\bar{\tau}\left(f\left\{A\right\}-\mathbf{\imath}\right)}\right] \tag{21}$$

Notice that Eq. (21) may be solved as well for $\mathbf{\imath}$ which yields

$$\mathbf{\imath} = \left(\frac{\bar{A}\delta}{\bar{A}-A} - \bar{\tau}f\left\{A\right\}\right)\left(1-\bar{\tau}\right)^{-1} \tag{22}$$

Eq. (20) and (22) describe the stationary lines of the dynamic system. These lines are drawn in Figure 1 together with the arrows of motion. The steady state E_0, drawn for the absence of taxes and subsidies, is reached via a downward sloping saddle-point stable trajectory. The low-level steady state is unstable, as we explain below.

Notice that, everything else constant, increasing taxation increases innovation investments by shifting up the stationary line represented by Eq. (20) in

[6] See Appendix A for details on the derivation of Eq. (19).

Figure 2 compared to Figure 1. As we explain in more detail in Section 5.2 below.

$$\left.\frac{\partial \textsc{i}}{\partial \bar{\tau}}\right|_{\dot{\textsc{i}}=0} = \frac{\left(r+\delta\frac{A}{\bar{A}-A}\right)-f'A\left(1-\frac{A}{\bar{A}}\right)}{\left(r+\delta\frac{A}{\bar{A}-A}\right)-f'A\left(1-\frac{A}{\bar{A}}\right)\bar{\tau}} + \frac{f'A\left(1-\frac{A}{\bar{A}}\right)\left[\left(r+\delta\frac{A}{\bar{A}-A}\right)-f'A\left(1-\frac{A}{\bar{A}}\right)\right]}{\left[\left(r+\delta\frac{A}{\bar{A}-A}\right)-f'A\left(1-\frac{A}{\bar{A}}\right)\bar{\tau}\right]^2} > 0 \tag{23}$$

Likewise, according to Eq. (22), increasing $\bar{\tau}$ leads to lower $\textsc{i}$ for every given A. Hence, the $\dot{A}=0$ isocline for positive taxes must be below the one for zero taxes.

$$\left.\frac{\partial \textsc{i}}{\partial \bar{\tau}}\right|_{\dot{A}=0} = \frac{\left(\frac{\bar{A}\delta}{\bar{A}-A}-\bar{\tau}f\{A\}\right)-\left(1-\bar{\tau}\right)f\{A\}}{\left(1-\bar{\tau}\right)^2} < 0 \tag{24}$$

With Eq. (20) shifting up and Eq. (22) shifting down after an increase in taxation, we get a new steady state at a higher level of innovation in Figure 2 implying catching up to be closer to the frontier $\bar{A}$.

In general terms we find that, under the tax and subsidy mechanism, the economy could experience an increase of investments, an increase of innovation and, therefore, an increase in economic growth. Of course, the increase in taxation cannot be too large to depress consumption in current value terms. The recursive nature of this process involving taxation, investment, further innovation and economic growth is analyzed in detail in order to determining the equilibrium properties of the system.

5.1 Baseline Scenario ($\bar{\tau}=0, \tau_A=0$)

To illustrate the main implications of our model in terms of *the tax and subsidy mechanism* on economic growth and general well being, we first analyze the baseline scenario without taxes nor subsidies.

Notice, from Eq. (12), that under a $\bar{\tau}=0$ scenario, $\tau_A=0$. In this case, the temporary objective function of the agent is $f\{A\}-\textsc{i}-\kappa\textsc{i}^2$ and the state equation $\dot{A}=\textsc{i}A\left(1-A/\bar{A}\right)-\delta A$. The optimal solution in Eq. (20) becomes

$$\textsc{i} = \frac{f'A\left(1-\frac{A}{\bar{A}}\right)}{r+\delta\frac{A}{\bar{A}-A}} - 1 \tag{25}$$

Likewise, Eq. (22) becomes

$$\textsc{i} = \frac{\bar{A}\delta}{\bar{A} - A} \tag{26}$$

The vector field determined by Eq. (25)-(26) are plotted in the $\textsc{i}$-A plane in Figure 1. From Eq. (25), the $\dot{\mathbf{i}} = 0$ locus determines a bell-shape curve. This curve is increasing for small values of A and decreasing for large values. Innovation investments rise for points above the $\dot{\mathbf{i}} = 0$ locus and fall for points below it. The vertical arrows of motion illustrate this behavior.

From Eq. (26), the $\dot{A} = 0$ curve is an increasing function that, asymptotically, approaches $\bar{A}$. This curve has an intercept on the vertical axis when $A \overset{a}{\to} 0$ at $\textsc{i} = \delta$. A is increasing (decreasing) above (below) the $\dot{A} = 0$ locus as is shown by the horizontal arrows of motion.

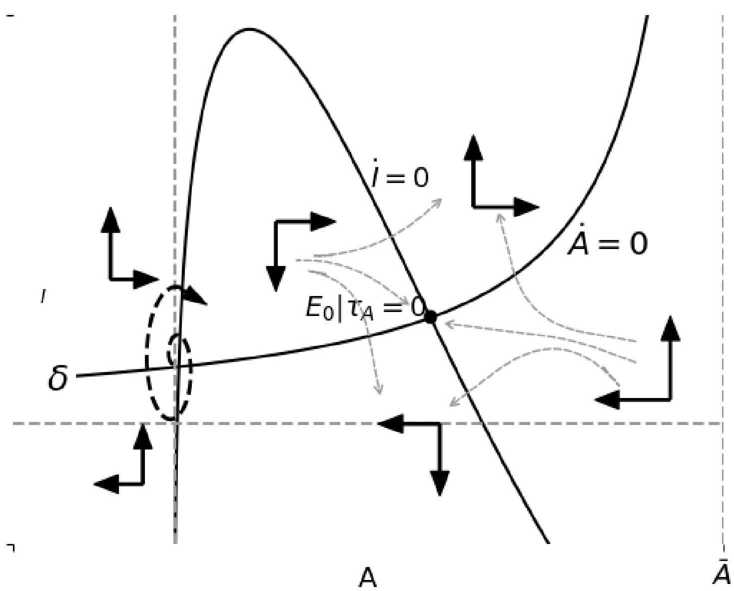

Figure 1: *A values go from 0-100. The arrows of motion show that the leftmost side equilibrium is unstable and that on the rightmost side is saddlepoint stable. Note that here* $\bar{\tau} = \tau_A = 0$*. We use* $f\{A\} = A^{\alpha}$ *with* α*=1/3, r=0.15,* δ*=0.2.*

There are two equilibria in Figure 1. The leftmost equilibrium is featured by low values of innovation and investment. This is an *unstable locus* that oscillates and moves away from the equilibrium unless $A(0) = A_{ss}$ and $\textsc{i}(0) = \textsc{i}_{ss}$. The rightmost equilibrium, is *saddlepoint* stable. From the information provided in the Jacobian matrix, we deduce that the innovation trajectory is stable while the investment trajectory is unstable. So sufficiently large disturbances on the investment dynamics will take the system away from the equilibrium.

Eq. (25) suggests that investment is a declining function of the rate of return while the effect of the depreciation rate on investment is ambiguous. A higher rate of depreciation leads to lower investments through Eq. (25), but higher investments through Eq. (26). The relationship between investment and innovation, on the other side, is quite cumbersome.

Numerical calculations in Table 1 allows us to make sense of the above interrelationships between the variables in the system and the way they are affected by changes in key parameters. In particular, notice that under the $\tau = 0$ scenario, both investment and innovation decrease as the rate of return increases from low ($r = 5\%$) to high values ($r = 20\%$). On the other hand, a high rate of depreciation leads to higher values of investments and decreasing levels of innovation (as when this parameter is increased from 5% to 10% in the table). Finally, using $f\{A\} = A^{\alpha}$, and letting α to increase from 1/3 to 2/3 leads to both, higher levels of innovation and higher levels of investment.

5.2 *The tax and subsidy mechanism* $(0 < \bar{\tau} < \tau_A)$

The core argument of the model in this paper is that it captures an essential fact in the objectives of the innovation policy: setting a flat tax rate on consumption and using the revenues to fund additional innovation investment should lead to increasing innovation and, therefore, economic growth at the economy wide level.

In Figure 2, we plot the original scenario $\bar{\tau} = \tau_A = 0$ jointly with a plot of the alternative scenario $0 < \bar{\tau} < \tau_A$. We focus on the right hand region *saddlepoint* equilibria.

Assume that we start from the equilibrium without policy, $E_0|\tau_A = 0$, the investment subsidy granted under the *tax and subsidy mechanism* causes the economy to suddenly jump up to a high value of investment for given A at $E_0|\tau_A > 0$. Then a new equilibrium trajectory takes over eventually reaching a new *steady state* at $E_1|\tau_A > 0$. Below, we provide a more formal analysis of the system dynamics.

We pointed out, from Eq. (23) and (24), that the investment loci shifts up and the innovation loci shifts down as the tax rate increases. Formally, the shift of the $\mathbf{i} = 0$ locus is obtained from Eq. (23) where

$$\left.\frac{\partial \mathbf{I}}{\partial \bar{\tau}}\right|_{\dot{\mathbf{I}}=0} > 0$$

in turn, the shift of the $\dot{A} = 0$ is obtained from Eq. (24)

$$\left.\frac{\partial \mathbf{I}}{\partial \bar{\tau}}\right|_{\dot{A}=0} < 0$$

Thus, the dynamical process triggered by the *tax and subsidy mechanism* involves changing linear combinations of investment and innovation until they

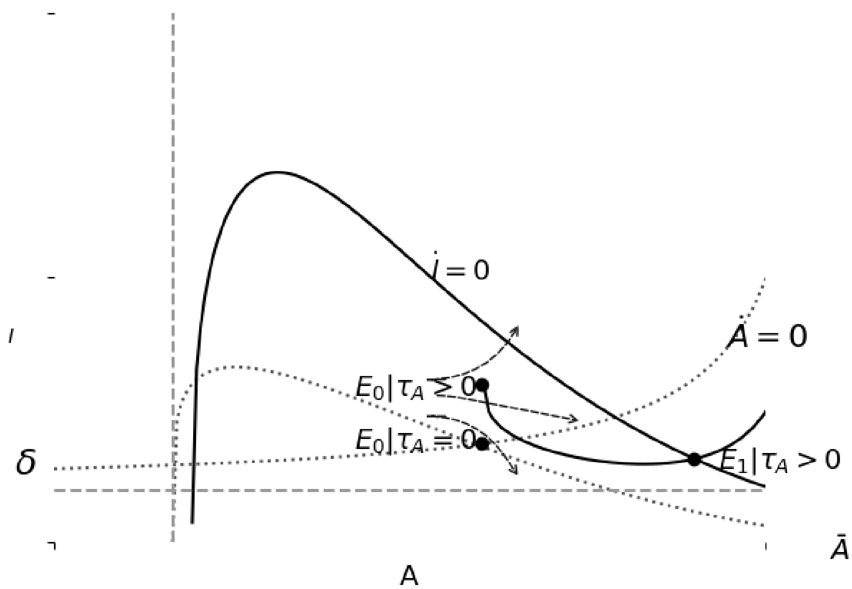

Figure 2: *A values go from 0 to $\bar{A}$=100. Equilibrium at E_0 and the corresponding stationary (dotted) lines assume $\tau_A = \bar{\tau}$=0. Equilibrium at E_1 and the corresponding stationary (solid) lines assumes $\tau_A > \bar{\tau}$=0.05. We use $f\{A\} = A^{\alpha}$ with α=1/3, r=0.15, δ=0.2.*

reach equilibrium trajectories that finally are joined in the new saddle point at $E_1|\tau_A > 0$.

From our graphical approach, the transition to the new equilibrium seems to be consistent with an increase in innovation, hence output. However, the behavior of investment in the new equilibrium is not clear. Intuitively, the *tax and subsidy mechanism* should lead to a higher level of investment under the new *steady state* $E_1|\tau_A > 0$ relative to the origin at E_0. The numerical solutions provided in Table 1 for various parameters values show higher total investment I+ (including the subsidy value) in spite of lower privately paid investment I (excluding the subsidy).

The dynamic system outlined above is one way to illustrate how public subsidies, and other policies in this direction, may be self sustainable strategies to boost a virtual cycle of innovation and growth. In fact, as mentioned earlier, the *tax and subsidy mechanism* formalized in our model has been actual practice in the innovation policy followed by both countries at the frontier and successful catching up countries.

A final step, for the overall assessment of this mechanism, regards its potential to improve social welfare.

Tax\ Return	r=0.05			r=0.10			r=0.15			r=0.20		
	I	I+	A	I	I+	A	I	I+	A	I	I+	A
α=1/3, δ=5%, $\bar{A}$=100												
τ=0.00	0.240	0.240	79.180	0.217	0.217	77.000	0.197	0.197	74.700	0.179	0.179	72.050
τ=0.01	0.203	0.243	79.517	0.181	0.221	77.435	0.161	0.201	75.200	0.142	0.182	72.660
τ=0.02	0.165	0.247	79.857	0.144	0.226	77.900	0.124	0.206	75.700	0.106	0.187	73.300
τ=0.05	0.049	0.262	81.000	0.027	0.240	79.200	0.007	0.219	77.300	-0.009	0.202	75.234
α=1/3, δ=10%, $\bar{A}$=100												
τ=0.00	0.346	0.346	71.120	0.321	0.321	68.900	0.298	0.298	66.500	0.277	0.277	63.885
τ=0.01	0.311	0.349	71.400	0.287	0.325	69.300	0.265	0.302	67.000	0.244	0.281	64.500
τ=0.02	0.278	0.355	71.870	0.254	0.331	69.790	0.231	0.307	67.547	0.210	0.286	65.100
τ=0.05	0.171	0.371	73.056	0.147	0.346	71.200	0.126	0.324	69.200	0.106	0.303	67.063
α=2/3, δ=10%, $\bar{A}$=100												
τ=0.00	0.867	0.867	88.470	0.845	0.845	88.170	0.825	0.825	87.880	0.804	0.804	87.570
τ=0.01	0.715	0.907	88.975	0.690	0.881	88.700	0.674	0.865	88.450	0.656	0.847	88.200
τ=0.02	0.563	0.951	89.500	0.542	0.930	89.260	0.523	0.911	89.025	0.505	0.892	88.800
τ=0.05	0.118	1.124	91.110	0.105	1.111	91.000	0.084	1.090	90.827	0.069	1.074	90.700

Table 1: *Investment and productivity values for high level steady states with alternative tax and interest rates. Total investment (I+) includes the subsidy, calculated using Eq. (13) as* $\mathbf{I}(1+\tau_A) = \mathbf{I} + \bar{\tau}\,(y - \mathbf{I})$

5.3 Welfare effects

A further implication in the shift of the equilibrium point from $E_0|\tau_A = 0$ to $E_1|\tau_A > 0$ in Figure 2 is that, in the first instance, consumption, hence social welfare, declines. But then, along the new optimal path, consumption increases along with investment given the higher values of productivity in the new scenario.

More specifically, as investment increases at the jump between $E_0|\tau_A = 0$ and $E_0|\tau_A > 0$, consumption declines via taxes. However, as the economy moves from $E_0|\tau_A > 0$ to the new equilibrium $E_1|\tau_A > 0$, it exhibits a larger amount of productivity, and hence a larger amount of output. Following from Eq. (15) and the A-values in Table 1, we verify the condition that consumption (and investment) are higher under the *tax and subsidy mechanism* than otherwise, as may be seen from the result presented in Table 2.

From Eq. (11) and Eq. (26), the baseline scenario $\tau_A = \bar{\tau} = 0$ implies,

$$\begin{aligned} c\Big|_{\tau_A=0} &= f\{A\} - \mathbf{I} - \kappa \mathbf{I}^2 \\ &= f\{A\} - \frac{\bar{A}\delta}{\bar{A}-A} - \kappa \left(\frac{\bar{A}\delta}{\bar{A}-A} \right)^2 \end{aligned} \tag{27}$$

where $\mathbf{I}$ is expressed in terms of A-values in going from the first to the second line. Notice, from Eq (27), that consumption increases in $A \to \bar{A}$ as f(A) increases and private investment I falls, according to Table 1.

By relying, in the new steady state, on the *tax and subsidy mechanism*, using the steady state property established in Eq. (22), we obtain

$$\begin{aligned} c\Big|_{\tau_A>0} &= (1-\bar{\tau}) \Big(f\{A\} - \mathbf{I} \Big) - \kappa \mathbf{I}^2 \\ &= (1-\bar{\tau}) \left(f\{A\} - \left(\frac{\frac{\bar{A}\delta}{\bar{A}-A} - \bar{\tau} f\{A\}}{1-\bar{\tau}} \right) \right) - \kappa \left(\frac{\frac{\bar{A}\delta}{\bar{A}-A} - \bar{\tau} f\{A\}}{1-\bar{\tau}} \right)^2 \\ &= f\{A\} - \frac{\bar{A}\delta}{\bar{A}-A} - \kappa \left(\left(\frac{\frac{\bar{A}\delta}{\bar{A}-A} - \bar{\tau} f\{A\}}{1-\bar{\tau}} \right) \right)^2 \end{aligned} \tag{28}$$

Using again $\kappa = 1/2$, and deriving Eq. (28) with respect to $\bar{\tau}$, we obtain the following steady state result

$$\begin{aligned} \frac{\partial c}{\partial \bar{\tau}}\bigg|_{\tau_A>0} &= -\frac{-f\{A\}(1-\bar{\tau}) + \left(\frac{\bar{A}\delta}{\bar{A}-A} - \bar{\tau} f\{A\} \right)}{(1-\bar{\tau})^2} \\ &= \frac{f\{A\} - \frac{\bar{A}\delta}{\bar{A}-A}}{(1-\bar{\tau})^2} \end{aligned}$$

which implies that consumption is a positive and increasing function of $\bar{\tau}$.

Tax\ Return	r=0.05			r=0.10			r=0.20		
	c	I+	f{A}	c	I+	f{A}	c	I+	f{A}
				α=1/3, δ=5%, $\bar{A}$=100					
τ=0.00	4.025	0.240	4.294	4.014	0.217	4.254	3.966	0.179	4.161
τ=0.01	4.036	0.243	4.300	4.024	0.221	4.262	3.980	0.182	4.173
τ=0.02	4.045	0.247	4.306	4.034	0.226	4.271	3.992	0.187	4.185
τ=0.05	4.063	0.262	4.327	4.054	0.240	4.294	4.019	0.202	4.222

Table 2: *Output, consumption and investment values for high level steady states with alternative tax and interest rates. We rely on the steady state values from Table 1 and use $f\{A\} = A^{\alpha}$. Total investment ($\boldsymbol{I}$+) includes the subsidy. Consumption values are generated using Eq. (11): $c = (1-\bar{\tau})\Big(f\{A\} - \boldsymbol{I}\Big) - \kappa \boldsymbol{I}^2$*

Whether the welfare benefits of increasing consumption in the future are worth the sacrifice incurred by reducing consumption in the earlier phase, after the introduction of the policy, may be evaluated from the steady state values that clearly are higher in the equilibrium–and a bit earlier– under the *tax and subsidy mechanism*. Based on a subset of the steady state values calculated in Table 1, Table 2 shows higher consumption values under the tax/subsidy policy.

An important implication of this analysis is that implementing the *tax and subsidy mechanism* gives rise to an early phase with reduced consumption and utility and a later phase with increased consumption and utility. Discounting rates which give weights to these phases matter. A high discount rate means that the later positive phase gets a low weight. If the discount is high enough, the negative impact on consumption and utility of the initial phase dominates. Conversely, if the discount is sufficiently close to zero, the increased consumption of the later phase dominates because it lasts until infinity.

Summing up, in our view, the model that we have developed here captures an essential aspect in the use of fiscal instruments to increase the availability of investable resources to promote innovation, hence economic growth and catching-up. Economies that have a low discount rate will benefit from a policy that brings them closer to the technological frontier. Economies with a high discount rate stay more behind.

As we mentioned earlier, taxing current consumption and using the unconsumed resources to grant subsidies in order to boost economic growth is a policy arrangement that has been actually implemented, to some extent, in many countries. The limited application of this mechanism, particularly in less developed countries, is a testimony of the need to improve our current understanding on the fiscally rewarding benefits of a well-designed program using tax incentives to support innovation.

6 Concluding Remarks

Studying the interaction between the adoption of foreign technology and the process of local innovation is crucial for the research on the ability of backward countries to catching up, and for the design and implementation of innovation policy. We have set up a model where innovation, along technology trajectories that are associated with state-of-the-art inventions and working practices that are common to all countries, leads to a higher level of productivity closer to the frontier countries.

The key feature of the model that we have developed above is that it provides a formal framework for the analysis of the government when it seeks to manipulate policy instruments to obtain more favorable outcomes in knowledge leading to innovation. In particular, we have suggested that countries with high discount rates will not be willing to accept the taxation and the temporary consumption loss implied by the innovation policy under the *tax and subsidy mechanism*. But countries with low discount rates will be more likely willing to do so.

While the case for a *tax and subsidy mechanism* has been a limited practice, particularly in less developed countries, and this sort of mechanisms has been a subject of–mostly empirical–academic research for a longtime, we hope that the theoretical framework presented here shall become a basis for further theoretical and empirical work on the crucial relationship between technology diffusion, innovation and the process of catching up; and a technical basis for the modern discussion on the appropriate role of government in the promotion of innovation.

Appendix A

To go from Eq. (18) to Eq. (19), note that from Eq. (17)

$$\begin{aligned}\frac{\dot{\lambda}}{\lambda} =& r - \left(\mathbf{\imath} + \bar{\tau}\Big(f\{A\} - \mathbf{\imath}\Big)\right)\left(1 - \frac{A}{\bar{A}}\right) + \delta \\ & + \left(\mathbf{\imath} + \bar{\tau}\Big(f\{A\} - \mathbf{\imath}\Big)\right)\frac{A}{\bar{A}} - \bar{\tau} f' A \left(1 - \frac{A}{\bar{A}}\right) - \frac{(1-\bar{\tau}) f'}{\lambda} \\ =& r - \frac{\dot{A}}{A} + \left(\mathbf{\imath} + \bar{\tau}\Big(f\{A\} - \mathbf{\imath}\Big)\right)\frac{A}{\bar{A}} - \bar{\tau} f' A \left(1 - \frac{A}{\bar{A}}\right) - \frac{(1-\bar{\tau}) f'}{\lambda} \qquad (17')\end{aligned}$$

From Eq. (14´)

$$\frac{\dot{A}}{\bar{A} - A} = \left(\mathbf{\imath} + \bar{\tau}\Big(f\{A\} - \mathbf{\imath}\Big)\right)\frac{A}{\bar{A}} - \delta \frac{A}{\bar{A} - A}$$

Inserting these expressions into Eq. (18), and collecting terms, yields

$$\frac{1}{1 - \bar{\tau} + \mathbf{\imath}}\dot{\mathbf{\imath}} = r + \delta \frac{A}{\bar{A} - A} - \bar{\tau} f' A \left(1 - \frac{A}{\bar{A}}\right) - \frac{(1-\bar{\tau}) f'}{\lambda} \qquad (18')$$

Thus, from Eq. (16)

$$\lambda = \frac{1-\bar{\tau}+\mathbf{\imath}}{(1-\bar{\tau})A\left(1-\frac{A}{\bar{A}}\right)}$$

Using this expression in Eq. (18´), we obtain

$$\begin{aligned}\frac{1}{1-\bar{\tau}+\mathbf{\imath}}\dot{\mathbf{\imath}} =& r+\delta\frac{A}{\bar{A}-A}-\bar{\tau}f'A\left(1-\frac{A}{\bar{A}}\right)- \qquad \frac{(1-\bar{\tau})\,f'}{\lambda} \\ =& r+\delta\frac{A}{\bar{A}-A}-\bar{\tau}f'A\left(1-\frac{A}{\bar{A}}\right)-\frac{(1-\bar{\tau})^2}{1-\bar{\tau}+\mathbf{\imath}}f'A\left(1-\frac{A}{\bar{A}}\right) \\ =& r+\delta\frac{A}{\bar{A}-A}-\frac{\left(1-\bar{\tau}+\mathbf{\imath}\right)\bar{\tau}+(1-\bar{\tau})^2}{1-\bar{\tau}+\mathbf{\imath}}f'A\left(1-\frac{A}{\bar{A}}\right) \qquad (18´´)\end{aligned}$$

From where we finally obtain Eq. (19).

References

Acemoglu, D. (2012). Introduction to economic growth. Journal of economic theory, 147(2), 545-550.

Acemoglu, D., Aghion, P., & Zilibotti, F. (2006). Distance to frontier, selection, and economic growth. Journal of the European Economic association, 4(1), 37-74.

Abramovitz, M. (1986). Catching up, forging ahead and falling behind. Journal of Economic History, June.

Aghion, P., Fally, T. & Scarpetta, S. (2007) Credit constraints as a barrier to the entry and post-entry growth of firms, Economic Policy, 22-52, pp 731-779

Alesina, A. & Perotti, R. (1997). The Welfare State and Competitiveness, American Economic Review, December.

Barro, R., & Sala-i-Martin, X. (1997). Technology diffusion, convergence and growth. Journal of Economic Growth, 2(1), 1-25.

Benfratelloa, L., Schiantarellic F., & Sembenelli, A. (2008) Banks and innovation: Micro econometric evidence on Italian firms, Journal of Financial Economics, 90-2, pp 197-217

Benhabib, J., Perla, J., & Tonetti, C. (2017). Reconciling models of diffusion and innovation: A theory of the productivity distribution and technology frontier (No. w23095). National Bureau of Economic Research.

Benhabib, J., Perla, J., & Tonetti, C. (2014). Catch-up and fall-back through innovation and imitation. Journal of Economic Growth, 19(1), 1-35.

Bernanke, B., & Gertler, M. (1990). Financial fragility and economic performance. The quarterly journal of economics, 105(1), 87-114.

Breznitz, D., Ornston, D., & Samford, S. (2018). Mission critical: the ends, means, and design of innovation agencies. Industrial and Corporate Change, 27(5), 883-896.

Bruno, C., Duguet, E., & Mairesse, J. (1998). Research, innovation and productivity: An econometric analysis at the firm level. Economics of Innovation and new Technology, 7(1), 115-158.

Caselli, F. (2005). Accounting for cross-country income differences. Handbook of economic growth, 1, 679-741.

Chudnovsky, D., López, A., Rossi, M., & Ubfal D. (2006). Evaluating a program of public funding of private innovation activities: An econometric study of FONTAR in Argentina. Documento de trabajo de la OVE, vol. 16, no 06.

Coe, D., & Helpman, E. (1995). International r&d spillovers. European economic review, 39(5), 859-887.

Crespi, G. (2012). Fiscal Incentives for Business Innovation. In A. Corbacho, coordinator, The Fiscal Institutions of Tomorrow. Washington, DC: IDB.

Damsgaard, E., & Krusell, P. (2010). The world distribution of productivity: Country tfp choice in a nelson-phelps economy (No. w16375). National Bureau of Economic Research.

Denes, M., Howell, S., Mezzanotti, F., Wang, X., & Xu, T. (2020). Investor Tax Credits and Entrepreneurship: Evidence from US States. Available at SSRN 3596342.

Jones, C. (2005). Growth and ideas. In Handbook of economic growth (Vol. 1, pp. 1063-1111). Elsevier.

Jorgenson, D. (2009). The economics of productivity. Edward Elgar Publishing.

Gould, J. (1976). Diffusion processes and optimal advertising policy. In Mathematical models in marketing (pp. 169-174). Springer, Berlin, Heidelberg.

Hall, R., & Jones, C. (1999). Why do some countries produce so much more output per worker than others?. The quarterly journal of economics, 114(1), 83-116.

Hall, B., & Lerner, K. (2010). The Financing of R&D and innovation. Handbook of the Economics of Innovation, 1, 610-635.

Hirsch-Kreinsen, H. (2015). Patterns of knowledge use in low-tech'industries. Prometheus, 33(1), 67-82.

Howell, S. T. (2017). Financing innovation: Evidence from R&D grants. American Economic Review, 107(4), 1136-64.

Hu, A. (2020). Public funding and the ascent of Chinese science: Evidence from the National Natural Science Foundation of China. Research Policy, 49(5), 103983.

Kamien, M., & Schwartz, N. (1991). Dynamic optimization: the calculus of variations and optimal control in economics and management. Second Edition, Advanced Textbooks in Economics, 31. North Holland.

Keller, W. (2004). International technology diffusion. Journal of Economic Literature, 17(Sep), 752-782.

Keller, W. (2002). Geographic localization of international technology diffusion. American Economic Review, 92(1), 120-142.

Kerr, W., & Nanda, R. (2015). Financing innovation. Annual Review of Financial Economics, 7, 445-462.

Lerner, Josh (1999), "The Government as venture capitalist: The long-run effects of the SBIR program," Journal of Business, 72, 285–318.

Lichtenberg F. (1988), Government subsidies to private military R&D investment. DOD's R&D policy. NBER WP. 2745.

Lin, J., Monga, C., te Velde, D., Tendulkar, S., Amsden, A., Amoako, K., & Lim, W. (2011). DPR debate: growth identification and facilitation: the role of the state in the dynamics of structural change. Development Policy Review, 29(3), 259-310.

Luttmer, E. (2015). Four models of knowledge diffusion and growth. Federal Reserve Bank of Minneapolis, Research Department.

Mazzucato, M. (2018). Mission-oriented innovation policies: challenges and opportunities. Industrial and Corporate Change, 27(5), 803-815.

Mazzucato, M. (2013). Financing innovation: creative destruction vs. destructive creation. Industrial and Corporate Change, 22(4), 851-867.

Mazzucato, M., & Penna, C. (2015). Mission-oriented finance for innovation: New ideas for investment-led growth. Policy Network and Rowman & Littlefield International.

Nanda, R., Younge, K., & Fleming, L. (2015). Innovation and entrepreneurship in renewable energy. In The Changing Frontier: Rethinking Science and Innovation Policy, eds. Jaffe, A., and Jones, B., National Bureau of Economic Research.

Navarro, J., Benavente, J., & Crespi, G. (2016) The New Imperative of Innovation: Policy Perspectives for Latin America and the Caribbean. Inter-American Development Bank.

Nelson, R. (Ed.). (1993). National innovation systems: a comparative analysis. Oxford University Press on Demand.

Nelson, A., Earle, A., Howard-Grenville, J., Haack, J., & Young, D. (2014). Do innovation measures actually measure innovation? Obliteration, symbolic adoption, and other finicky challenges in tracking innovation diffusion. Research Policy, 43(6), 927-940.

OECD (2007). Innovation and Growth, Rationale for an innovation Strategy.

OECD (2005). The OSLO manual: the measurement of scientific and technological activities. Guidelines for collecting and interpreting innovation data. 3rd ed. Paris, France: OECD/Eurostat.

Pack, H., & Nelson, R. (1999). The Asian miracle and modern growth theory. The World Bank.

Pagés, C. (2010). The importance of Ideas, innovation and productivity in Latin America. In The Age of Productivity. Transforming economies from the bottom up. IDB. Palgrave Macmillan, New York. Ch. 10. p. 223-255.

Parente, S., & Prescott, E. (2002). Barriers to riches. MIT press.

Parente, S. & Prescott, E. (1999). Monopoly rights: A barrier to riches. American Economic Review, 89(5), 1216-1233.

Perla, J., Tonetti, C., & Waugh, M. (2015). Equilibrium technology diffusion, trade, and growth (No. w20881). National Bureau of Economic Research.

Reppy, J. (1977), Defense Department Payments for 'Company-Financed' R&D, Research Policy, 6, pp. 396—410.

Romer, P. (2000). Should the government subsidize supply or demand in the market for scientists and engineers?. Innovation policy and the economy, 1, 221-252.

Romer, P. (1994). The origins of endogenous growth. Journal of Economic perspectives, 8(1), 3-22.

Romer, P. (1993). Idea gaps and object gaps in economic development. Journal of monetary economics, 32(3), 543-573.

Sampson, T. (2015): Dynamic Selection: An Idea Flows Theory of Entry, Trade and Growth, The Quarterly Journal of Economics.

Som, O., & Kirner, E. (2016). Low-tech innovation. Springer International Pu.

Spence, M. (2011). The next convergence: The future of economic growth in a multispeed world. Farrar, Straus and Giroux.

Stiglitz, J. (2014a). Intellectual property rights, the pool of knowledge, and innovation (No. w20014). National Bureau of Economic Research.

Stiglitz, J. (2014b). Leaders and followers: Perspectives on the Nordic Model and the economics of innovation. Journal of Public Economics.

Stokey, N. (2015). Catching up and falling behind. Journal of Economic Growth, 20(1), 1-36.

Turnovsky, S. (1996). Fiscal policy, adjustment costs, and endogenous growth. Oxford Economic Papers, 48(3), 361-381.

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