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Abstract

In this study, we investigate the relationship between receptivity to novelty and innovation. Receptivity, an individual propensity to accept new goods, may affect innovation at the aggregate level. Using World Values Survey data, in fact, we discover that innovation is negatively correlated with the share of people who recognize themselves as highly receptive to novelty. Receptivity may not be always conducive to innovation. We propose a new dynamic general equilibrium model compatible with this fact. Using this model, we demonstrate that an economy where the consumer has too little or too much receptivity to novelty is likely to be caught in an underdevelopment trap with no innovation. Only an economy with moderate receptivity can achieve innovation and thereby long-run growth. In the latter case, balanced growth and perpetual cycles are both possible; the cycles are caused because the introduction of new goods is costly and takes time. Other than receptivity, we also identify critical roles of population and knowledge accumulation in innovation.

JEL Classification Codes: E32; O40; Z10
Keywords: Openness/aversion to novelty; underdevelopment traps; endogenous growth; innovation cycles

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1 Introduction

It has been a commonplace assertion in the economics literature that, together, cultural values and individual propensities play a role in innovation as an aggregate phenomenon. Recently, Benabou et al. (2015, 2016) documented an important finding by using data from five available waves of the World Values Survey (WVS) (i.e., 1980, 1990, 1995, 2000, and 2005): religiosity has a significant and negative relationship with innovation across countries, and concurrently with "openness to novelty" at the individual level. In this study, we will address a new and equally important relationship—namely, that between openness to novelty and innovation, both as an individual propensity and as an aggregate outcome. One may think the relationship to be positive at any level, and this intuition is consistent with Benabou et al. (2015, 2016).

Inspection of the data, however, reveals a more complex relationship between openness to novelty and innovation across countries. Figure 1 shows that while moderate receptivity correlates positively with innovation (b), there is a significant and negative relationship between innovation and the share of people who recognize themselves as highly receptive to novelty (a). Surprisingly, receptivity to novelty is not always conducive to innovation.[1]

In this study, we propose a new dynamic general equilibrium model that is equipped to explain such a complex relationship between individual-level receptivity and innovation at the aggregate level. We achieve this by introducing a new preference parameter that measures a representative consumer's receptivity to newly invented goods relative to time-tested and traditional commodities that have already been fully introduced into the economy. In doing so, we distinguish two phases of innovation, i.e., the creation of new goods and their diffusion, and embed them into a research and development (R&D)-based growth model (Romer 1990). In line with Mokyr's (2004) findings and many historical events, innovation in our model is a complex process, in which invention and introduction interact with each other.[2] In the present study, we think that innovation does not merely refer to an invention or patent, but its introduction, as a dictionary definition puts it.[3]

Under the dynamic optimization of an infinitely lived consumer, we demonstrate that when consumers' receptivity to novelty is too high or too low, their economy tends to be caught in an underdevelopment trap, in which new goods are invented over time but none of them will be introduced, and ultimately become obsolete along an equilibrium path. As such, there is no innovation in the long run.[4] The intuition behind this result is straightforward: when consumers are averse to novelty, on one hand, the demand for—and profits related to—newly invented goods will be small, and there are almost no new goods to be invented in the marketplace. The cost incurred by firms in finding and introducing a new good becomes high. In equilibrium, thus, only invention occurs, but less actively; there is no innovation in the long run.[5] When, on the other hand, consumers are open to

[1] As shown in Figure (1c), the relationship between weak receptivity and innovation is negative; however, it depends on the measure of weak receptivity. See Appendix C (not for publication) for details.

[2] Benabou et al. (2015) also point out this aspect of innovation.

[3] Dictionaries (e.g., Oxford Advanced Learner's Dictionary) define "innovation" as the introduction of new things and ideas. Since inventions are, by definition, new things, innovation is considered synonymous to their introduction.

[4] The trap here can be regarded as a kind of low-level equilibrium trap (Nelson 1956), because in the present model, no innovation results in zero long-run growth in national income.

[5] Note that we assume that new goods rapidly become obsolete without introduction, while introduced

novelty, the demand for and profits related to newly invented goods are large, relative to introduced goods. In such a scenario, invention is even more profitable than introduction. As a result, the economy tends to be specialized in inventing new goods on an equilibrium path, yielding once again to a lack of innovation. In both cases—that is to say, with too-low or too-high receptivity—the economy is caught in an underdevelopment trap and has no innovation. We formally prove that only those economies with moderate receptivity to novelty can achieve self-sustained innovation and growth in the long run. In such an endogenously growing economy, paths are balanced in a frictionless case (benchmark) in which the elasticity of substitution between consumption goods is equal to 1 and there is no depreciation of knowledge. Otherwise, the economy may perpetually fluctuate between periods where new goods are invented and periods where invented goods are introduced. We formally derive a condition that determines whether the economy stably converges to a unique balanced growth path or the path is perpetually cyclical. Over the cycle, innovation persists, but intermittently. We conclude that innovation may be depressed by too-high or too-low receptivity to novelty on the part of the representative consumer (Figure 1).

Our result suggests a role of governments in innovation to "fix" overly high or overly low receptivity among individuals, and adjust it to a moderate level. In some cases, policies unintentionally affect receptivity to novelty. In the United States, for example, the authority of the Department of Health and Human Services to fund human embryonic stem cell research had been limited by U.S. Presidential actions from 2001 through to 2009. These limitations were removed by U.S. President Barack Obama, in March 2009.[6] The Internet provides another example. Until 1995, the U.S. government restricted the use of the Internet to non commercial purposes. Although the market grew rapidly after deregulation, many market participants had been unwilling to accept the forthcoming policy change when the removal of the restriction was on the table.

In addition to receptivity to novelty, we focus on three other important factors that interact with receptivity to affect innovation and growth. The first is gross substitutability between goods. The mechanism through which the consumer's receptivity affects innovation is at work only when receptivity changes the expenditure share for newly invented goods; it does not work if the elasticity of substitution between goods is equal to 1 (i.e., a Cobb–Douglas case).

The second factor is country size. When a country has a large population, the demand and profit for any firm are larger; this promotes all stages in the innovation spectrum by making both invention and introduction activities more profitable. Thus, larger-sized economies are more likely to achieve perpetual innovation. This is in line with Boserup's (1965) view that population growth triggers the adoption of new technology, since people are forced to adopt new technology when their population becomes too large to be supported by existing technology. It also approximates the empirical finding of Kremer (1993), that total research output increases population, given the idea that a higher population means more potential investors (Kuznets 1960, Simon 1977).

The third factor is knowledge depreciation. If the depreciation rate is zero, our results show that the economy converges to a unique balanced growth path, in which case receptivity has no role. As the rate increases, it becomes more likely that the economy would be caught in an invention trap. This implies that an economy that efficiently archives

goods take root in the economy to contribute to long-run growth.

[6]For details, see Executive Order 13505 of March 9, 2009, titled "Removing Barriers to Responsible Scientific Research Involving Human Stem Cells."

knowledge would presumably succeed in innovation. This can be interpreted in the context of patent policy. An important role of a patent is, as is well known, the detailed public disclosure of an invention (see, e.g., Machlup 1957), which is typically made in exchange for granting monopoly rights to the inventor. Under a well-designed patent system, the depreciation rate should be very low. Our results imply that the enforcement of intellectual property rights would support a society in perpetually achieving innovation, by not only stimulating firm incentives but also disclosing and archiving knowledge.

In the remainder of this section, we will discuss the relevant literature. Individual-level receptivity to novelty is relevant to various fields outside economics. In a psychological study, Cloninger (1986) refers to a human personality trait associated with "exhilaration or excitement in response to novel stimuli" as novelty seeking. Subsequent papers have shown that the degree of novelty seeking varies among countries as well as individuals; see Chandrasekaran and Tellis (2008) and Tellis et al. (2009). The view that the degree of novelty seeking, or openness to novelty, varies has also been considered in fields such as consumer research (Hirschman 1980) and business (Rogers 1962, Rogers and Shoemaker 1971). The present research complements these studies outside economics by formally providing an economic explanation for the relationship between the individual propensity for novelty and macroeconomic innovation.

In economic history, receptivity *at a societal level* is an important concept. Mokyr (1991) writes:[7] "the success of new techniques depends both on the level of inventive activity and the receptivity of the surrounding economy to new ideas." The theory says that if consumers are sufficiently averse or receptive to novelty, that the economy as a whole will not be receptive to new ideas in equilibrium, and thus fail to bring about innovation. This explains why inventions fail to be implemented despite their potential economic superiority; this explanation is also consistent with history (Mokyr 2000).

Showing the possibility of perpetually cyclical innovation, the present study relates to the field of innovation and growth cycles. We follow the literature when we assume that the patent length in a discrete time model is just one period (Shleifer 1986, Deneckere and Judd 1992, Gale 1996, Francois and Shi 1999, Matsuyama 1999, 2001, Yano and Furukawa 2013, Furukawa 2015). In the existing models, the role of receptivity or openness to novelty is not considered; at the same time, our model clearly distinguishes invention and its introduction, both of which are costly investment activities. We contribute to this literature by showing the existence of a new innovation cycle over which invention and introduction alternate along an equilibrium path. This finding is consistent with some historical facts indicating that these two phenomena often take place at different times (e.g., Mokyr 2000).[8]

This study relates closely to a growing body of literature on culture and growth. The

[7] See also Mokyr (1990, 1992, 1999). A good example is Crete's Phaistos Disk in about 1700 B.C. (Diamond 1997), which indicates the early invention of an efficient printing technique, but it received little social acceptance. Being lost for a long time, printing technology was reinvented and widely introduced in Renaissance Europe and then spread worldwide. Even for inventions that will eventually take root in the society, the path from invention to acceptance is far from smooth. Steam engines, invented by Thomas Savery (in 1698) and then by Thomas Newcomen (in 1712), would not have been introduced during the industrial revolution without the genius of James Watt (in 1781). If we borrow a term of business, Watt's activity may be called "incubation." This should not be considered a degraded from of invention; rather, incubation—a result of which is introduction—is as laborious and creative an activity as invention.

[8] Our result is also consistent with the basic understanding in evolutionary biology that when evolutionary systems are overly open to novel things, the result will be chaos (Kauffman 1995).

results of a seminal study by Galor and Moav (2002) show that individual preferences for offspring quality play a role in population growth and human capital formation. Subsequent studies by Ashraf and Galor (2007, 2013a, 2013b, 2017) explore cultural/genetic diversity and regional development at different stages and in different places.[9] From an empirical viewpoint, Tabellini (2010) shows that cultural propensities such as trust have a significant effect on regional per-capita income in Europe. Alesina and Giuliano (2010) examine the effects of family ties on economic performance. In a more growth theoretic approach, Chu (2007) provides the interesting argument that entrepreneurial overconfidence can cause different rates of economic growth across countries. Chu and Cozzi (2011) investigate the effects of cultural preferences for fertility on economic growth. As Yano (2009) points out, the coordination of such cultural factors with laws and rules is indispensable to deriving high quality markets and thereby healthy economic growth. The present study extends this literature by investigating a composition effect of receptivity to novelty, patent protection, and population on long-run economic growth.

In our model, as mentioned, there are two different creative activities—namely, invention and introduction. In this sense, the present study relates to the literature on two-stage innovation models, which distinguishes basic and applied research; see Aghion and Howitt (1996), Michelacci (2003), Akiyama (2009), Cozzi and Galli (2009, 2013, 2014), Acs and Sanders (2012), Chu et al. (2012), Chu and Furukawa (2013), and Konishi (2015). Our study complements these other studies by distinguishing two different processes of applied research (i.e., the invention of a new product and its introduction).

The remainder of this paper is organized as follows. Section II introduces our basic framework and derives equilibrium conditions. Section III characterizes the equilibrium dynamics of the model. Section IV looks at a special case as a benchmark in which the dynamical system has a globally stable balanced growth path. Departing from the benchmark, Section V demonstrates that besides balanced growth, an economy may experience a variety of dynamic phenomena such as traps, cycles, and history dependence. Section VI provides concluding remarks.

2 A Simple Model of Innovation through Invention and Introduction

2.1 Consumption and Receptivity

Time is discrete and extends from 0 to ∞. We think of a dynamic general equilibrium model with an infinitely lived representative consumer, who inelastically supplies L units of labor in each period. The infinitely lived consumer solves the standard dynamic optimization of consumption and saving:

$$\max U = \sum_{t=0}^{\infty} \beta^t \ln u(t), \tag{1}$$

where $\beta \in (0,1)$ is the time preference rate and $u(t)$ is a periodic utility function. As in Grossman and Helpman (1991), periodic utility u is defined over differentiated consumption goods, with each indexed by j. We assume a constant elasticity of substitution

[9] In the "bigger picture," our study also relates to the literature on a unified growth theory that is "designed to capture the complexity of the process of growth and development over the entire course of human history" (Galor 2005).

utility function as

$$u(t) = \left(\int_{j \in A(t) \cup N(t)} \left(\varepsilon(j,t)\ x(j,t) \right)^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}}, \tag{2}$$

where $x(j,t)$ denotes consumption of good j in period t and $\sigma \geq 1$ is the elasticity of substitution between any two consumption goods. The consumption goods are categorized into two types: a "prototype" and a "commodity." Let $N(t)$ be the set of prototypes available in period t and $A(t)$ be the set of commodities. A commodity is a fundamental good defined as a time-tested, complete design that reaches the stage of economy-wide commercial production. The commodity is fully introduced and takes root in the economy, so that it does not become obsolete. For simplicity of description, let $A(t)$ or $N(t)$ also denote the number (measure) of goods.

A prototype is a newly invented design of a good, which has not been fully introduced into the economy. Unlike commodities, it is only transient, and thus it becomes obsolete in one period. Given that "early models perform too poorly to be useful" (Diamond 1997),[10] we suppose that a prototype is not complete, in the sense that it has low quality and utility at its point of birth. In addition, earlier models are often associated with higher production costs.[11] Despite this, consumers prefer prototypes if they are endowed with not only a love of variety but also a love of novelty, so to speak. We incorporate such references to novelty into the model, by means of a weighting function, $\varepsilon(j,t)$, which is specified as

$$\varepsilon(j,t) = \begin{cases} 1 & \text{if} \quad j \in A(t) \text{ (commodities)} \\ \varepsilon & \text{if} \quad j \in N(t) \text{ (prototypes)} \end{cases}. \tag{3}$$

In (3), commodities are heavily weighted with $\varepsilon(j,t) = 1$, while the prototypes are lightly weighted with $\varepsilon(j,t) = \varepsilon$.[12] We interpret the weight to prototypes ε as a measure of how open consumers are to newly invented products that may be of low quality or sell at high prices. We refer to ε as consumer *receptivity to novelty.* If consumers have no receptivity to novelty whatsoever (or, a complete aversion to novelty), it holds that $\varepsilon = 0$, in which case they do not exhibit any preference with regard to prototypes. Consumers with receptivity to novelty (i.e., with $\varepsilon > 0$) will feel some utility for prototypes. If we borrow from a technical term in psychology, we may interpret this preference parameter ε as capturing a consumer's degree of "novelty-seeking," which is a widely accepted concept in various fields. Novelty-seeking is commonly defined as a human personality trait associated with "exhilaration or excitement in response to novel stimuli" (Cloninger 1986). Since consumers in different cultures can have different degrees of novelty-seeking on average (Chandrasekaran and Tellis 2008, Tellis et al. 2009), we may consider ε as an intrinsic parameter on preference that historically and culturally characterizes a society.

Each good j, a commodity or a prototype, is dominated by a monopolistic producer. We consider a one-for-one technology in goods production. Namely, any producer, $j \in A(t)$ or $N(t)$, hires $x(j,t)$ units of labor to produce $x(j,t)$ units of commodity j, and monopolistically sells them to the consumer.

[10] This view is supported by various historical examples; see, for instance, Diamond (1997).

[11] We do not explicitly have within the model this cost aspect of prototypes, because it does not change any equilibrium condition, other than to add an extra parameter that only appears everywhere in the model as a product with some existing parameter.

[12] It would be natural to assume $\varepsilon < 1$. In some cases, however, people may show an unusually strong affinity for novelty, so we allow for ε to be higher than 1, as an extreme case, in which the consumer would always prefer new things, despite their low quality, to old but complete goods. This case may be characterized as so-called neophilia, a tendency to like anything new.

2.2 Innovation through Invention and Introduction

We extend the endogenous process of innovation *à la* Romer (1990) by considering that innovation is the introduction of inventions; in that process, both invention and introduction are endogenous activities that require time and resources.

A potentially infinite number of firms can be involved in the innovation process. Any firm has access to a public stock of knowledge by which it can invent a prototype, which is represented by the set $A(t)$ of existing commodities.[13] As in Romer (1990), creating an invention in period $t+1$ requires an investment of $1/A(t)$ units of labor in period t.

A commodity is, in contrast, a perfect good from which an economy will permanently enjoy high levels of quality and utility. In our view, introducing a commodity is about elevating crude ideas as found in prototypes to the level of perfection, and about compelling consumers to know the utility of the commodity. Investment in introduction covers various activities, including marketing, advertising, lobbying as well as quality improvements. It would be natural to assume that the introduction of a commodity calls for a deeper understanding of the existing commodities than would the invention of a prototype. To obtain such deeper understanding, we believe it is essential to learn from trial-and-error history—which can be formalized as the economy's past experience in the invention of prototypes, since in our model all commodities originally come from prototypes. The introduction of a commodity thus requires extended knowledge, denoted as $K(t)$, which is a composite of public knowledge of existing commodities and of the history behind them.

We assume that only a few select firms have access to this composite, $K(t)$. We call these firms "incubators," for the reason mentioned above,[14] and we normalize their population to 1.[15] An incubator indexed by ω first invests $m(\omega,t)$ units of labor to review its knowledge $K(t)$; then, it can introduce $\rho(\omega,t+1)K(t)$ units of commodities in period $t+1$, thus earning monopolistic profits. We consider a linear technology, $\rho(\omega,t+1) \equiv \kappa m(\omega,t)$. The parameter κ represents the incubator's productivity.[16] When this happens, we say that the economy accepts a commodity as a product that fully takes root, which brings about "innovation."

The law of motion governing the growth of public knowledge (i.e., the commodities) $A(t)$ is given by

$$A(t+1) - A(t) = \int_0^1 \rho(\omega,t+1)K(t)d\omega. \tag{4}$$

None of the public knowledge becomes obsolete since commodities, by definition, fully take root in the economy.[17] Meanwhile, the incubators' private knowledge $K(t)$ includes

[13]We think that public knowledge does not include prototypes, since they are incomplete, of low quality, and transient. Nevertheless, even if we allow for prototypes $N(t)$ in public knowledge, the main results will not change qualitatively.

[14]See footnote 7.

[15]We can see that the incubators of measure 1 are randomly chosen in each period from an infinite number of potential firms. Otherwise, if we consider that the incubators are chosen in the initial period, the equilibrium conditions will not change at all.

[16]From a broader perspective, this can relate to firms' absorptive capacity (Cohen and Levinthal 1989). In order to have balanced growth in a benchmark case (which we will consider in Section 4), we assume that the incubators' productivity is sufficiently high to satisfy $\kappa > 1$; additionally, the potential resource for incubators is also high, to satisfy $\kappa L > \Lambda_+$. Here, Λ_+ is a parameter composite, and the formal definition appears in Appendix A. While this assumption seems overly restrictive, it is burdensome but straightforward to extend the analysis in later sections for the case of $\kappa L \le \Lambda_+$.

[17]We could allow for some small depreciation for $A(t)$, without rendering any essential change to the

not only knowledge on commodities $A(t)$ but also that on past prototypes that have ceased to exist. Newly created prototypes, $N(t)$, as well as the increment of public knowledge, $A(t+1)-A(t)$, contribute to the growth of $K(t)$. We also assume that some fraction of $K(t)$, $\delta K(t)$, becomes supplanted or depreciates, due to the emergence of new ideas. We thus express the evolution of $K(t)$ by the following equation.

$$K(t+1)-K(t)=N(t+1)+\int_0^1 \rho(\omega,t+1)K(t)d\omega-\delta K(t). \tag{5}$$

Since the incubators are symmetric, $m(\omega,t)\equiv m(t)$ and $\rho(\omega,t)=\rho(t)$ hold for any $\omega\in[0,1]$ in equilibrium. Here, $\rho(t)$ is equal to a macroeconomic rate at which commodities are accepted in the society from period t to $t+1$. Unlike consumer receptivity ε as a preference parameter, one may interpret $\rho(t)$ as an equilibrium rate of receptivity at the aggregate level.

2.3 Market Equilibrium

The infinitely lived consumer solves static optimization in (1); as is well known, we have the demand functions as

$$x(j,t)=\varepsilon(j,t)^{\sigma-1}\frac{E(t)p(j,t)^{-\sigma}}{P(t)^{1-\sigma}}, \tag{6}$$

where $E(t)\equiv\int_{j\in A(t)\cup N(t)}p(j,t)x(j,t)dj$ is the spending on differentiated goods, $p(j,t)$ denotes the price of good j in period t, and $P(t)$ is the usual price index, defined as

$$P(t)\equiv\left(\int_{j\in A(t)\cup N(t)}(p(j,t)/\varepsilon(j,t))^{1-\sigma}dj\right)^{\frac{1}{1-\sigma}}. \tag{7}$$

Solving dynamic optimization, we also obtain the Euler equation:

$$\frac{E(t+1)}{E(t)}=\beta(1+r(t)), \tag{8}$$

where $r(t)$ stands for the interest rate.

Assume that producing one unit of goods requires one unit of labor, and so the marginal cost is equal to the wage rate, $w(t)$. By (6), the consumption good producers, $j\in A(t)\cup N(t)$, face a constant price elasticity of market demand, equal to $\sigma\geq 1$. The unconstrained mark-up for a monopolistic producer is $\sigma/(\sigma-1)>1$. To allow for a Cobb-Douglas case with $\sigma=1$, we follow Li (2001), Goh and Olivier (2002), and Iwaisako and Futagami (2013) and introduce an upper bound of the mark-up—say, $\mu>1$—by considering potential imitators whose production cost increases with so-called patent breadth.[18] The breadth of a patent is identified with "the flow rate of profit available to the patentee" and often interpreted as "the ability of the patentee to raise price" (Gilbert and Shapiro 1990). Following the literature, we regard μ as the breadth of a patent and assume $\mu<\sigma/(\sigma-1)$.[19] Each firm thus sets a monopolistic price at

$$p(j,t)=\mu w(t) \tag{9}$$

result.

[18] See, for example, Chu et al. (2016) for a more recent examination.

[19] The upper bound of a mark-up, μ, can also be seen as a result of price regulation (Evans et al. 2003).

for all j. Using (3), (6), and (9), the output and monopolistic profit for a prototype firm are given by

$$x(j,t)=\frac{\varepsilon^{\sigma-1}E(t)}{P(t)^{1-\sigma}}\left(\mu w(t)\right)^{-\sigma}\equiv x^{n}(t)\text{ for }j\in N(t)\tag{10}$$

and

$$\pi(j,t)=\varepsilon^{\sigma-1}\frac{\mu-1}{\mu^{\sigma}}E(t)\left(\frac{w(t)}{P(t)}\right)^{1-\sigma}\equiv\pi^{n}(t)\text{ for }j\in N(t).\tag{11}$$

Equation (11) shows that the profit for a prototype, $\pi^n(t)$, increases with consumer receptivity ε and the total expenditure $E(t)$, and decreases with the real wage, $w(t)/P(t)$.

We follow Shleifer (1986), Deneckere and Judd (1992), Gale (1996), Francois and Shi (1999), Matsuyama (1999, 2001), and Furukawa (2015) by assuming that the monopolistic firm earns a profit only for one period. The one-period monopoly has also been used in a different context (e.g., in the field of directed technical change and the environment) (see Acemoglu et al. 2012). Therefore, the firm inventing a prototype j enjoys only a one-period monopoly. The discounted present value of creating a new prototype can be written as

$$W^{n}(t)\equiv\frac{\pi^{n}(t+1)}{1+r(t)}-\frac{w(t)}{A(t)}.\tag{12}$$

We also follow Acemoglu et al. (2012) by assuming that, after one period, monopoly rights will then be allocated randomly to a firm drawn from the pool of potential monopolistic firms. Consequently, in our model, goods are all monopolistically competitively produced in equilibrium. Alternatively, we could also proceed in such a way that goods with expired patents are sold at a perfectly competitive price (e.g., Matsuyama 1999) or become obsolete (e.g., Furukawa 2015). However, we understand that either will complicate the analysis without garnering any new insights. Although it could be an interesting extension, we keep the analysis as simple as possible to highlight the main issue discussed in the introduction.

Analogous to the case of a prototype, $j\in N(t)$, by (3), (6), and (9), the output and monopolistic profit for a commodity producer are given by

$$x(j,t)=\frac{E(t)}{P(t)^{1-\sigma}}\left(\mu w(t)\right)^{-\sigma}\equiv x^{a}(t)\text{ for }j\in A(t)\tag{13}$$

and

$$\pi(j,t)=\frac{\mu-1}{\mu^{\sigma}}E(t)\left(\frac{w(t)}{P(t)}\right)^{1-\sigma}\equiv\pi^{a}(t)\text{ for }j\in A(t),\tag{14}$$

respectively. The profit associated with a commodity increases with the expenditure, $E(t)$, and decreases with the real wage, $w(t)/P(t)$. Given the one-period patent protection, the incubator's expected value is expressed as

$$W^{a}(t)\equiv\rho(\omega,t+1)K(t)\frac{\pi^{a}(t+1)}{1+r(t)}-w(t)m(\omega,t).\tag{15}$$

As shown in (11) and (14), the real wage $w(t)/P(t)$ is an important component of the profits. It is thus beneficial to have

$$\frac{w(t)}{P(t)}=\frac{1}{\mu}\left[A(t)+\varepsilon^{\sigma-1}N(t)\right]^{\frac{1}{\sigma-1}},\tag{16}$$

which uses $p(j,t) = \mu w(t)$ for any $j \in A(t) \cup N(t)$ with (7).

Under free entry of firms into invention and introduction, the present value of their payoff must be equal to or less than 0:

$$W^n(t) \leq 0 \text{ and } W^a(t) \leq 0. \tag{17}$$

for any $t \geq 0$. The labor market clearing condition is

$$L = \underbrace{\int_{j \in A(t) \cup N(t)} x(j,t) dj}_{\text{production}} + \underbrace{\int_0^1 m(\omega, t) d\omega}_{\text{introduction}} + \underbrace{\frac{N(t+1)}{A(t)}}_{\text{invention}}. \tag{18}$$

From (10), (13), (16), and (18),[20] the labor demand from the production sector is calculated as

$$\int_{j \in A(t) \cup N(t)} x(j,t) dj = \frac{1}{\mu} \frac{E(t)}{w(t)}. \tag{19}$$

3 Equilibrium Dynamics

We are now ready to derive the dynamic system that characterizes the law of motion that determines the equilibrium trajectory of the economy. In doing this, it is beneficial to define $k(t) \equiv K(t)/A(t)$, which is the ratio of the incubator's private knowledge to public knowledge. The equilibrium dynamics can be completely characterized by means of this knowledge ratio. By the free entry conditions in (17), with (11), (12), (14), and (15), we derive the following lemma.

Lemma 1 *Only the invention of a prototype takes place in equilibrium when $k(t) < \varepsilon^{\sigma-1}/\kappa$. Only the introduction of a commodity takes place when $k(t) > \varepsilon^{\sigma-1}/\kappa$.*

The cut-off level of $k(t)$, $\varepsilon^{\sigma-1}/\kappa$, generates two equilibrium regimes in the economy. The first corresponds to $k(t) \in (0, \varepsilon^{\sigma-1}/\kappa)$, which we call an invention regime; there, only invention takes place. The second regime corresponds to $k(t) \in (\varepsilon^{\sigma-1}/\kappa, \infty)$, which we call an introduction regime; there, only the introduction of commodities takes place. At the cut-off point, the economy does both activities; however, we can ignore it, since the point has zero measure.

As shown in Lemma 1, a kind of specialization takes place in the present model. In reality, any economy appears to be engaged in both invention and introduction, more or less, at any point of time. Therefore, this model captures only a certain aspect of real-world behavior—that is, the economy invests in either invention or introduction. We can easily remove this unrealistic aspect concerning specialization from the model by assuming, for instance, a strictly concave function in invention and introduction. As this would provide a deeper analysis but make the analysis intractable, we adopt the present setting for simplicity, given that it is among the first to address the relationship between receptivity to novelty ε and underdevelopment traps.

[20] Noting (10) and (13), with (16), we have

$$\int_{j \in A(t) \cup N(t)} x(j,t) dj = N(t) x^n(t) + A(t) x^a(t) = \frac{1}{\mu} \frac{E(t)}{w(t)}.$$

Lemma 1 reveals that an economy is engaged in invention activity in equilibrium only if $k(t)$ is relatively small (i.e., if the incubators can have access to less knowledge, $K(t)$, which is necessary for the introduction of a commodity) relative to the public knowledge stock, $A(t)$, which does not help commodity creation. This is intuitive. If the economy has a sufficient amount of commodities $A(t)$, on one hand, people do not want more commodities, due to the law of diminishing marginal utility. On the other hand, as $k(t)$ is lower, the incubators will not have enough ideas for commodity introduction and, as a result, prototype invention will become relatively profitable. In the opposite case, in which $k(t)$ is relatively large, the economy is only engaged in introduction in equilibrium, for the analogous reason. Naturally, the cut-off level of $k(t)$ under which the economy specializes in invention is higher when the consumer's receptivity to novelty ε is higher. This is because the consumer with a higher ε relatively prefers prototypes to commodities, which results in a higher relative profit for the invention of a prototype. The cut-off also increases when the incubator's productivity is higher, which rather increases the profit associated with introducing commodities.

Invention Regime:
With $k(t) < \varepsilon^{\sigma-1}/\kappa$, the economy falls in the invention regime. With (8), (12), (11), and (16), the free entry condition for invention, $W^n(t) = 0$, becomes

$$N(t+1) = \frac{A(t)}{\varepsilon^{\sigma-1}} \left[\frac{\beta\varepsilon^{\sigma-1}}{\mu/(\mu-1)} \frac{E(t)}{w(t)} - 1 \right], \tag{20}$$

which uses $A(t+1) = A(t)$. Given $A(t)$, this describes a profit-motive aspect of the inventive activity; the larger the discounted profit from selling prototypes $((\beta\varepsilon^{\sigma-1}(\mu - 1)/\mu)E(t)/w(t))$, the greater the incentives are for firms to invent a prototype. The profit for a prototype is larger as the wage-adjusted expenditure $E(t)/w(t)$ becomes larger and, at the same time, as the consumer's receptivity to novelty ε becomes larger. With a larger stock of public knowledge, the cost of inventing a prototype decreases and the firms have greater incentives for invention. Meanwhile, when $k(t) < \varepsilon^{\sigma-1}/\kappa$, no incubator has any incentive to invest in equilibrium; in such a case, $m(\omega, t) = 0$ for all ω. The labor market condition (18) thus becomes

$$N(t+1) = A(t) \left[L - \frac{1}{\mu} \frac{E(t)}{w(t)} \right], \tag{21}$$

which uses (19). Given $A(t)$, the greater the wage-adjusted expenditure $E(t)/w(t)$, the more resources will be devoted to production, leaving less for prototype invention; this will result in a smaller $N(t+1)$.

Figure 2 depicts (20) and (21), labeled with FE and LE respectively, which determine the equilibrium number of invented prototypes, $N(t+1)$, and the wage-adjusted expenditure $E(t)/w(t)$ as a unique intersection. Looking at this figure, we can see that some standard properties hold in the present model. Given the predetermined variable, $A(t)$, the equilibrium number of invented prototypes $N(t+1)$ is increasing in the time preference rate β, the labor force L, and the patent breadth μ. Given these parameters, the invented prototype $N(t+1)$ is increasing in the public knowledge stock $A(t)$.

The effect of the elasticity of substitution between goods, σ, is more interesting. As is standard, σ determines the expenditure share spent on each good. If prototypes are preferable to commodities ($\varepsilon > 1$), a higher elasticity of substitution would lead to a higher expenditure share for the prototype, resulting in an upward shift of the FE curve in Figure 2. If commodities are preferable ($\varepsilon < 1$), there would be a lower expenditure share for the prototype, resulting in a downward shift of the FE curve. When $\sigma = 1$ (i.e., the case of a Cobb–Douglas preference), any expenditure share is always constant and free from receptivity to novelty ε. As a result, the invented prototype $N(t+1)$ is increasing (decreasing) in the elasticity of substitution σ in an economy with a strong (weak) preference for the prototype $\varepsilon > 1$ ($\varepsilon < 1$).

As for the receptivity to novelty ε, a higher ε provides an upward shift in the FE curve. This is simply because the equilibrium profit for prototypes, $(\beta\varepsilon^{\sigma-1}/\sigma)E(t)/w(t)$, is higher.[21] The upward shift of the FE curve leads to an increase in $N(t+1)$ in equilibrium. We can formally confirm this effect of ε by solving (20) and (21):

$$N(t+1) = \Theta A(t), \tag{22}$$

where

$$\Theta \equiv \frac{\varepsilon^{\sigma-1}(\mu-1)L - 1/\beta}{\varepsilon^{\sigma-1}\left((\mu-1)+1/\beta\right)}. \tag{23}$$

The coefficient Θ is increasing in the receptivity to novelty ε as well as the standard parameters β, L, and μ. We can interpret the parameter composite Θ as the potential demand for prototypes. We assume $\Theta > 0$ to allow for positive growth, i.e., $N(t+1) > 0$, by imposing $\varepsilon^{\sigma-1}(\mu-1)L - 1/\beta > 0$, which gives a lower bound of $\varepsilon^{\sigma-1}$ as $1/(\beta(\mu-1)L) \equiv \varepsilon_0$. Since $m(t) = 0$ and thus $\rho(t+1) = 0$ in the invention regime, from (4), (5), and (22), we obtain the equilibrium dynamic system for the invention regime as

$$k(t+1) = (1-\delta)\,k(t) + \Theta, \tag{24}$$

which as a unique fixed point $k^* \equiv \Theta/\delta$.

Introduction Regime:

With $k(t) > \varepsilon^{\sigma-1}/\kappa$, the economy is in the introduction regime in period t; $m(t) \geq 0$ and $N(t+1) = 0$. Rearranging the labor market condition (18), with the incubator's factor demand function, $m(\omega,t) = \rho(t+1)/\kappa$, and (19), yields the economy's equilibrium rate of receptivity as

$$\rho(t+1) = \kappa\left(L - \frac{1}{\mu}\frac{E(t)}{w(t)}\right). \tag{25}$$

Analogous to (21), (25) captures the trade-off on resources between the production of goods and the investment in introduction by the incubators. With (8), (15), and (14), the perfect competition condition for introduction, $W^a(t) = 0$, becomes

$$\rho(t+1) = \frac{\kappa\beta}{\mu/(\mu-1)}\frac{E(t)}{w(t)} - \frac{A(t)}{K(t)}, \tag{26}$$

which uses $N(t+1) = 0$ and $A(t+1) = A(t) + K(t)\rho(t+1)$ from (4). Naturally, the equilibrium rate $\rho(t+1)$ of receptivity at the aggregate level increases with the discounted profit from producing the commodity $(\beta(\mu-1)/\mu)E(t)/w(t)$; note that $\rho(t+1)$ is equal to a rate at which commodities are introduced in the economy. In addition, $\rho(t+1)$ decreases with the commodity stock $A(t)$, since the profit is lower when the economy has sufficient commodities. It increases with the ideas to which the incubator has access, $K(t)$, since it makes introduction more profitable.

[21] See also (11).

Figure 3 illustrates how the equilibrium rate of receptivity $\rho(t+1)$ is determined by (25) and (26). Solving (25) and (26), we obtain

$$\rho(t+1)=\frac{\beta\,(\mu-1)\,\kappa L}{1+\beta\,(\mu-1)}-\frac{1}{1+\beta\,(\mu-1)}\frac{A(t)}{K(t)}.^{22} \tag{27}$$

Using (4), (5), and (27), we can derive the equilibrium law of motion for the introduction regime. The global dynamics can be summarized as follows.

$$k(t+1)=\begin{cases}(1-\delta)\,k(t)+\Theta\equiv f^N(k(t)) & \text{for } k(t)<\varepsilon^{\sigma-1}/\kappa\\ \frac{(\psi+\kappa L)k(t)-1/(\beta(\mu-1))}{\kappa Lk(t)+1}\equiv f^A(k(t)) & \text{for } k(t)>\varepsilon^{\sigma-1}/\kappa\end{cases}, \tag{28}$$

where $\psi\equiv(1-\delta)\,(1+1/(\beta(\mu-1)))$. Note that f^N is linear and increasing in $k(t)$ with a positive y-intercept and f^A is increasing and concave in $k(t)$ with a strictly negative y-intercept. Since each regime can have a steady state, there is the possibility of multiple steady states in the system (28). Denote as $k^*\equiv\Theta/\delta$ a unique steady state for the invention regime; also denote two possible steady states for the introduction regime as k_-^{**} and k_+^{**}.[23]

4 A Benchmark: Monotone Convergence and Balanced Growth

In this section, we present a special case, in which an economy with any level of receptivity ε permanently grows along an equilibrium path for any initial condition, due to the absence of knowledge depreciation and a unit elasticity of substitution between goods. This case provides us with a convenient benchmark from which we depart in identifying the role of the consumer's preference to new inventions in self-sustained growth. With $\delta=0$ and $\sigma=1$, the system (28) converges to

$$k(t+1)=\begin{cases}k(t)+\frac{L-1/(\beta(\mu-1))}{1+1/(\beta(\mu-1))} & \text{for } k(t)<1/\kappa\\ \left(1+\frac{1}{\beta(\mu-1)}\right)\frac{k(t)-1}{\kappa Lk(t)+1}+1 & \text{for } k(t)>1/\kappa\end{cases}. \tag{29}$$

Figure 4 illustrates a typical phase diagram for this system.[24] As in the standard growth model, there is no equilibrium trap, and any equilibrium path converges to a unique balanced growth path, k_+^{**}. In this special case, we can state that independent of ε, any economy will be receptive along an equilibrium path, by which it achieves self-sustained innovation, i.e., the introduction of commodities, in the long run. The consumer's receptivity to novelty ε has no role; this is partially because, in the present case, the preference parameter ε does not affect demands and profits, as $\sigma=1$ (i.e., the expenditure share of the consumer for prototypes is constant with the Cobb–Douglas preference). Another reason is that the growth path is monotonically increasing in the invention regime, since no knowledge depreciates or is supplanted (i.e., $\delta=0$).

[22] Note that $\rho(t+1)>0$ always holds since $k(t)>\varepsilon^{\sigma-1}/\kappa$ and the condition for positive growth, i.e., $\varepsilon^{\sigma-1}(\mu-1)L-1/\beta>0$.

[23] Obviously, $z=f^N(z)$ has a unique solution, k^*, for $z>0$ unless $\delta=0$. Owing to the assumption of $\kappa L>\Lambda_+$, $z=f^A(z)$ has two fixed points, k_-^{**} and k_+^{**}, for $z>0$. See Appendix A for details.

[24] In this case, we can verify that $k_-^{**}=(\beta(\mu-1)\kappa L)^{-1}<1/\kappa$ and $k_+^{**}=1>1/\kappa$, noting $\kappa>1$ and the condition for positive growth, i.e., $(\mu-1)L-1/\beta>0$.

Remark 1 *The consumer's receptivity to novelty ε has no role in equilibrium if consumption goods are independent goods (i.e., $\sigma = 1$) and, at the same time, knowledge does not depreciate over time (i.e., $\delta = 0$). In this benchmark case, independent of ε, the economy monotonically converges to a unique balanced growth path.*

5 Invention Traps and Innovation Cycles

In this section, we depart from the benchmark to characterize the role of ε in innovation, by assuming substitutability, i.e., $\sigma > 1$, and knowledge depreciation, i.e., $\delta > 0$. First, let us consider the case where $\Theta < \varepsilon^{\sigma-1}(\delta/\kappa)$. In other words, the economy's inventive potential Θ is relatively small and, at the same time, the consumer's receptivity to novelty ε is relatively high. On the one hand, the invention regime is larger due to a high ε. On the other hand, the invention flow $N(t)$ within the regime tends to be small, due to a low Θ. Figure 5 illustrates three possible phase diagrams for the system (28). In all cases, due to $\Theta < \varepsilon^{\sigma-1}(\delta/\kappa)$, there is a unique steady state, k^*, in the invention regime. This results in an equilibrium trap, in that any path $\{k(t)\}$ starting from the invention regime, $(0, \Theta/\delta)$, converges to k^*. The economy is therefore trapped in the invention regime in the long run. Any trapped economy invents prototypes that soon become obsolete, but never introduces any of them on an equilibrium path. As we show later, in this case, innovation—defined as the introduction of inventions—does not exist, and there is no self-sustained growth. We may call this situation an "invention trap."

More specifically, Figure 5 illustrates three cases, with $k_+^{**} < \varepsilon^{\sigma-1}(\delta/\kappa)$ (Figure 5A), $k_-^{**} < \varepsilon^{\sigma-1}(\delta/\kappa) < k_+^{**}$ (Figure 5B), and $\varepsilon^{\sigma-1}(\delta/\kappa) < k_-^{**}$ (Figure 5C). The invention trap may be local or global. In Figure 5A, the steady state k^* is globally stable, so that the economy is fatally caught in an invention trap for any initial condition.

In Figure 5B, there are two steady states, and both are locally stable. The lower steady state k^* is an invention trap, and the higher steady state k_+^{**} corresponds to a balanced growth path. As with the benchmark, the economy achieves self-sustained growth on the balanced growth path. Which steady state the economy heads towards depends entirely on the initial condition. If the economy starts with a lower $k(t)$ (i.e., the incubators' knowledge is scarce, relative to public knowledge), it will converge to the invention trap k^*. If it starts with higher $k(t)$, it converges to the balanced growth path, k_+^{**}. The threshold of $k(t)$, $\varepsilon^{\sigma-1}(\delta/\kappa)$, is critical in determining whether the economy will be trapped or perpetually grow. Since k^*, k_-^{**}, and k_+^{**} are all free from ε, the receptivity to novelty ε can be seen as a parameter essential to economic development.

In Figure 5C, there are three steady states. The lowest steady state, k^*, is locally stable and implies an invention trap. The middle steady state, k_-^{**}, is located in the introduction regime; in this steady state, the incubators' relative knowledge $k(t)$ is so large that both invention and introduction takes place in equilibrium, but there is local instability. The highest steady state, k_+^{**}, is a balanced growth path, and it is locally stable. Therefore, k_-^{**}, rather than $\varepsilon^{\sigma-1}(\delta/\kappa)$, is the critical threshold level of $k(t)$ for economic development.

We can now conclude that the economy can be caught in an invention trap—in which it invents prototypes but fails to bring about self-sustained growth—if

$$\Theta < \varepsilon^{\sigma-1}(\delta/\kappa) \tag{30}$$

holds. Given that the invention potential Θ is a function in ε, there will be a mixed role of ε, under the assumption of $\sigma > 1$ (see Remark 1). If the receptivity to novelty ε is high, on one hand, the consumer will prefer prototypes to commodities. With this effect, the invention of prototypes becomes more profitable than the introduction of commodities, and so the invention regime will become large (i.e., the threshold $\varepsilon^{\sigma-1}$ becomes large). This will make the economy more likely to get caught in the invention trap. On the other hand, a higher ε results in a higher Θ. This means that the potential demand for prototypes Θ is large, as the consumer likes prototypes. This increase in Θ is accompanied by an increase in the prototypes $N(t)$. The incubators' knowledge $K(t)$ grows more rapidly. With this effect of ε, the left-hand side of (30) increases, and the economy is less likely to be trapped. These two opposite effects interact to create an ambiguous role for the receptivity to novelty ε. To see which effect dominates, we will have the following lemma, recalling the lower bound of ε, $\varepsilon > \varepsilon_0 \equiv [1/(\beta(\mu-1)L)]^{1/(\sigma-1)}$.

Lemma 2 *If*

$$L < 2\sqrt{\frac{\delta}{\kappa}\left(1+\frac{1}{\beta\,(\mu-1)}\right)\frac{1}{\beta\,(\mu-1)}} \equiv L_0, \tag{31}$$

(30) holds for any $\varepsilon > \varepsilon_0$. Otherwise, there exist $\varepsilon_+ \geq \varepsilon_- > \varepsilon_0$ such that (30) holds if and only if $\varepsilon \notin [\varepsilon_-, \varepsilon_+]$.

Proof. Rewriting (30), we obtain

$$F(\varepsilon^{\sigma-1}) \equiv \frac{\delta}{\kappa}\left(1+\frac{1}{\beta\,(\mu-1)}\right)\left(\varepsilon^{\sigma-1}\right)^2 - L\varepsilon^{\sigma-1} + \frac{1}{\beta\,(\mu-1)} > 0, \tag{32}$$

which is a second-order polynomial inequality in terms of $\varepsilon^{\sigma-1}$. Since the leading coefficient is positive, this inequality is always true if the discriminant is negative—that is to say,

$$D := L^2 - \frac{4\delta/\kappa}{\beta\,(\mu-1)}\left(1+\frac{1}{\beta\,(\mu-1)}\right) < 0,$$

which is equivalent to (31). For $D \geq 0$, let

$$\varepsilon_-^{\sigma-1} = \frac{L-\sqrt{D}}{2(\delta/\kappa)(1+1/(\beta(\sigma-1)))}, \quad \varepsilon_+^{\sigma-1} = \frac{L+\sqrt{D}}{2(\delta/\kappa)(1+1/(\beta(\sigma-1)))}. \tag{33}$$

For any $\varepsilon^{\sigma-1}$ between $\varepsilon_-^{\sigma-1}$ and $\varepsilon_+^{\sigma-1}$ or at one of them, the left-hand side of (32), i.e., $F(\varepsilon^{\sigma-1})$, is nonpositive, and otherwise it is positive. Finally, to show $\varepsilon_- > \varepsilon_0$, let us suppose $\varepsilon_0^{\sigma-1} \geq \varepsilon_-^{\sigma-1}$; then, $\varepsilon_0^{\sigma-1} > \varepsilon_+^{\sigma-1}$ must hold, because $F(\varepsilon_0^{\sigma-1}) = (\delta/\kappa)\,(1+1/(\beta(\mu-1)))\,((\sigma-1)/(\beta L(\mu-1)))^2$ is strictly positive.[25] Taking, for instance, $\varepsilon^{\sigma-1} = \varepsilon_1^{\sigma-1} \equiv 2/(\beta L(\mu-1)) > \varepsilon_0^{\sigma-1}$, $F(\varepsilon_1^{\sigma-1}) > 0$ must also hold, since $\varepsilon_1^{\sigma-1} > \varepsilon_0^{\sigma-1} > \varepsilon_+^{\sigma-1}$. However, by substituting $\varepsilon^{\sigma-1} = \varepsilon_1^{\sigma-1}$ into (32), we verify that $F(\varepsilon_1^{\sigma-1}) > 0$ can hold only for $D < 0$, and this contradicts $D \geq 0$. ■

Lemma 2 implies that the economy will become fatally trapped in the invention regime if the country size, L, is too small; this clarifies an essential role of the so-called scale effect within the model. While the existence of a scale effect has been empirically rejected

[25] Potentially, because of $F(\varepsilon_0) > 0$, either $\min\{\varepsilon_-, \varepsilon_+\} > \varepsilon_0$ or $\max\{\varepsilon_-, \varepsilon_+\} < \varepsilon_0$ necessarily holds, given that the leading coefficient of $F(\varepsilon^{\sigma-1})$ is positive.

from a long-run perspective by using 100 years of data (Jones 1995), it might play a role in world development in the *very* long run, such as in terms of millennia (Boserup 1965, Kremer 1993). Consistent with this view, Lemma 2 shows that population size affects innovation and growth in the long run. The threshold level of L in (31), L_0, comprises several parameters. Since, for instance, L_0 increases with δ, equilibrium traps are more likely to emerge as the rate of knowledge depreciation δ grows. The incubators' productivity κ negatively affects L_0, so that the productivity of incubators has a role in avoiding traps. These facts are natural and intuitive. In the remainder of this paper, to focus on receptivity ε, we restrict analyses to the case with $L \geq L_0$.

An important implication of Lemma 2 is that only an economy with moderate receptivity to novelty ε, such as $\varepsilon \in [\varepsilon_-, \varepsilon_+]$, can avoid falling into traps. In other words, if consumers' preferences for new prototypes are too strong or too weak, the economy can be caught in an invention trap. That is, $\varepsilon \notin [\varepsilon_-, \varepsilon_+]$ is the trap condition. This nonlinear effect comes from the interaction between the two opposite roles of ε. When the consumer hardly appreciates prototypes, and there is therefore a very low ε, the potential demand for prototypes Θ is also too small for $K(t)$ to grow faster. When the consumer extremely appreciates prototypes, with a very high ε, the investment in prototypes is very profitable, making the threshold $\varepsilon^{\sigma-1}/\kappa$ much higher. With this high $\varepsilon^{\sigma-1}/\kappa$, the economy can scarcely emerge from such a large invention regime. These two forces interact with each other to create the nonlinear effect of ε. Specifically, noting that k_-^{**} and k_+^{**} are independent of ε (see Appendix A), the trap is globally stable for a too-large ε and only locally stable for a too-small ε. In the latter case, whether the economy converges to a balanced growth path or an invention trap depends on the initial condition. There is a so-called path dependence, implying that the economy may suffer from a lock-in by virtue of historical events (e.g., Arthur 1989).

Proposition 1 (Extreme Receptivity Causes Underdevelopment Traps) *When the infinitely lived consumer's receptivity to novelty, ε, is sufficiently low or high, such that $\varepsilon \notin [\varepsilon_-, \varepsilon_+]$, there is a globally or locally stable equilibrium trap, k^*, as shown in Figure 5. If the trap is globally stable, the economy necessarily converges to the situation in which invention occurs, but there is no innovation in the long run. If it is locally stable, lock-in may occur due to the presence of path dependence.*

Proposition 1 implies that not only the "fear of novelty" (Beveridge 1959, Barber 1961) but also a love of novelty may cause an economy to fall into an underdevelopment trap. Together with Remark 1, this critical effect of consumer receptivity to novelty ε appears only when consumption goods are gross substitutes and the knowledge more or less depreciates over time. Intuitively, given that prototypes and commodities are substitutes ($\sigma > 1$), a consumer with a weak preference for prototypes (low ε) and who suffers from a fear of novelty will have a small demand for prototypes, which are the origins of commodities. This effect discourages an absolute amount of invented prototypes $N(t)$, causing the economy to be more likely to be caught in the invention regime. Meanwhile, there is another relative effect of low ε, where inventing a prototype becomes less profitable than introducing commodities; such circumstances would shrink the invention regime itself (i.e., a lower threshold $\varepsilon^{\sigma-1}/\kappa$). This causes the economy to be less likely to be caught in the invention regime. As shown in Proposition 1, these two opposite effects interact with each other to generate the nonlinear effect of the receptivity to novelty ε. On one hand, if preferences for prototypes ε are sufficiently weak, our result shows that the former absolute effect dominates—that is, the invention of prototypes ($N(t)$) is too slow to increase the relative knowledge for introduction, $K(t)/A(t)$, to a level over the threshold, $\varepsilon^{\sigma-1}/\kappa$, due to the presence of an outflow of $K(t)$ (i.e., knowledge depreciation ($\delta > 0$)). On the other hand, if a consumer with a strong preference for prototypes (high ε), with a love of novelty, the latter relative effect dominates. The invention of prototypes $N(t)$ is rapid due to the former effect, but the invention regime, $(0, \varepsilon^{\sigma-1}/\kappa)$, is large, due to the latter effect. As in the case of a small ε, therefore, the economy tends to be trapped in the invention regime. Consequently, both too much fear and too much love of novelty can generate a stable underdevelopment trap in equilibrium.

What if the receptivity to novelty ε were moderate, such that (30) is violated? Figure 6 depicts two representative cases. For $\varepsilon \in [\varepsilon_-, \varepsilon_+]$, the invention regime is always explosive, so that any path starting from initial values lower than $\varepsilon^{\sigma-1}/\kappa$ will eventually move towards the introduction regime. After that, if $k_-^{**} < \varepsilon^{\sigma-1}(\delta/\kappa) < k_+^{**}$, the economy will converge to a unique balanced growth path for any initial condition (Figure 6A), as in a benchmark case. If $k_+^{**} < \varepsilon^{\sigma-1}(\delta/\kappa)$ (Figure 6B), there is no steady state in the introduction regime, either; a path starting from almost any initial point will be cyclical. The economy perpetually fluctuates, moving back and forth between invention and introduction regimes. We may interpret this as an innovation cycle, in the sense that innovation takes place only in the introduction regime.[26] We summarize this finding as a proposition.

Proposition 2 (Moderate Receptivity Supports Perpetual Innovation) *When the infinitely lived consumer's receptivity to novelty, ε, is moderate, such that $\varepsilon \in [\varepsilon_-, \varepsilon_+]$, the economy necessarily avoids traps and achieves perpetual innovation.*

In Propositions 1 and 2, we demonstrate that an economy with too much receptivity or aversion to novelty becomes caught in an underdevelopment trap, where there is only invention, and no innovation takes place. Only an economy with moderate receptivity to novelty ε can achieve self-sustained innovation. The path may be balanced in the long run or be perpetually cyclical. The cyclical case, in which invention and introduction alternate over time, seems consistent with history, where invention and introduction often take place in different times (e.g., steam engines, the internet). The critical role of receptivity to novelty appears only if prototypes and commodities are gross substitutes and knowledge can depreciate over time.

Finally, we verify that in our model, innovation as the introduction of commodities is the only engine of long-run growth. To proceed, we follow the standard definition of an "economic growth rate": $\gamma(t) \equiv (u(t+1) - u(t))/u(t)$. By using (2), (10), (13), and (16), we have $u(t) = \tilde{\mu}(t)A(t)^{\frac{1}{\sigma-1}}$, where $\tilde{\mu}(t) = (E(t)/w(t))\ (1 + \varepsilon^{\sigma-1}N(t)/A(t))^{\frac{1}{\sigma-1}}$ includes the wage-measured expenditure, $E(t)/w(t)$, and the prototype fraction $N(t)/A(t)$. Note that $\tilde{\mu}(t)$ is bounded and does not continue to grow on an equilibrium path. Thus, the economic growth rate can be expressed as

$$1 + \gamma(t) = \mu(t)\,(1 + g(t))^{\frac{1}{\sigma-1}}\,, \tag{34}$$

where $g(t) \equiv (A(t+1) - A(t))/A(t)$ and $\mu(t) \equiv \tilde{\mu}(t+1)/\tilde{\mu}(t)$. Since $E(t)/w(t)$ and $N(t)/A(t)$ do not grow in the steady state,[27] $\mu(t)$ is bounded. If the economy is caught

[26] Our innovation cycle is new to the literature (Shleifer 1986), in the sense that in our model, both invention and introduction are endogenous, time-consuming, and costly activities.

[27] See Appendix B for details.

in the trap, there is no commodity growth (i.e., $g(t) = 0$) and, at the same time, $\tilde{\mu}(t)$ does not change over time (i.e., $\mu(t) = 1$). As a result, the economic growth rate $\gamma(t)$ equals zero. This implies that while generating inventions, any trapped economy cannot achieve self-sustained long-run growth. Using Proposition 2, therefore, we may conclude that having moderate receptivity to novelty ε is essential to self-sustained *growth*, as well as innovation.

6 Concluding Remarks

In the present study, we investigated the relationship between individual openness to novelty and innovation at the aggregate level. First, we offered a new fact: the relationship may be more complex than is naturally considered, by illustrating a basic scatterplot by means of using WVS data. This documented fact indicates that innovation indexes negatively correlate with some variables that represent the share of people who recognize themselves as being highly receptive to novelty, while moderate receptivity positively correlates with innovation. To explain a mechanism through which openness to novelty affects innovation in such a way, we developed a new endogenous growth model in which innovation is a complex process of invention and introduction, and the infinitely lived consumer's receptivity to new inventions is parameterized.

The endogenous growth literature has, thus far, emphasized the importance of endogenous innovation as an engine of long-run growth (Romer 1990, Grossman and Helpman 1991, Aghion and Howitt 1992). Existing models were basically designed to identify the role of innovation through its ultimate contribution to the long-run growth rate, but neither explicitly through its internal process of interacting with different stages in the growth process nor its relation to the receptivity to novelty as a cultural preference. In the present study, we developed an innovation-based growth model in which invention and introduction are treated as discrete (and costly) activities that interact with each other to achieve innovation and govern the evolution of an economy. In our model, we clearly distinguished the invention of a new good from its introduction, by introducing a new preference parameter; we also examined the role of receptivity to novelty in creating self-sustained innovation and endogenous growth. The model was designed to be simple and tractable, and yet capable of drawing new insights into the role of innovation in economic growth and providing a theory consistent with the new fact we documented in the introduction.

Needless to say, the present study offers only a glance at how receptivity to novelty affects innovation-driven growth, when we earnestly delve the details of the complex process of innovation. The model we proposed does not contain all the aspects of receptivity/aversion to novelty or innovation. It is, for example, considered exogenous, but it may change over time, in line with consumer behavior. Although the formulation for knowledge accumulation takes a specific form, we could work with a more general setting for knowledge. These restrictions help make analysis sufficiently tractable, but they also make the equilibrium unrealistic. Most importantly, in the present model, there is no equilibrium where invention and introduction coexist; in reality, however, the two components of innovation often take place concurrently. For future work, one can rectify this problem by assuming strictly concave technologies, rather than linear ones. Otherwise, allowing for consumers' learning activities with regards to novel prototypes would also work well. Nevertheless, given its simplicity, we believe our model has an advantage over such extended models: the equilibrium dynamic system is described as a one-dimensional system and, therefore, all analyses can be undertaken with simple phase diagram methods to demonstrate various phenomena (e.g., equilibrium traps, balanced growth, innovation cycles, and path dependence).

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Appendix A

In this appendix, we demonstrate the formal definitions of Λ_+, Λ_-, k_+^{**}, and k_-^{**}. If $f^A(k(t)) < k(t)$ for all $k(t) > 0$, $k(t+1) = f^A(k(t))$ does not have any fixed point (or any steady state). Noting the definition of f^A in (28), we can rewrite $f^A(k(t)) < k(t)$ as

$$\kappa L k(t)^2 + (1 - \psi - \kappa L)\, k(t) + 1/(\beta(\mu - 1)) > 0.$$

This is a second-order polynomial inequality in terms of $k(t)$. Since $\kappa L > 0$, the inequality holds for any $k(t) > 0$ if and only if the discriminant is negative—that is to say, if

$$(\kappa L)^2 - 2\left(\delta + \tfrac{1+\delta}{\beta(\mu-1)}\right)(\kappa L) + \left(\delta - \tfrac{1-\delta}{\beta(\mu-1)}\right)^2 < 0,$$

which uses $\psi \equiv (1-\delta)\left(1 + 1/(\beta(\mu-1))\right)$. This holds if and only if $\Lambda_- < \kappa L < \Lambda_+$, where

$$\Lambda_- \equiv \delta + \tfrac{1+\delta}{\beta(\mu-1)} - 2\sqrt{\delta\left(1 + \tfrac{1}{\beta(\mu-1)}\right)\left(\tfrac{1}{\beta(\mu-1)}\right)},$$
$$\Lambda_+ \equiv \delta + \tfrac{1+\delta}{\beta(\mu-1)} + 2\sqrt{\delta\left(1 + \tfrac{1}{\beta(\mu-1)}\right)\left(\tfrac{1}{\beta(\mu-1)}\right)}.$$

The difference equation $k(t+1) = f^A(k(t))$ thereby has two steady-state points if $\kappa L > \Lambda_+$. Specifically, $z = f^A(z)$ has the following solution: $z = k_-^{**},\ k_+^{**}$ where

$$k_-^{**} \equiv \tfrac{1}{2\kappa L}\left(\kappa L + \tfrac{1}{\beta(\mu-1)} - \delta\left(1 + \tfrac{1}{\beta(\mu-1)}\right) - \sqrt{(\kappa L - \Lambda_-)(\kappa L - \Lambda_+)}\right),$$
$$k_+^{**} \equiv \tfrac{1}{2\kappa L}\left(\kappa L + \tfrac{1}{\beta(\mu-1)} - \delta\left(1 + \tfrac{1}{\beta(\mu-1)}\right) + \sqrt{(\kappa L - \Lambda_-)(\kappa L - \Lambda_+)}\right).$$

Note $f^A(\varepsilon^{\sigma-1}/\kappa) > \varepsilon^{\sigma-1}/\kappa$ is equivalent to

$$G(\varepsilon^{\sigma-1}) \equiv L\left(\varepsilon^{\sigma-1}\right)^2 + (1 - \psi - \kappa L)\,\varepsilon^{\sigma-1} + \kappa\frac{\sigma-1}{\beta} < 0.$$

If $L \notin (\xi_-, \xi_+)$, $G(\varepsilon^{\sigma-1}) = 0$ has two solutions—say $\varepsilon^{\sigma-1} = \kappa k_+^{**}$ and κk_-^{**}—both of which must be positive due to the configuration of a graph of $f^A(\cdot)$. Since $G(\varepsilon_0) > 0$, only one of $\varepsilon_0^{\sigma-1} < k_-^{**} < k_+^{**}$ and $k_-^{**} < k_+^{**} < \varepsilon_0^{\sigma-1}$ must hold. We can show that the latter situation is not a possibility for the same logic in the proof of Lemma 2.

Appendix B

In either regime, $E(t)/w(t)$ is constant over time in the steady state (in which $A(t)/K(t)$ is constant). To show this, by (20) and (21), we can have

$$\frac{E(t)}{w(t)} = \frac{\mu}{\beta\,(\mu - 1) + 1}\left(L + \frac{1}{\varepsilon^{\sigma-1}}\right)$$

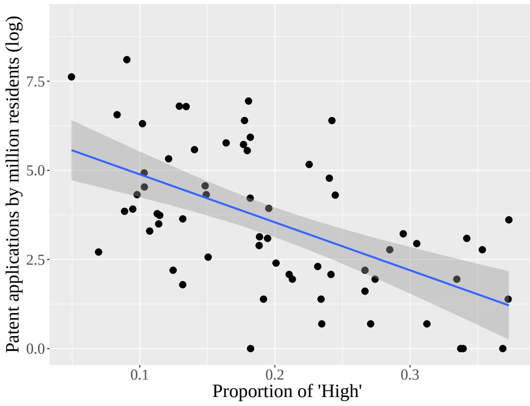
in the invention regime. By (25) and (26), we can have

$$\frac{E(t)}{w(t)} = \frac{\mu}{1 + \beta\,(\mu - 1)}\left(L + \frac{1}{\kappa}\frac{A(t)}{K(t)}\right)$$

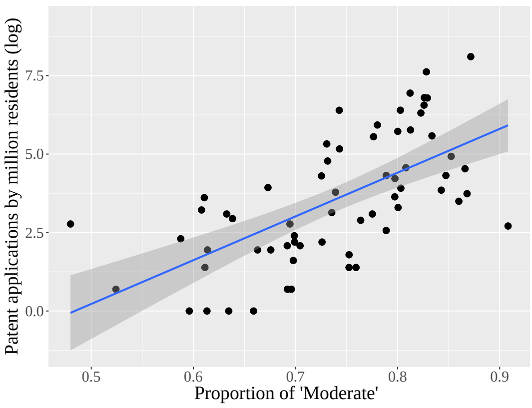
in the introduction regime. Since $A(t)/K(t)$ is constant in the steady state, $E(t)/A(t)$ is also constant there. As for $N(t)/A(t)$, it is easy to show that in the invention regime, $N(t)/A(t)$ converges to a constant level equal to Θ, using (4) and (22). In the introduction regime, $N(t) = 0$, whereby $\tilde{\mu}(t) = E(t)/w(t)$ (which is constant in the steady state as mentioned above).

[A189] Now I will briefly describe some people. Using this card, would you please indicate for each description whether that person is very much like you, like you, somewhat like you, not like you, or not at all like you? “It is important to this person to think up new ideas and be creative; to do things one’s own way.”

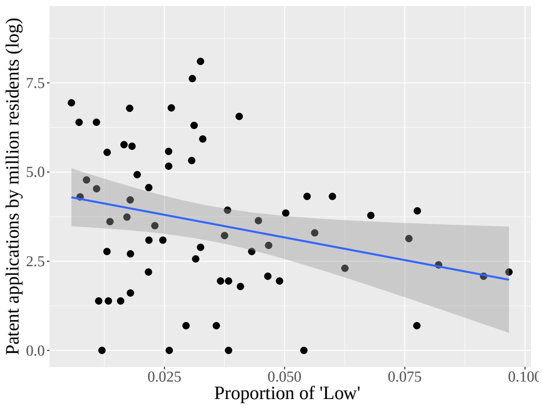
Code	Response	Receptivity
1	Very much like me	High
2	Like me	Moderate
3	Somewhat like me	
4	A little like me	
5	Not like me	
6	Not at all like me	Low
-5	Missing or Inappropriate	
-4	Not asked in survey	*Removed
-3	Not applicable	
-2	No answer	
-1	Don’t know	



(a) Log patent vs. High



(b) Log patent vs. Moderate



(c) Log patent vs. Low

Figure 1: The scatter plots of log patent applications per million residents against measures of receptivity. The patent data are taken from the World Intellectual Policy Organization. We in particular use the latest available statistics, from after 2013. As measures of receptivity we defined aggregate measures from answers to Question A189 (see the above table) of the World Values Survey longitudinal data. We recategorize the answers into three groups (High, Moderate, Low) and calculate the proportion of each group among the total response count within each country. While the proportion of Moderate (b) positively correlates to patent filings, those of High (a) and Low (c) negatively do. This tendency is mostly robust.[1]

[1] As shown in Appendix C (not for publication), we have made similar analysis with different receptivity measures such as High composed of both “Very much like me” and “Like me” and Moderate composed of only “Somewhat like me” and “A little like me.” We obtain the qualitatively same relationships for measures computed from E046. It is, in addition, robust to a different innovation measure such as Global Innovation Index. We observe qualitatively equivalent results under different specifications except for low receptivity groups. The negative correlations between proportion of Low and different innovation measures are subtle; they may or may not be observed.

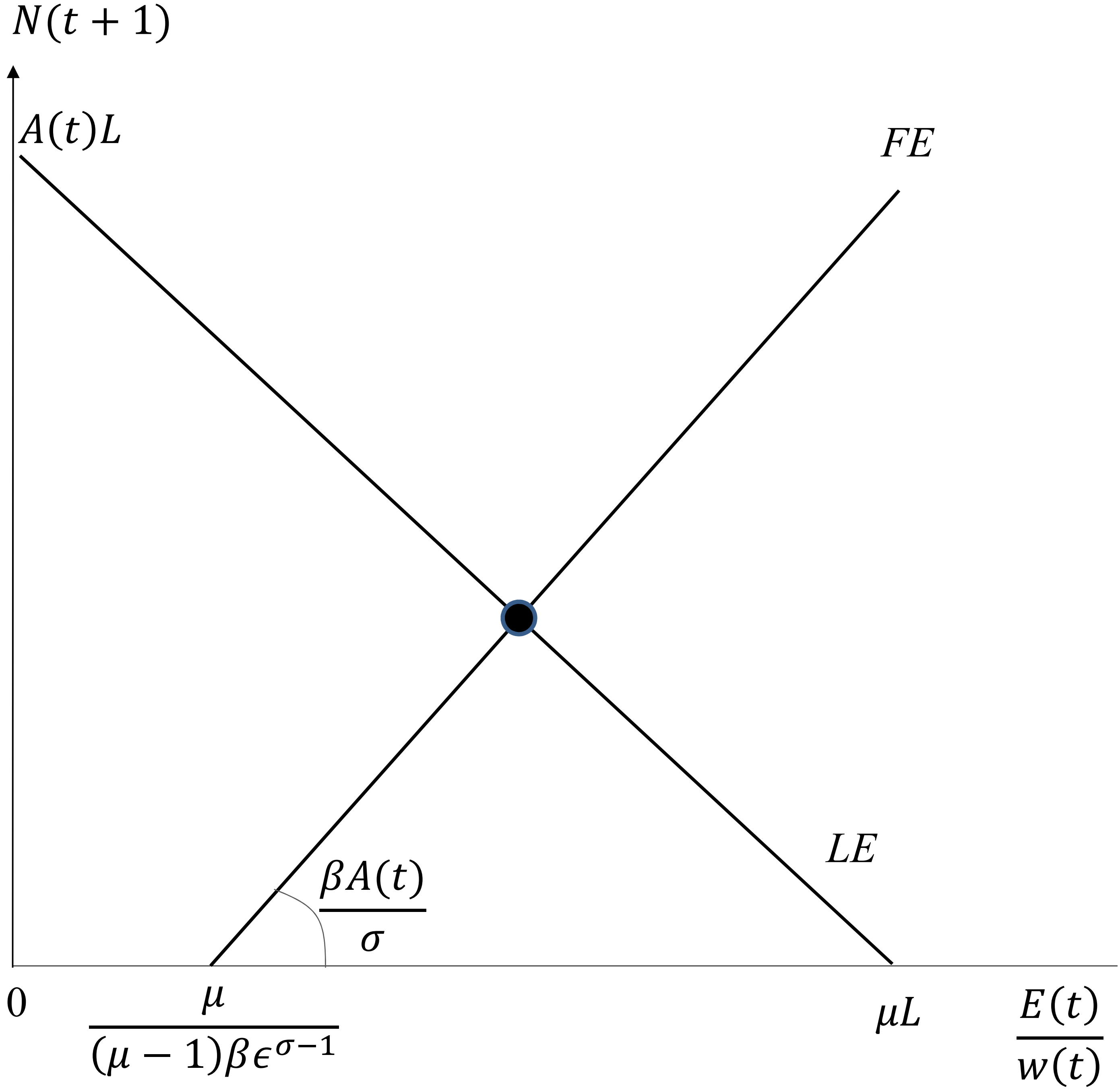


Figure 2: Temporary Equilibrium in the Invention Regime

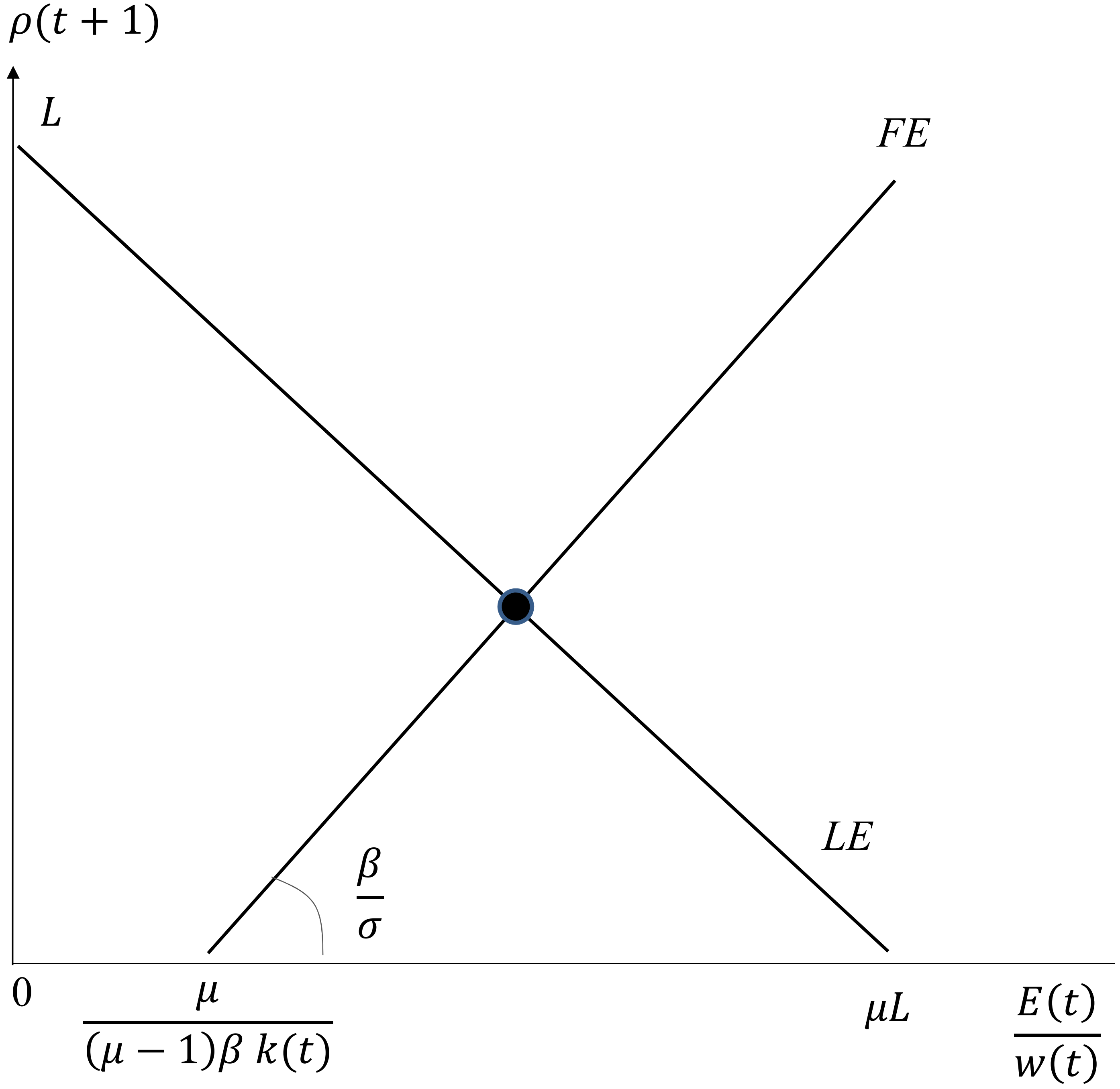


Figure 3: Temporary Equilibrium in the Introduction Regime

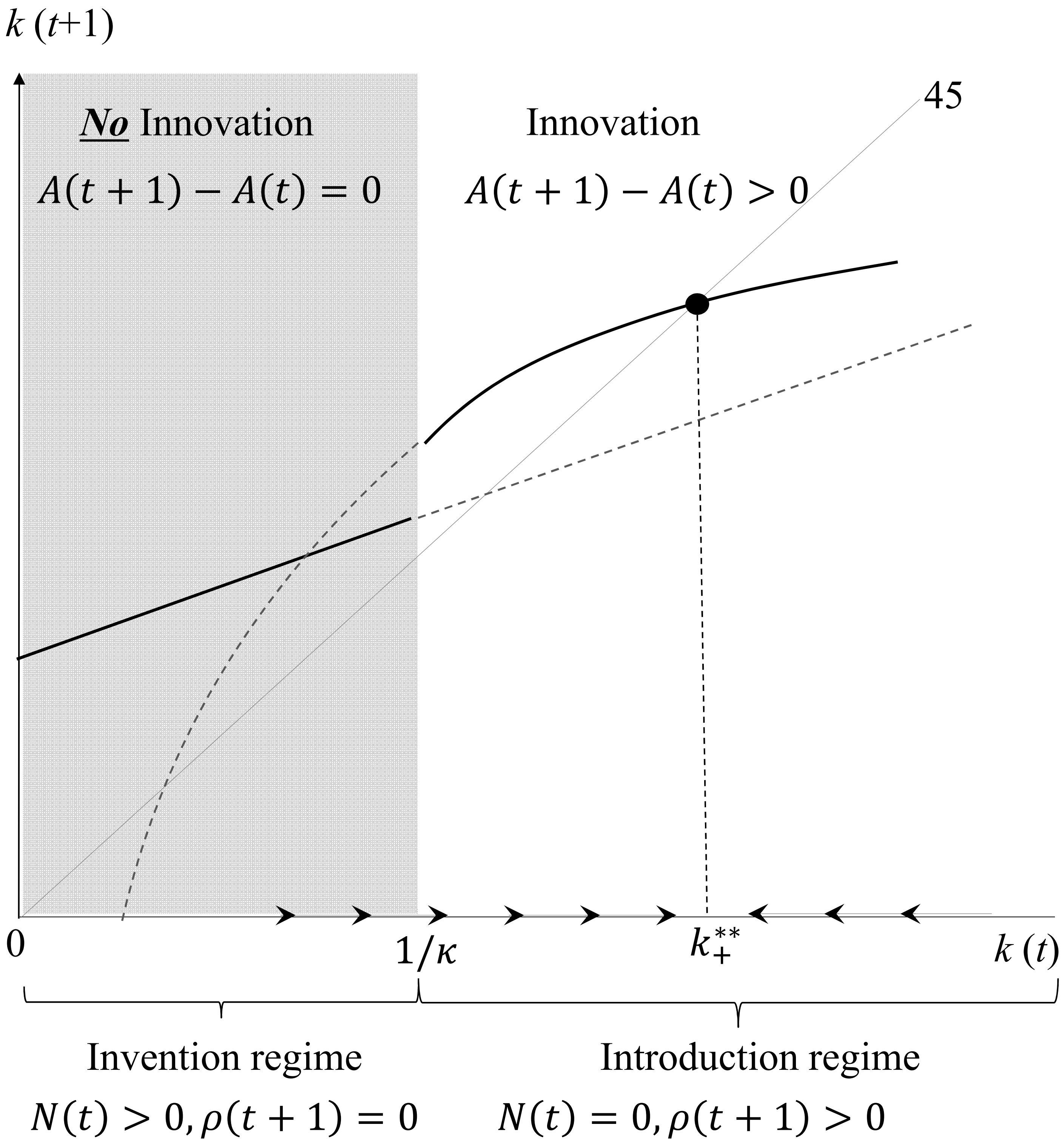


Figure 4: Balanced Growth

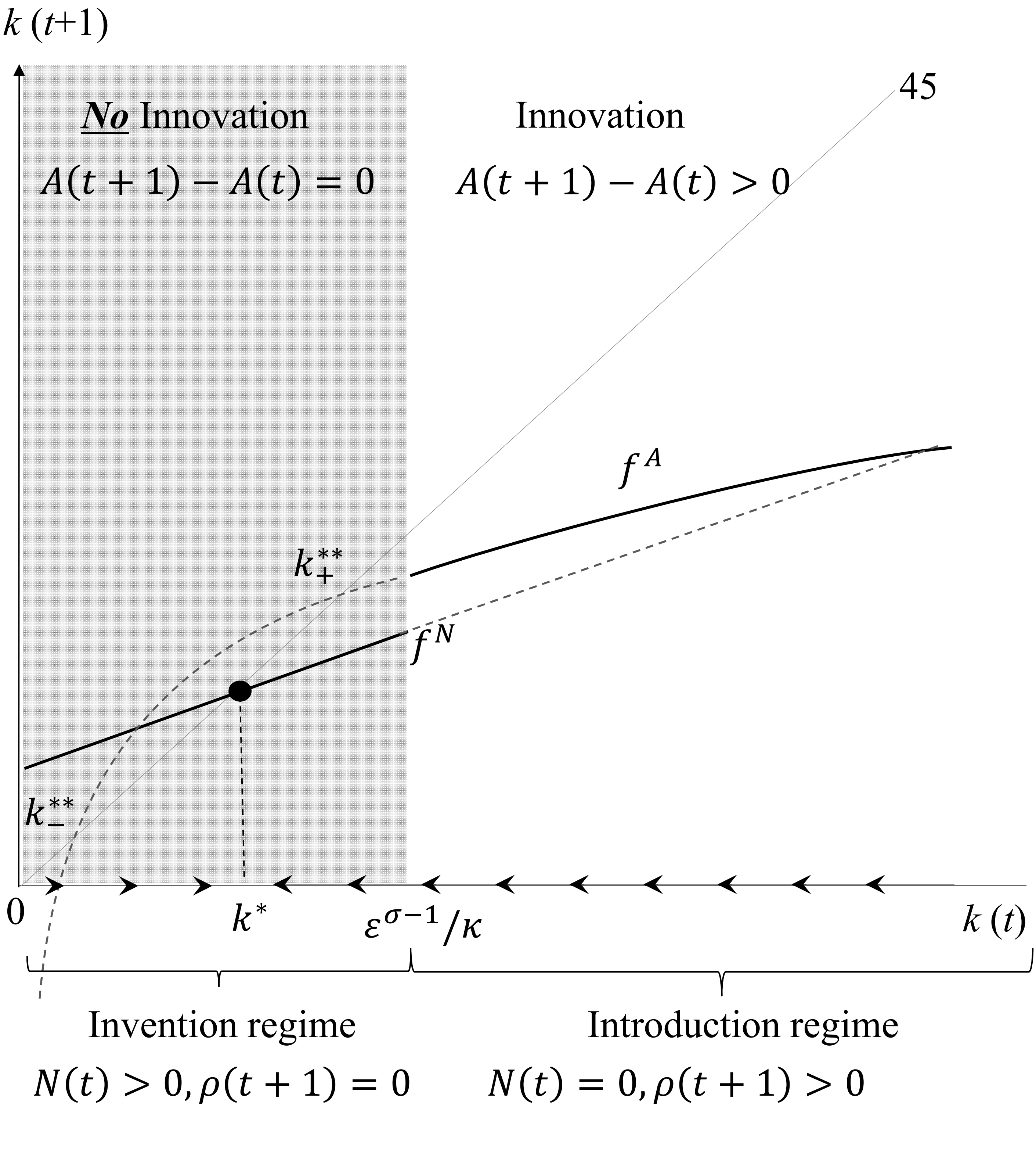


Figure 5A: Global Invention Trap

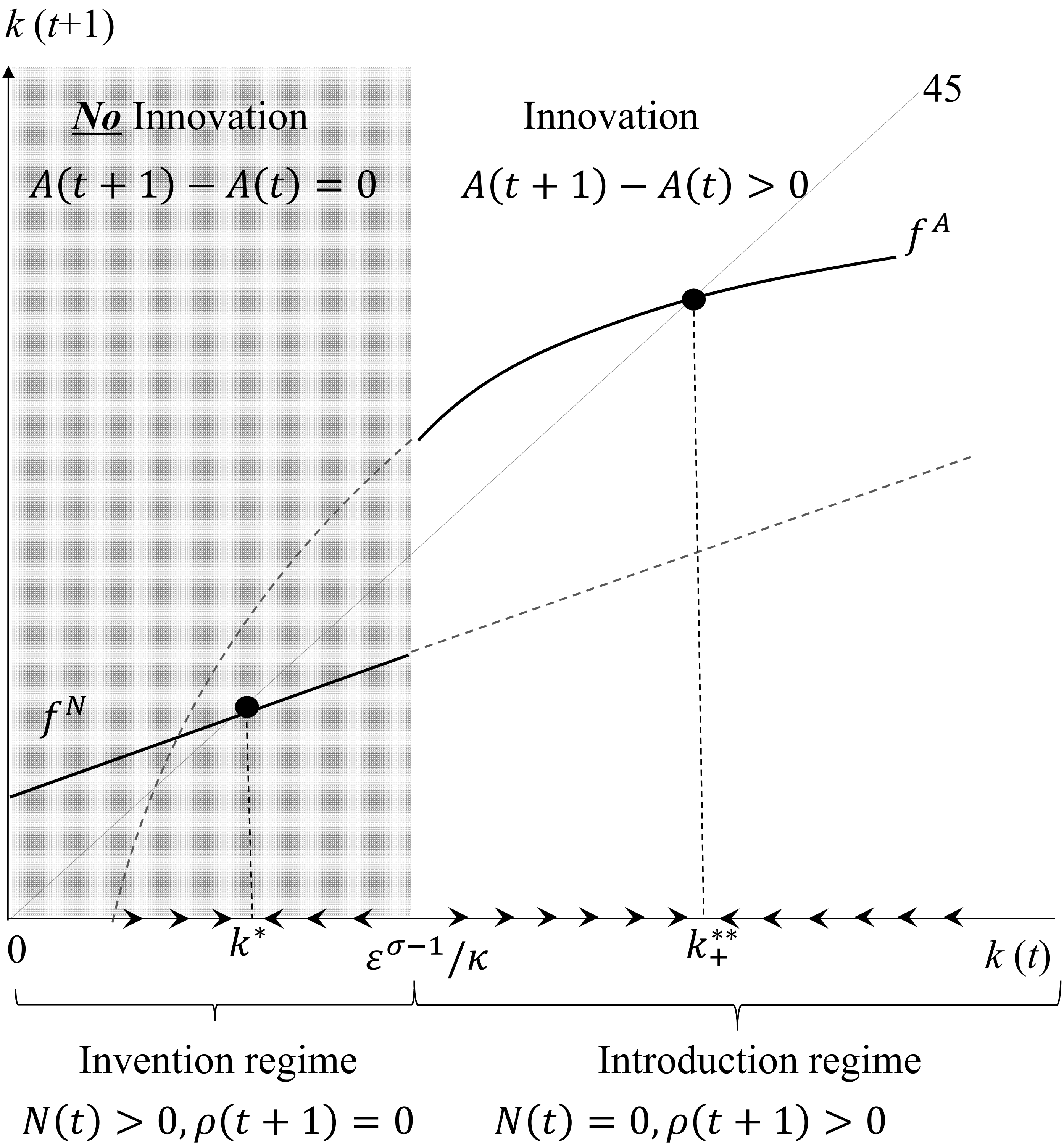


Figure 5B: Traps with Path Dependency

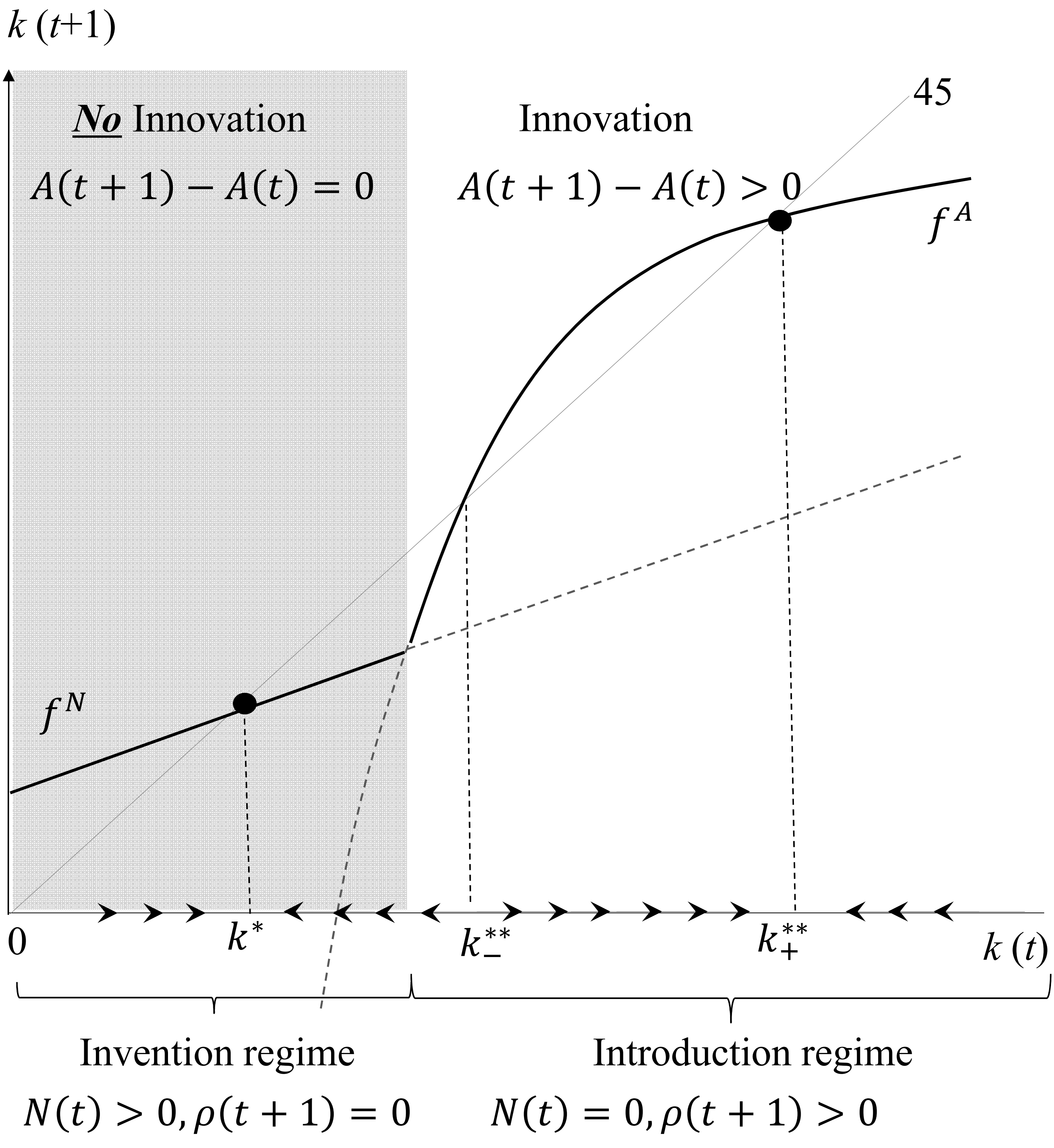


Figure 5C: Traps with Path Dependency II

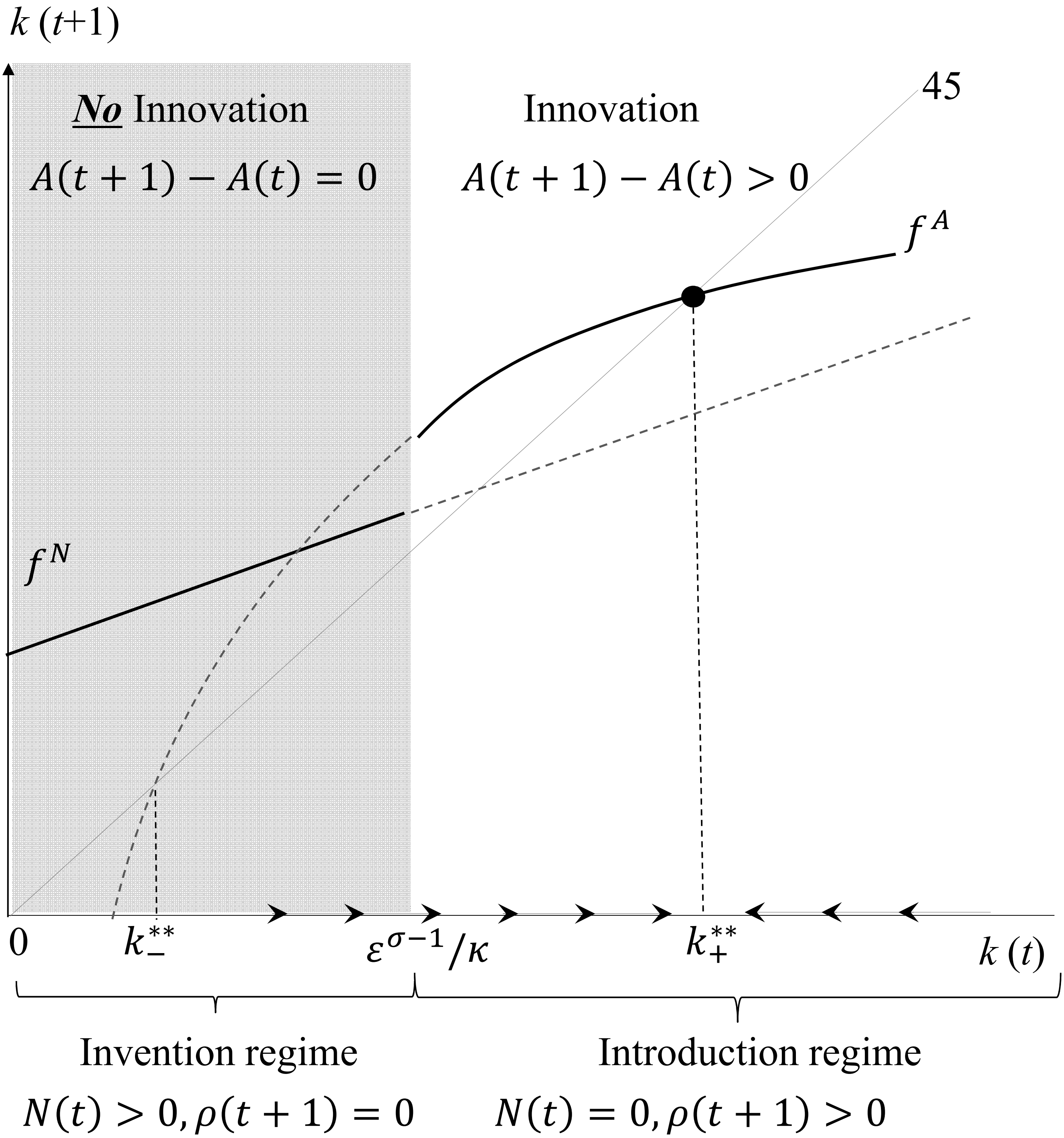


Figure 6A: Balanced Growth

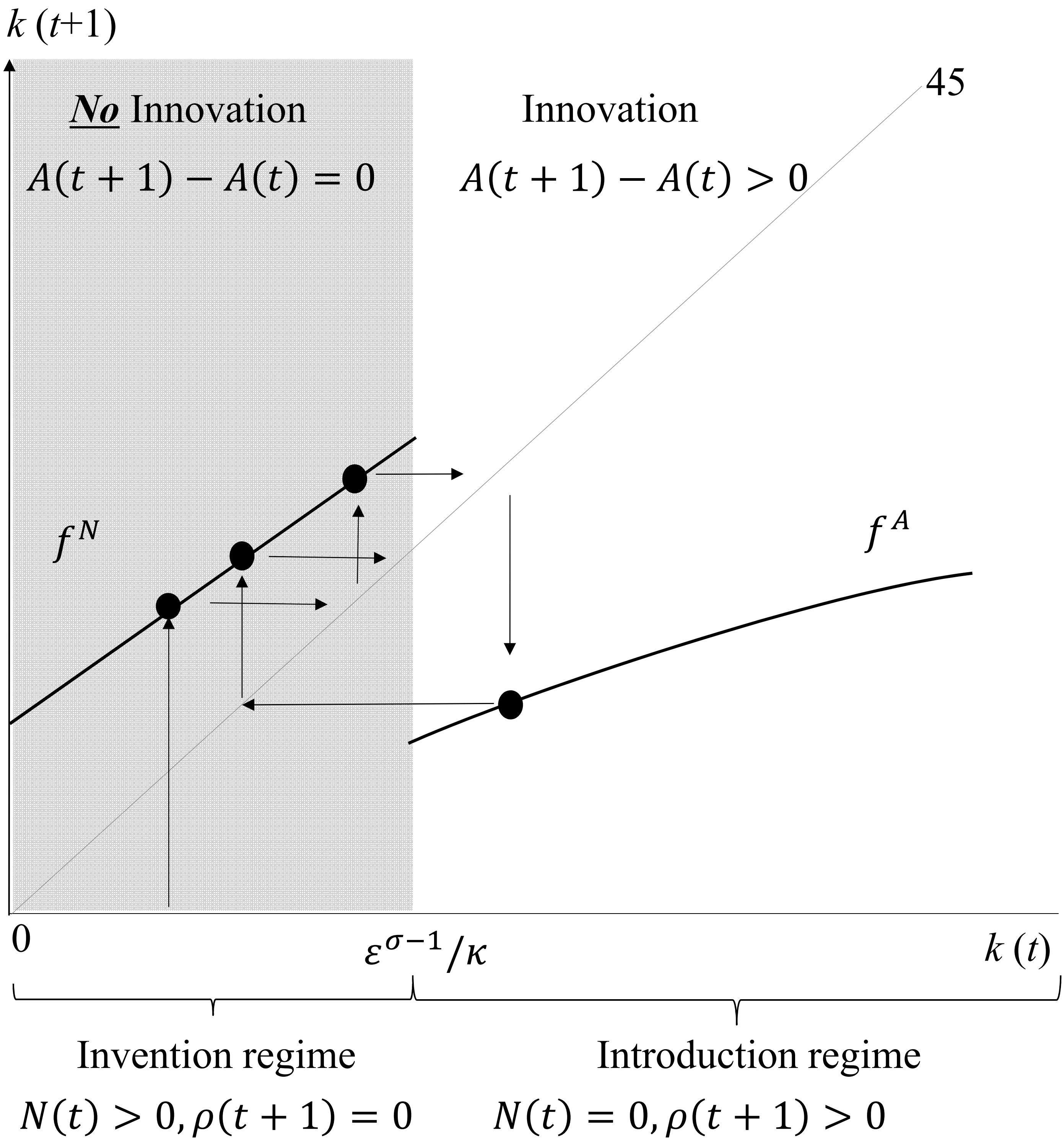


Figure 6B: Innovation Cycles

Appendix C (Not for publication)

In this appendix, we discuss robustness of our data analysis.

C.1 An alternative grouping rule

In the paper, receptivity of a country is defined by using the data for Question A189 (Schwartz: It is important to this person to think up new ideas and be creative) in the World Values Survey longitudinal data.[1]

We used the reclassification rule shown in Table C.1a to assign receptivity to each country. Another natural classification would be like Table C.1b.

Table C.1: Alternative grouping rules

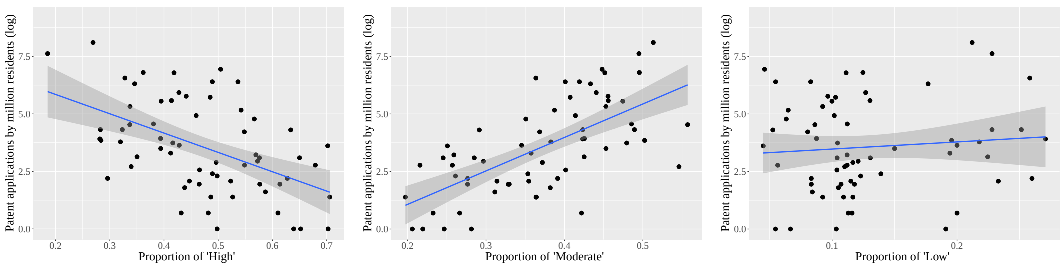
(a) Grouping for Figure 1

Code	Response	Receptivity
1	Very much like me	High
2	Like me	Moderate
3	Somewhat like me	
4	A little like me	
5	Not like me	
6	Not at all like me	Low
-5	Missing or Inappropriate	*Removed
-4	Not asked in survey	
-3	Not applicable	
-2	No answer	
-1	Don't know	

(b) Alternative grouping rule

Code	Response	Receptivity
1	Very much like me	High
2	Like me	
3	Somewhat like me	Moderate
4	A little like me	
5	Not like me	Low
6	Not at all like me	
-5	Missing or Inappropriate	*Removed
-4	Not asked in survey	
-3	Not applicable	
-2	No answer	
-1	Don't know	

We can observe, in Table C.1b, that the ratio of respondants with 'High' receptivity correlates to the innovation measure negatively, while that of 'Moderate' receptivity does positively. The correlation between 'Low' and innovation is reversed. Notice, however, that the positive correlation obtained with the specification in Table C.1a is only weakly positive.



(a) Log patent vs. High (b) Log patent vs. Moderate (c) Log patent vs. Low

Figure C.1: Scatter plots under specifications in Table C.1b

C.2 E046: New and old ideas

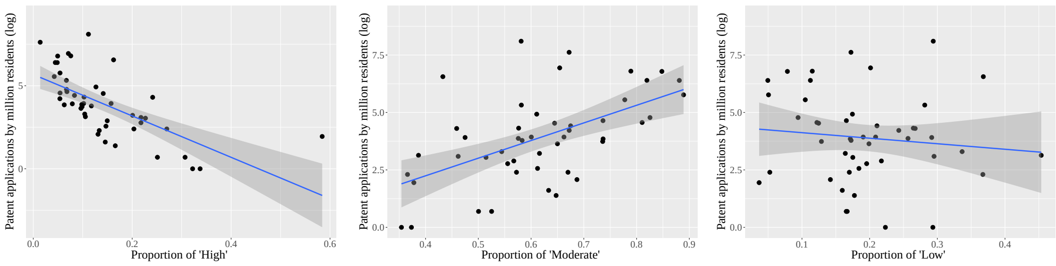
Another option is to use different questions in the World Values Survey. Following Bénabou et al., we perform a similar analysis with Question E046 (New and old ideas). See Table C.2. We consider a person who answered 10 to be the most receptive and 1 the least receptive. For each country, we calculate the ratio of responses with High/Moderate/Low receptivity. Basic scatter plots are shown in Figure C.2,

[1] WVS (2015). World Value Survey 1981-2014 Longitudinal Aggregate v.20150418, 2015. World Values Survey Association (www.worldvaluessurvey.org). Aggregate File Producer: JDSystems Data Archive, Madrid, Spain.

in which we again observe that the proportion of ‘High’ negatively correlates to innovation and the proportion of ‘Moderate’ positively does.

Table C.2: Grouping for E046

Code	Response	Receptivity
1	Ideas that stood test of time are generally best	Low
2		
3		Moderate
4		
5		
6		
7		
8		
9		High
10	New ideas are generally better than old ones	
-5	Missing; Unknown	*Removed
-4	Not asked in survey	
-3	Not applicable	
-2	No answer	
-1	Don’t know	



(a) Log patent vs. High (b) Log patent vs. Moderate (c) Log patent vs. Low

Figure C.2: Scatter plots for E046

C.3 Global Innovation Index as an innovation measure

In the paper and the previous section of this appendix, we used patent filings by residents as a innovation measure for each country. In this section, we perform a similr analysis with the Global Innovation Index (GII), which tries to quantify comprehensive innovation performance of each country.[2] The results are shown in Figure C.1a, where receptivity measure is calculated in the same way as in the paper (Table tbl:grouping-in-paper).

[2]Cornell University, INSEAD, and the World Intellectual Property Organization (2016) *The Global Innovation Index 2016: Winning with Global Innovation.* https://www.globalinnovationindex.org/

(a) GII vs. High (b) GII vs. Moderate (c) GII vs. Low

Figure C.3: Scatter plots with GII