Perpetual leapfrogging in international competition

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Abstract

Technological leadership has shifted at various times from one country to another. This analysis proposes a mechanism that endogenously explains this perpetual cycle of technological leapfrogging by incorporating international knowledge spillovers into a two-country dynamic model of innovation with the dynamic optimization of an infinitely-lived consumer. In the model, innovation productivity in each country endogenously increases over time because of domestic learning-by-doing and learning from foreign capital. The analysis shows that if international spillovers through learning from foreign capital are sufficiently large, technological leadership may first shift from one country to another, and then perpetually alternate between the two countries.

Keywords: Perpetual leapfrogging; innovation; spillovers

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1 Introduction

Throughout history, technological leadership has shifted at various times from one country to another. For instance, during the early 17th century, Venice and Spanish Lombardy were among the most technologically advanced regions in Europe (Davids 2008, p. 2). Over the centuries, the "technological center of gravity of Europe then moved, residing at various times in Italy, southern Germany, the Netherlands, France, England, and then again in Germany" (Mokyr 1990, p. 207). Some economic historians even claim that the US had begun to lose its technological leadership by the early 1990s (Nelson and Wright 1992).

An important question is why such economic and technological leapfrogging takes place. An equally fundamental question is why technological leapfrogging has repeatedly occurred. To respond to the first question, Brezis, Krugman, and Tsiddon (1993) provided an economic explanation based on major exogenous changes in technology. When such change occurs, the new technology appears less productive for leading nations, given their extensive experience with older technologies. Lagging nations with less experience will then introduce the new technology. As these accumulate sufficient experience with the new technology, the leapfrogging of technological leadership occurs. We may apply this same theory to the second question by considering the perpetual cycles of leapfrogging as responses to the perpetual changes in technology. This explanation is, however, essentially exogenous, as it is based on macro shocks in technology. Although a variety of studies have followed Brezis, Krugman, and Tsiddon, no existing work formally provides a fully endogenous explanation that responds to both of these questions.

The aim of this analysis is to develop a fully endogenous theory that explains both the leapfrogging of technological leadership and the perpetual cycle in technological leadership. For this purpose, we focus on international knowledge spillovers in a two-country dynamic general equilibrium model of innovation with the dynamic optimization of consumption and saving by an infinitely-lived consumer. As firms in a country develop innovations in this model, their innovation productivity endogenously increases over time because of domestic learning-by-doing and learning from foreign capital flows, both of which allow knowledge diffusion into the model.[1] By assuming

[1]This approach follows a number of related theoretical models (Brezis and Tsiddon 1998; van de Klundert and Smulders 2001; Desmet 2002). As argued by Brezis (1995), foreign capital plays a role in industrialization and development processes. We may also

that technological leadership is the state whereby a given country innovates most among all countries, we demonstrate that if the international knowledge spillovers are sufficiently efficient, technological leadership by that country will eventually shift to another country, and then perpetually alternate between countries.

The key driving force behind perpetual leapfrogging is the learning ability of a country from abroad. For example, a technologically lagging country may learn much more from the firms in the leading country than the leading country learns from the firms in the lagging country. Meanwhile, in a similar fashion, domestic learning-by-doing takes place that increases innovation productivity in each country. The analysis shows that if a country can learn sufficiently from the foreign country, technological leadership is likely to perpetually alternate between the countries.

In order to capture cyclical phenomena in the simplest fashion, we follow Shleifer (1986), Deneckere and Judd (1992), Gale (1996), Francois and Shi (1999), and Matsuyama (1999, 2001) by assuming that patents last only for one period. This assumption implies that the length of a unit period is sufficiently long, which can be somewhere around 20 years. Given that, in reality, many of innovated consumption goods become obsolete before patents expire, for the sake of simplicity, we assume that innovations are made obsolete in a single period. In line with those existing papers, we assume the temporary nature of the monopoly enjoyed by innovators, which plays a role in explaining perpetual leapfrogging.

Our analysis relates most to studies in international economics following the work in Brezis, Krugman, and Tsiddon (1993). Most closely related is a paper by van de Klundert and Smulders (2001), who focus on an international capital market in an endogenous growth model. By allowing for nontradable goods, capital flows, and endogenous innovations, they explain the well-documented fact that a leading country (e.g., England) tends to lose its technological leadership by becoming a rentier economy that invests in a new technologically leading country. However, as in the other related studies described below, their analysis does not address the second question of why the leapfrogging of technology leadership produces a perpetual cycle. In an earlier contribution, Brezis and Tsiddon (1998) show that capital mobil-

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accept that international capital flows, as well as imports, are an important channel for international knowledge spillover, as discussed in the literature (Grossman and Helpman 1991; Feenstra 1996). See Branstetter (2006) for recent empirical evidence.

ity may spur leapfrogging. Desmet (2002) extends the Ricardian model in Brezis, Krugman, and Tsiddon (1993) to a Heckscher–Ohlin framework by introducing mobile capital and spillovers.

In other work, Desmet specifies a mechanism by which the most advanced country may reinforce its dominant position by adopting the new technology if spillovers between the old and new technologies are sufficiently strong, which weakens the opportunity for lagging nations to take off and leapfrog. In a different context, the literature on industrial organization has clarified the conditions for leapfrogging. For example, Motta, Thisse, and Cabrales (1997) illustrate in a model with vertical product differentiation that free trade may either encourage or reverse quality leadership. The present study extends these existing studies by explicitly and formally providing a fully endogenous explanation of why leapfrogging takes place perpetually using a single factor, namely, international knowledge spillovers. Ohyama and Jones (1995) provide a similar explanation for leapfrogging by firms, with a focus on comparative advantage. They argue that lagging regions typically have a comparative advantage in the new technology as the leading country has greater experience in the older technologies. This provides lagging regions with an opportunity to adopt the new technology first.

The notion of perpetual leapfrogging is not new in the context of price competition between firms. For instance, Giovannetti (2001) considers a duopoly in which firms considering infinite technological adoption set prices with Bertrand competition in the product market. Using this model, Giovannetti identifies the conditions whereby firms alternate in adopting the new technology, thereby representing a leapfrogging process. He shows that demand conditions, such as price elasticity, play a role in determining whether leapfrogging can be perpetual in Bertrand competition. Lee, Kim, and Lim (2011) have provided recent empirical support for this contention.

In demonstrating the cyclical occurrence of leapfrogging, we reveal that the dynamic general equilibrium of the model is characterized by a simple nonlinear dynamic system in discrete time. Along an equilibrium path generated by this system, we show that technological leadership may fluctuate perpetually. Nonlinear equilibrium dynamics in discrete time provide a useful tool for describing real-world, complicated economic phenomena (Nishimura and Yano 2008), which may include the perpetual cycle of leapfrogging. Our analysis extends this line of research by demonstrating the possibility of a perpetual cycle of leapfrogging using a one-dimensional nonlinear difference equation.

2 The model

We assume time is discrete and extends from $t = 0$ to $+\infty$. Consider two countries, A and B, with identical preferences, and which differ only in their initial levels of innovation productivity. The countries are denoted by i or k ($i = A,\ B$; $k = A,\ B$), using a superscript for variables pertaining to the production side and a subscript for those pertaining to the consumption side.

There is a continuum of differentiated consumption goods in each period t. Each good is indexed by j. Given we later allow for foreign direct investment (FDI), the country where a particular firm innovates and manufactures may change. Let $\Gamma^i(t)$ be the set of innovated goods in period t by the firms in country i and let $\Lambda^i(t)$ be the set of goods manufactured in country i in period t. Let $N(t) = \int_{j\in\{\Lambda^A(t)\cup\Lambda^B(t)\}} dj$ be the total number of goods manufactured in t.

2.1 Consumption

In each country, an infinitely-lived representative consumer inelastically supplies L units of labor for production and R&D in every period. Note that the two countries are assumed to have equal labor forces, L. We endow both consumers with the same intertemporal utility function

$$U_i = \sum_{t=0}^{\infty} \beta^t \ln u_i(t),$$

where $\beta \in (0,1)$ is the time preference rate. The temporary utility $u_i(t)$ is defined on the set $\{\Lambda^A(t) \cup \Lambda^B(t)\}$ of goods manufactured in both countries (free trade), taking the standard Dixit–Stiglitz form:

$$u_i(t) = \left(\int_{j\in\{\Lambda^A(t)\cup\Lambda^B(t)\}} x_i(j,t)^{1-\theta} dj \right)^{\frac{1}{1-\theta}}, \tag{1}$$

where $x_i(j,t)$ is the consumption of good j in country i. Parameter $\theta \in (0,1)$ characterizes preferences in the two senses. Let $E_i(t)$ be the spending in country i. Solving the utility maximization problem in (1) leads to the demand function for good j as $x_i(j,t) = p(j,t)^{-(1/\theta)} E_i(t)/P(t)^{1-(1/\theta)}$, where $p(j,t)$ denotes the price of good j and $P(t)$ is the price index.[2] Aggregating

[2] As is well known, the index is defined as $P_t = \left(\int_{j\in\{\Lambda^A(t)\cup\Lambda^B(t)\}} p(j,t)^{1-(1/\theta)} dj \right)^{\frac{1}{1-(1/\theta)}}$.

these expressions, we obtain the derived market demand, $x_A(j,t)+x_B(j,t) \equiv x(j,t)$, as

$$x(j,t) = \frac{E(t)p(j,t)^{-(1/\theta)}}{P(t)^{1-(1/\theta)}}, \tag{2}$$

where $E(t) = E_A(t) + E_B(t)$ is the aggregate spending in period t. The price elasticity of demand is constant at $1/\theta$ for any j.

Solving the dynamic optimization of the consumer's utility for consumption and saving or investment decisions under the intertemporal budget constraint results in the usual Euler equation $E_i(t+1)/E_i(t) = \beta(1+r(t))$, where $r(t)$ is the interest rate in period t. We then obtain

$$\frac{E(t+1)}{E(t)} = \beta(1 + r(t)). \tag{3}$$

2.2 Innovation, manufacturing, and capital flows

A single firm innovates and monopolistically supplies each differentiated consumption good, following the R&D-based growth model with expanding variety (Romer 1990). Innovating a new good takes one period. When an R&D firm in country i invests $1/A^i(t-1)$ units of labor in period $t-1$, it innovates a new good *at the end of* period $t-1$. In the subsequent period, t, the firm sets up a production plant. The firm will choose the country in which to manufacture the good in order to maximize profits. In equilibrium, the firm may transfer production to a foreign country $k(\neq i)$ through FDI, as foreign profits may be greater.[3]

After the firm chooses the country in which to manufacture, it monopolistically produces $x(j,t)$ units of good j using domestic labor as the input. Assume that there are constant returns to scale in the production of good j and that the productivity of labor is the same in both countries, which is normalized to be one.[4] The marginal cost is thus equal to the wage rate in country i, $w^i(t)$.

[3] In line with the literature on international trade and growth (Lai 1998), we do not distinguish between the various forms of production transfer, including fully and partially owned subsidiaries and licensing.

[4] Here we simply consider that efficiency in manufacturing is normalized across countries. We can extend this simple setting by allowing for country-specific manufacturing efficiency and its endogenous progress. In such an extended model, we can easily verify that the comparative advantage between R&D and manufacturing (rather than the ab-

When the firm that innovates technology for good j in period t chooses to manufacture in country i, captured by $j \in \Lambda^i(t)$, it maximizes monopolistic profits by setting a price at $p(j,t) = w^i(t)/(1-\theta) \equiv p^i(t)$, taking into account the constant price elasticity $1/\theta$ according to (2). This monopolistic price does not depend on the country for innovation, only on the country for manufacture. With this monopolistic price $p^i(t)$, we can derive from (2) the demand and profit functions as

$$x(j,t) = \frac{E(t)p^i(t)^{-(1/\theta)}}{P(t)^{1-(1/\theta)}} \equiv x^i(t) \tag{4}$$

and

$$\pi(j,t) = \theta E(t)\left(\frac{p^i(t)}{P(t)}\right)^{1-(1/\theta)} \equiv \pi^i(t) \tag{5}$$

for $j \in \Lambda^i(t)$ ($i = A, B$). As firms prefer the country where profits are higher, the net value of the firm innovating in country i is expressed as

$$V^i(t-1) = \frac{\max\{\pi^A(t), \pi^B(t)\}}{1+r(t-1)} - \frac{w^i(t-1)}{A^i(t-1)}. \tag{6}$$

In order to capture cyclical phenomena in the simplest fashion, we follow Shleifer (1986), Deneckere and Judd (1992), Gale (1996), Francois and Shi (1999), and Matsuyama (1999, 2001) by assuming that patents last only for one period. This assumption implies that the length of a unit period is sufficiently long, which can be somewhere around 20 years given the real-world patent length. Given that, in reality, many of innovated consumption goods become obsolete before patents expire, we may assume that innovations are made obsolete in a single period.[5] As shown below, this assumption makes the analysis tractable without any fundamental change in the results. Finally, free entry guarantees that the net value of a firm should not be positive in equilibrium: $V^i(t-1) \leq 0$ for each i.

solute advantage in R&D) plays an important role in perpetual leapfrogging, although the resutls and their intuition in perpetual leapfrogging do not change fundamentally.

[5]This assumption may also be justified if each innovation could be interpreted as specific and relatively minor. For example, "innovation" in this model would be represented by the specific innovation associated with iPhone 4S instead of smart phones, cell phones, or information technology more generally.

2.3 Learning-by-doing and international spillovers

Technology advances with two kinds of learning: domestic learning-by-doing and learning from abroad. First, we consider that a country that develops an innovation immediately learns how to innovate efficiently. Assume that the productivity increase for a country, $A^i(t+1) - A^i(t)$, linearly depends on the number of domestic innovations, $\int_{\Gamma^i(t)} dj \equiv N^i(t)$,[6] which is a proxy for the flow of knowledge generated as a by-product of the innovations in period t (Romer 1990). Second, the international knowledge spillovers accompany FDI, such that we assume that country i learns from its foreign capital inflows. The productivity of country i also increases linearly with $\int_{j \in \Gamma^k(t-1) \cap \Lambda^i(t)} dj \equiv M^i(t)$, with $k \neq i$, which is the amount of foreign capital that flows into the country. Accordingly, we simply describe technological progress using

$$A^i(t+1) - A^i(t) = N^i(t) + \mu M^i(t), \tag{7}$$

where $\mu \in [0, 1]$ captures the efficiency of the contribution of international knowledge spillovers through foreign capital inflows to technological progress. The efficiency of international knowledge spillovers increases with μ. If $\mu = 1$, spillovers from FDI are as efficient as domestic spillovers; if $\mu = 0$, there is no learning at all from foreign capital.

3 Perpetual leapfrogging

In this section, we prove the main result that technological leadership may fluctuate over time, thereby perpetually moving back and forth between countries. To do this, we identify a condition under which no country can retain technology leadership for infinitely successive periods. Before proceeding, we provide a formal definition of the concept of technological leadership. Taking into account the notion in economic history (David 2008),[7] we refer to a country that develops innovations most among the countries as the technological leader, and a country developing relatively few innovations as a lagging country. In the present model, and as will be made apparent later, this definition is equivalent to that in trade theory (Brezis, Krugman, and

[6] Note $N^A(t) + N^B(t) = N(t+1)$, reflecting the assumption that innovating a new good takes one period.

[7] David (2008) considered that a country that has technological leadership plays an initiating role in the development of new technologies across a wide variety of fields.

Tsiddon 1993), which defines leadership as the state whereby a given country has the highest productivity among the countries. Thus, in equilibrium, country i innovates more if and only if its innovation productivity is higher; $N^i(t) > N^k(t)$ if and only if $A^i(t) > A^k(t)$. For sake of simplicity, we will use $A^i(t) > A^k(t)$ to mention that country i is the technological leader.

Without loss of generality, we suppose that country A is the leading country in period t, $A^A(t) > A^B(t)$ (and thus $N^A(t) > N^B(t)$ in equilibrium), and refer to this situation as regime A. If $A^A(t) < A^B(t)$ (and thus $N^A(t) < N^B(t)$ in equilibrium), we refer to it as regime B.

In any period of time, the model can be regarded as a variant of a conventional two-good Ricardian model, where two outputs are considered innovation and production. Given $A^A(t) > A^B(t)$, there are potentially three possible equilibria in period t: (1) one in which both countries engage in manufacturing; (2) one in which both countries engage in R&D; (3) one in which both countries are specialized. We adopt a sufficiently large θ to focus on the most important case. The assumptions that θ is sufficiently large and that the two countries have the same labor force amount L rule out the first and third kinds of equilibria and ensure that the leading country will always be specialized in innovation and the lagging country will be involved in both R&D and manufacturing.[8] Given the same labor force, this implies that the leading country innovates more than the lagging country; $N^A(t) > N^B(t)$ for $A^A(t) > A^B(t)$.

In the equilibrium (2), manufacturing takes place only in country B, so that $\pi^A(t+1) < \pi^B(t+1)$ must hold. Then, by substituting the price $p^i(t)$ into (4) and (5), we can have

$$x^B(t) = (1-\theta)\frac{A^B(t)E(t)}{N(t)\omega(t)} \tag{8}$$

and

$$\pi^B(t+1) = \theta\frac{E(t+1)}{N(t+1)}. \tag{9}$$

As R&D takes place in both countries in this case, the two countries would share the same cost for R&D in equilibrium; $w^A(t)/A^A(t) = w^B(t)/A^B(t) = \omega(t)$. By $V^A(t) = V^B(t) = 0$ and $\max\{\pi^A(t+1), \pi^B(t+1)\} = \theta E(t+1)/N(t+$

[8] See the appendix for details.

1), with the Euler equation (3), we have

$$\frac{\beta\theta E(t)}{N(t+1)} = \omega(t). \tag{10}$$

Suppose that one country, say A, retains the leadership for two consecutive periods, assuming $A^A(t) > A^B(t)$ and $A^A(t-1) > A^B(t-1)$. In periods $t-1$ and t, country A is specialized in R&D while B is not. By combining (8) and (10) with $N(s+1) = N^A(s) + N^B(s)$, the labor conditions in periods $t-1$ and t can give rise to:

$$N^A(s) = A^A(s)L \text{ and } N^B(s) = \tfrac{\beta\theta}{1-\theta+\beta\theta}\left(A^B(s)L - \tfrac{1-\theta}{\beta\theta}A^A(s)L\right), \tag{11}$$

where $s = t-1, t$.

Recall that in (7) the technological progress in period t, $A^i(t+1) - A^i(t)$, depends on domestic innovations and a flow of foreign innovations. In period t, by assumption, $N^A(t-1)$ innovations flow from country A to B. Thus,

$$A^A(t+1) - A^A(t) = N^A(t) \text{ and } A^B(t+1) - A^B(t) = N^B(t) + \mu M^A(t), \tag{12}$$

where $M^A(t) = N^A(t-1)$. Given $A^A(t) - A^A(t-1) = N^A(t-1)$ by $A^A(t-1) > A^B(t-1)$, together with (11) for $s = t-1$, we obtain

$$A^A(t-1) = A^A(t)/(L+1). \tag{13}$$

From (11), (12), and (13), noting $s = t-1, t$, we derive the equilibrium dynamical equilibrium system in periods t and $t+1$ as follows:

$$\alpha(t+1) = \frac{(L+1)\alpha(t)}{\left(\frac{\beta\theta}{1-\theta+\beta\theta}L + 1\right) + L\alpha(t)\left(\mu/(L+1) - \frac{1-\theta}{1-\theta+\beta\theta}\right)} \tag{14}$$

for $\alpha(t) > 1$ and $\alpha(t-1) > 1$. The condition for leapfrogging is also similar to that originally ($\mu > 2(1-\theta)$) given by

$$\mu > \frac{2\,(1-\theta)\,(L+1)}{1-\theta+\beta\theta}. \tag{15}$$

If (15) holds, $\alpha(t+1) < 1$ for $\alpha(t) > 1$ and $\alpha(t-1) > 1$, which, given symmetry for both countries, implies that $\alpha(t+1) > 1$ for $\alpha(t) < 1$ and $\alpha(t-1) < 1$. This proves the following theorem, by applying the above analysis to (11)–(15) repeatedly to subsequent periods $t+2, t+3, \cdots$.

Theorem 1 *Under the infinitely-lived agent's dynamic optimization, if (15) holds, neither country can retain its technological leadership for more than two periods in a row.*

We can easily derive the next proposition from Theorem 1, noting (15).

Proposition 1 *Leapfrogging may take place repeatedly and perpetually if the efficiency of international spillovers μ is sufficiently high.*

The key driving force behind perpetual leapfrogging is the learning ability of a country from abroad. In the model, the lagging country learns from the leading country's capital firms while the leading country does not. This creates the possibility of leapfrogging. Needless to say, this is a very extreme case, as specialization takes place in the present model, which can be regarded as a dynamic version of the Ricardian model. In reality, the leading country also manufactures foreign innovations (those in the lagging country) and may also learn from them. Therefore, we may assume that this model captures one aspect of real-world behavior. That is, lagging countries may have an advantage in international technology competition with the leading country because they can learn from the leader's active innovation as well as their own experience in innovation. This analysis formally shows in a two-country model with dynamic optimization of the infinitely-lived consumer that if a country can learn sufficiently from the foreign country, technological leadership is likely to perpetually alternate between the countries.[9]

3.1 An illustration

The previous section proved the condition of perpetual leapfrogging under dynamic optimization, (15). To obtain a visual intuition, in this section we provide a graphical illustration by means of the usual phase diagram. In

[9]Given the historical fact that technology leadership has often shifted between countries, it is important to provide an extended case comprising more than two countries. We can demonstrate that three or more countries on an equilibrium path can perpetually experience various forms of leapfrogging including, for example, growth miracles, in which the least productive country leapfrogs all rival countries with higher productivity levels in a single burst. Such growth miracles may take place sporadically or consecutively, or in a complex combination of the two. See Furukawa (2012) for a formal analysis.

doing so, we assume innovation activities are completed within one period. Thus, the innovation value in (6) should be replaced by

$$V^i(t) = \max\{\pi^A(t), \pi^B(t)\} - w^i(t)/A^i(t). \tag{16}$$

We also assume, for reasons made clear shortly, that an inverse measure of the elasticity of substitution, θ, is greater than 0.5.[10] In this simplified model, the equilibrium dynamics can be completely characterized by the following one-dimensional difference equation. See Furukawa (2012) for a proof.

$$\alpha(t+1) = \Phi(\alpha(t)) \equiv \begin{cases} \frac{\mu L + \alpha(t)}{L+1} & \text{for } 0 < \alpha(t) < \frac{1-\theta}{\theta} \\ \frac{(\theta L+1)\alpha(t) + L(\mu-(1-\theta))}{L+1} & \text{for } \frac{1-\theta}{\theta} \le \alpha(t) < 1 \\ \alpha(t)\frac{L+1}{(\mu L\alpha(t)+1)+L(\theta-(1-\theta)\alpha(t))} & \text{for } 1 < \alpha(t) < \frac{\theta}{1-\theta} \\ \alpha(t)\frac{L+1}{\mu L\alpha(t)+1} & \text{for } \frac{\theta}{1-\theta} \le \alpha(t) \end{cases} \tag{17}$$

The equilibrium dynamical system Φ is autonomous and nonlinear. Figure 1 depicts the phase diagram of system Φ for the efficiency μ of knowledge spillovers smaller than $2(1-\theta)$. There are two steady states, both of which are stable. For all initial points, technological leadership can never alternate internationally. Figure 2 depicts a typical path for the case in which the efficiency μ of international spillovers exceeds $2(1-\theta)$. Given that no steady state exists, $\alpha(t)$ will move perpetually back and forth between the two regimes $(1,\infty)$ and $(0,1)$. Finally, note that the condition of perpetual leapfrogging in the simplified model, $\mu > 2(1-\theta)$, is similar to the original model (15) and that $\theta > 0.5$ is a necessary condition as $\mu \le 1$.

Appendix:

Suppose that both countries produced goods (pattern (1)). Then the wages would be internationally equated, $w^A(t) = w^B(t) = w(t)$, implying $x^i(t) = x(t)$. The labor conditions would be $N^A(t)/A^A(t) + (N(t) - M^B(t))x(t) = L = M^B(t)x(t)$. Since $E(t)/w(t) = (\beta\theta)^{-1} N(t)/A^A(t)$ from $V^A(t) = 0$, this implies that $N^A(t)/A^A(t) = 2L - \frac{1-\theta}{\beta\theta} N(t)/A^A(t)$, noting

[10] A higher θ indicates a lower elasticity of substitution. Li (2001) argues that the evidence regarding whether there is any conventional value or a range of values for the elasticity of substitution is inconclusive. For example, Broda and Weinstein (2006) show that the elasticity of substitution is, on average, greater than two, but tends to decline over time and is actually less than two in some sectors (e.g., motor vehicles).

$x(t) = (1-\theta)E(t)/\left(w(t)N(t)\right)$. Note that $N(t)$ and $A^A(t)$ are given in period t. Thus, if θ is sufficiently large, we have $N^A(t)/A^A(t) \to 2L > L$, which violates the labor market equilibrium.

Suppose that both coutnries are completely specialized (pattern (3)). Then the labor condirions imply $N^A(t)/A^A(t) = L = N(t)x^B(t)$. Noting $V^A(t) = 0$, we have $E(t)/w^A(t) = (\beta\theta)^{-1} N(t+1)/A^A(t)$. Noting $x^B(t) = (1-\theta)E(t)/\left(w^B(t)N(t)\right)$, thus, a resource constraint $L > N(t)x^B(t)$ by the labor market condition requires $L > (1-\theta)L/(\beta\theta)$, where $w^A(t) > w^B(t)$ is used. If θ is sufficiently large, this does not hold.

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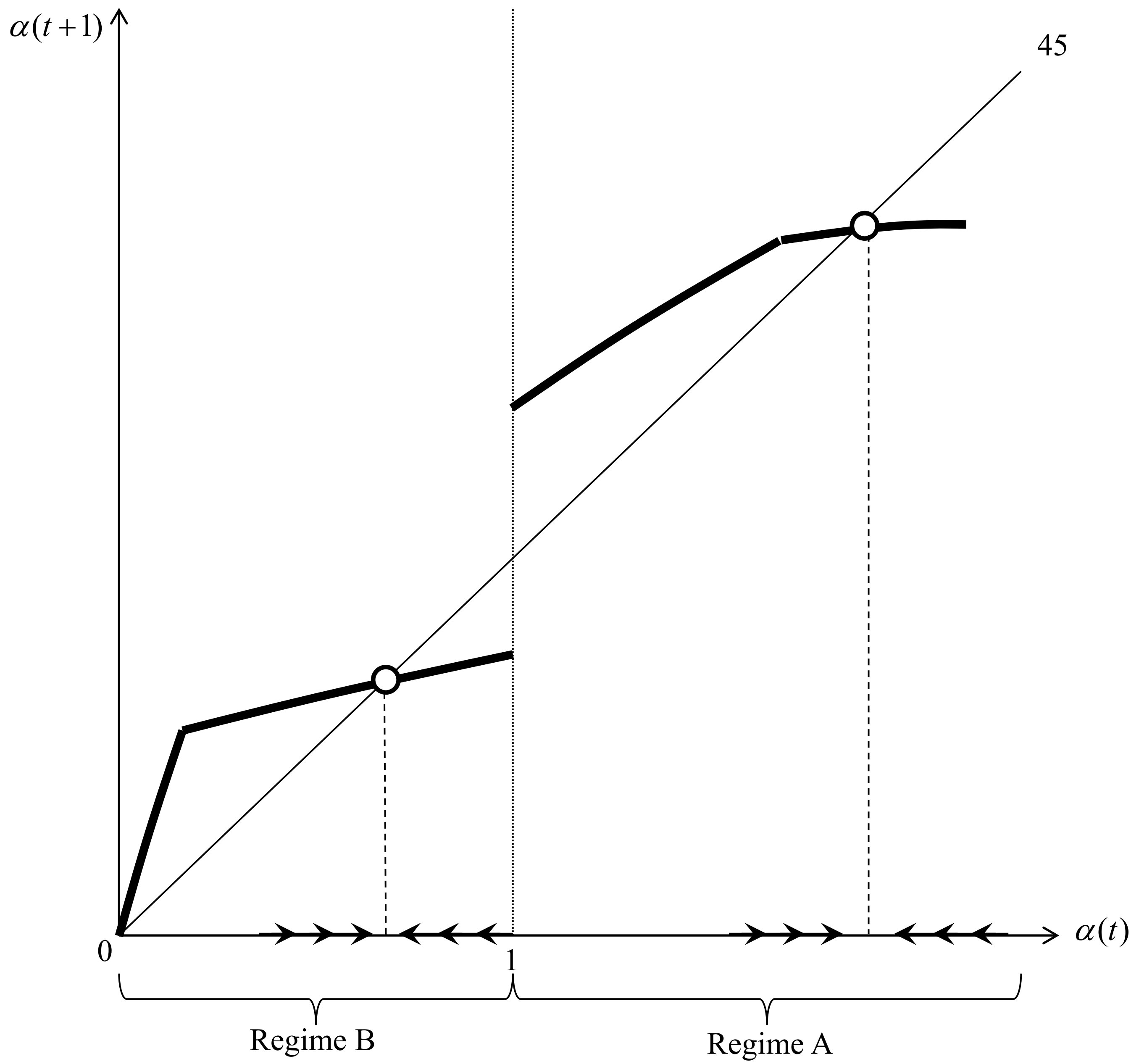

Figure 1: no leapfrogging under $\mu < 2(1-\mu)$

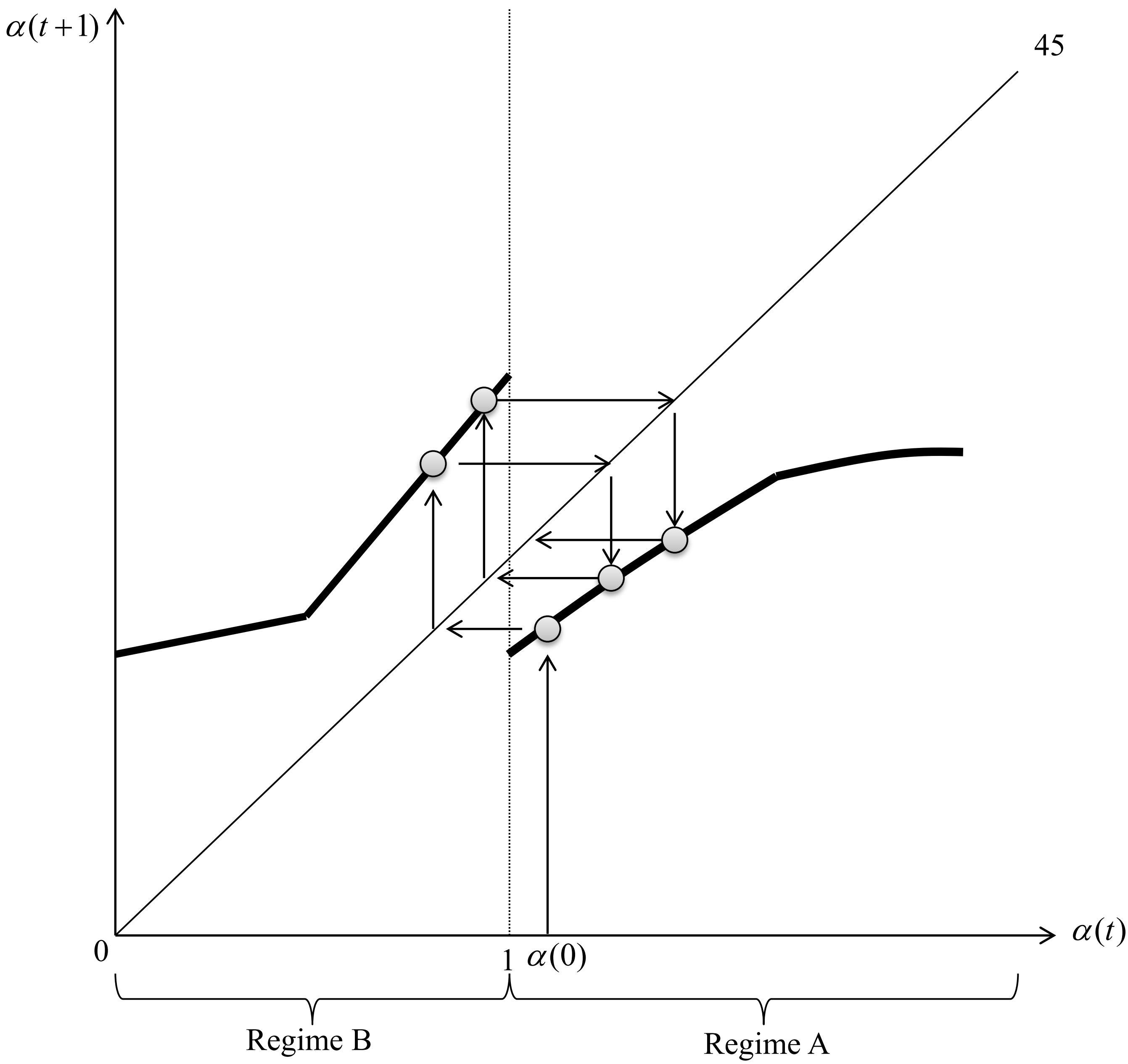

Figure 2: perpetual leapfrogging under $2(1-\theta) < \mu \leq 1$