Receptivity and Innovation*

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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. On analyzing data from the World Values Survey, we find that innovation is negatively correlated with the share of people who recognize themselves as highly receptive to novelty. Receptivity may not always be conducive to innovation. Thus, we propose a new dynamic general equilibrium model to 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 time-consuming. Further, other than receptivity, we also identify the critical roles of population and knowledge accumulation in innovation.

JEL Classification Codes: E32; O40; Z10

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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 (1b), there is a significant and negative relationship between innovation and the share of people who recognize themselves as highly receptive to novelty (1a).[1] Surprisingly, receptivity to novelty is not always conducive to innovation, and this finding is robust to alternative measures of receptivity and innovation.[2] What accounts for this counterintuitive effect of strong receptivity on innovation? Why does the public desire for innovativeness ambiguously affect aggregate innovation?

These questions provide the motivation for our paper and require a framework where individuals' preferences for novelty can be studied. The framework we present for this purpose extends the research and development (R&D)-based growth model (Romer 1990) to allow for ideas to be first invented as new prototypes and, eventually, introduced into the economy as familiar commodities; the economy invests some resources in inventing prototypes and others in introducing commodities. The relative/absolute profitabilities of these two investment activities are determined by consumers' desire for newly invented prototypes, called *receptivity to novelty*, and drive the process of innovation. In this way, "innovation" in our model does not merely refer to an invention or patent, but its introduction, as the dictionary defines it;[3] the entire process of innovation is quite complex, in which invention and introduction interact with each other, akin to Mokyr's (2004) findings and many historical events.[4]

We show that there are two interactive factors generating the ambiguous effect of receptivity to novelty on innovation: (a) the market mechanism, which encourages the development of technologies (for prototypes or commodities) that earn a relatively large profit, and (b) knowledge accumulation, which gradually enriches a so-called innovation-possibilities frontier by agglomerating newly invented ideas, called prototypes, into a knowledge stock for "innovation." These two forces are complementary in the sense that, while the latter reduces the cost for innovation over time, the former determines the

[1]Considering the constraint that the proportions add up to 1 and the observation that the proportion of low receptivity is very small, we could rephrase our research question as: "Why should the public desire for novelty be moderate, rather than strong, for the encouragement of innovation?"

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

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

distribution of resources to investments in prototypes and those in commodities in each period of time. We will demonstrate that the receptivity to novelty, together with the elasticity of substitution between goods and the depreciation rate of knowledge, plays an essential role in determining the balance between these two factors.

The core finding of this study is 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 will be introduced, and, ultimately, become obsolete along an equilibrium path. As such, there is no innovation in the long run.[5] The intuition behind this result is straightforward: when consumers are averse to novelty, on the one hand, the demand for—and profits related to—newly invented prototypes will be relatively small, and there are almost no new prototypes to be invented in the marketplace, through the market mechanism. Since it slows the expansion of an innovation-possibilities frontier, the cost incurred by firms in finding and introducing a complete commodity becomes high, due to the knowledge accumulation effect. In equilibrium, thus, only invention occurs, but less actively; there is no innovation in the long run.[6] When, on the other hand, consumers are open to novelty, the demand for and profits related to newly invented prototypes are large, relative to introduced commodities. In such a scenario, invention is even more profitable than introduction, through the market mechanism yet again, and there are more new prototypes to be invented in the marketplace. Although abundant inventions imply a lower cost for innovation due to knowledge accumulation, the economy is specialized in inventing new ideas on an equilibrium path when consumers are highly open to novelty, yielding, once again, 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. In this benchmark, both forces, as explained above, still work, but are parallel; the receptivity to novelty has no role in equilibrium. Departing from here, the two forces start to interact with each other and bring receptivity back to the center, whereby the economy may perpetually fluctuate between periods where new goods are invented and periods where invented goods are introduced. We 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. Therefore, 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 the role of governments in innovation to "fix" overly high or low receptivity among individuals, and adjust it to a moderate level. In some cases, policies unintentionally affect receptivity to novelty. In the U.S., 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 to 2009. These limitations were removed by U.S. President Barack Obama in March 2009.[7] The Internet provides

[5] Here, the trap 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.

[6] Note that we assume that new goods rapidly become obsolete without introduction, while introduced goods take root in the economy to contribute to long-run growth.

[7] For details, see Executive Order 13505 of March 9, 2009, titled "Removing Barriers to Responsible

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 0, 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 will be caught in an invention trap, which implies that an economy that efficiently archives 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, 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:[8] "the success of new techniques depends both on the level of inventive

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Scientific Research Involving Human Stem Cells."

[8] 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

activity and the receptivity of the surrounding economy to new ideas." The theory says that if consumers are sufficiently averse or receptive to novelty, 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, and 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 between 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).[9]

This study relates closely to a growing body of literature on culture and growth. The 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.[10] 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. Moreover, 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 previously 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, e.g., 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, 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).

take root in 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 from business, Watt's activity may be called "incubation." This should not be considered a degraded form of invention; rather, incubation—a result of which is introduction—is as laborious and creative an activity as is invention.

[9] 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).

[10] 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).

The remainder of this paper is organized as follows. Section 2 introduces our basic framework and derives equilibrium conditions. Section 3 characterizes the equilibrium dynamics of the model. Section 4 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 5 demonstrates that besides balanced growth, an economy may experience a variety of dynamic phenomena such as traps, cycles, and history dependence. Finally, Section 6 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 utility function as:

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

where $x(j, t)$ denotes the 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: "prototype" and "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 the 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 a commodity, it is only transient and, thus, it becomes obsolete in one period. Given that "early models perform too poorly to be useful" (Diamond 1997),[11] 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.[12] 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

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

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

such references to novelty into the model, by means of a weight 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), the commodities are heavily weighted with $\varepsilon(j,t) = 1$, while the prototypes are lightly weighted with $\varepsilon(j,t) = \varepsilon$.[13] We interpret the weight of 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 the preference that historically and culturally characterizes a society.

Each good j, a commodity or 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.

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 this 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.[14] 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 concerned with elevating crude ideas, as found in prototypes, to the level of perfection, and with compelling consumers to be knowledgeable of the utility of the commodity. Investment in introduction covers various activities, including marketing, advertising, and lobbying, as well as quality improvements. It is 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 an understanding, we believe that it is essential

[13] 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.

[14] We believe 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 qualitatively change.

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 originate from prototypes. The introduction of a commodity, thus, requires extensive 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 above-mentioned reason,[15] and we normalize their population to 1.[16] 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.[17] 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., 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.[18] Meanwhile, the incubators' private knowledge $K(t)$ includes 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 $K(t)$ as:

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

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 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.

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[15] See footnote 8.

[16] 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.

[17] 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 $\kappa L \leq \Lambda_+$.

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

2.3 Market Equilibrium

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

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

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.

We assume that producing one unit of goods requires one unit of labor and, thus, 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.[19] 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 $\mu < \sigma/(\sigma-1)$.[20] Each firm, thus, sets a monopolistic price at:

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

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

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

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

Acemoglu et al. 2012). Therefore, the firm inventing 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 option 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 the 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:

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

Using (10), (13), (16), and (18),[21] 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 dynamical 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 to public knowledge. The equilibrium dynamics can be completely characterized by means of this knowledge ratio. By the free entry conditions in (17), along 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 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 includes 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 in 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.

As discussed in the Introduction, there are two interactive forces determining the role of consumer receptivity to novelty ε in innovation, that is, the market mechanism and knowledge accumulation. Lemma 1 reveals the first force, by showing that for any given $k(t)$, an economy is engaged in invention activity in equilibrium if (and only if) the invention regime, $(0, \varepsilon^{\sigma-1}/\kappa)$ is sufficiently large. Since the consumer's desire for prototypes, relative to commodities, becomes stronger as ε increases, and since the cost for introduction becomes higher as κ decreases, there is a higher relative profit for the invention of a prototype when the individual receptivity to novelty ε is high and/or the incubators' productivity κ is low. Consequently, the economy is more likely to specialize in invention activity for prototypes, because the development of technologies that earn a higher profit is encouraged in market equilibrium. For the same reason, an economy

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

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

is engaged in introduction activity in market equilibrium for sufficiently low $\varepsilon^{\sigma-1}/\kappa$, in which case there is a higher relative profit for the introduction of a commodity. In sum, through the market mechanism, the economy develops new technologies to produce the goods that the consumer relatively prefers, whereby the receptivity to novelty ε plays a role in strengthening invention, rather than introduction.

3.1 Invention Regime

With $k(t) < \varepsilon^{\sigma-1}/\kappa$, the economy falls into 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 for firms to invent a prototype. The profit for a prototype increases as the wage-adjusted expenditure $E(t)/w(t)$ increases and, at the same time, as the consumer's receptivity to novelty ε increases. With a larger stock of public knowledge, the cost of inventing a prototype decreases and 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 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 causes 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.[22] 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 prototype invention. We assume $\Theta > 0$ to allow for positive growth, that is, $N(t+1) > 0$, by imposing $\varepsilon^{\sigma-1}(\mu-1)L - 1/\beta > 0$, which provides 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 has a unique fixed point $k^* \equiv \Theta/\delta$.

Inspection of (24) reveals the second force determining the role of consumer receptivity ε, that is, knowledge accumulation. From (24), the growth of (relative) knowledge for introduction, $k(t)$, is faster as the invention potential Θ is larger and depreciation rate of knowledge δ is smaller. Given that stronger preferences for prototypes increase their potential demand (i.e., Θ increases with ε), the consumer receptivity to novelty ε is conducive to knowledge accumulation for introduction. This is because higher ε yields more prototypes and the invention of prototypes, by assumption, essentially increases the incubators' knowledge for commodity introduction, $K(t)$ (see (5)).

3.2 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 the 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

[22] See also (11).

has sufficient commodities. It increases with the ideas to which the incubators have access, $K(t)$, since it makes introduction more profitable. Figure 3 illustrates how the equilibrium rate of receptivity $\rho(t+1)$ is determined by (25) and (26). Solving (25) and (26), we obtain:

$$\rho(t+1) = \frac{\beta\,(\mu-1)\,\kappa L}{1+\beta\,(\mu-1)} - \frac{1}{1+\beta\,(\mu-1)}\frac{A(t)}{K(t)}.^{23} \tag{27}$$

Using (4), (5), (24), and (27), we can derive the equilibrium law of motion for the introduction regime. The global dynamics can be summarized as:

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

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_+^{**}.[24]

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 for new inventions in self-sustained growth. With $\delta = 0$ and $\sigma = 1$, the system (28) converges to:

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

Figure 4 illustrates a typical phase diagram for this system.[25] 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, that is, the introduction of commodities, in the long run. The consumer's receptivity to novelty ε plays 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

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

[24] 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 $z > 0$, satisfying $\varepsilon^{\sigma-1}/\kappa < k_-^{**} < k_+^{**}$. See Appendix A for details.

[25] 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, that is, $(\mu-1)L - 1/\beta > 0$.

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., $\delta = 0$).

Remark 1 *The consumer's receptivity to novelty ε has no role in equilibrium if the 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, that is, $\sigma > 1$, and knowledge depreciation, that is, $\delta > 0$. First, let us consider the case where $\Theta < \varepsilon^{\sigma-1}(\delta/\kappa)$. In other words, the economy's inventive potential Θ is relatively low 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 low, 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 refer to this situation as 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. Toward which steady state the economy heads 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 will converge 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 that is 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 the following holds.

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

Given that the invention potential Θ is an increasing 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 the one hand, the consumer will prefer prototypes to commodities. With this effect, the invention of prototypes becomes more profitable than does the introduction of commodities, and, thus, the invention regime $(0, \varepsilon^{\sigma-1}/\kappa)$ will become large, through the market mechanism. 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 wants prototypes. This increase in Θ is accompanied by an increase in the prototypes $N(t)$. The incubators' knowledge for introduction $K(t)$ grows more rapidly. With this effect of ε through knowledge accumulation, 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 present 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 exists $\varepsilon_+ \geq \varepsilon_- > \varepsilon_0$, 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), that is, $F(\varepsilon^{\sigma-1})$, 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.[26] 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

[26]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.

$\varepsilon_1^{\sigma-1} > \varepsilon_0^{\sigma-1} > \varepsilon_+^{\sigma-1}$. 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 $D < 0$, which 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 the scale effect has been empirically rejected 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 our 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 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 very much 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 (Figure 5a) and only locally stable for a too-small ε (Figure 5b). In the latter case, whether the economy converges to a balanced growth path or invention trap depends on the initial condition. There is 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 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 knowledge accumulation $K(t)$ for introduction, 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 does 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—each emerging with knowledge accumulation and the market mechanism—interact with each other to generate the nonlinear effect of the receptivity to novelty ε. On the 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 has 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 $k_-^{**} < \varepsilon^{\sigma-1}(\delta/\kappa) < k_+^{**}$,[27] the economy will converge to a unique balanced growth path for any initial condition (Figure 6a), as in the 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. Therefore, when the receptivity to novelty ε is relatively high within the moderate range $[\varepsilon_-, \varepsilon_+]$, 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.[28] 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 perpetually cyclical. The cyclical case, which is likely to happen with a relatively high level of receptivity ε, seems consistent with history, where invention and introduction have often taken place in different times (e.g., steam engines and the Internet). The critical role of receptivity to novelty appears only if prototypes and commodities are gross substitutes and knowledge can depreciate over time (Remark 1).

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 obtain $u(t) = \tilde{\mu}(t)A(t)^{\frac{1}{\sigma-1}}$, where $\tilde{\mu}(t) = (E(t)/w(t))\ (1 + \varepsilon^{\sigma-1}N(t)/A(t))^{\frac{1}{\sigma-1}}$

[27] Note that $k_-^{**} > \varepsilon^{\sigma-1}/\kappa$ always holds, since $\kappa L > \Lambda_+$.

[28] 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.

includes the wage-measured expenditure, $E(t)/w(t)$, and 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:

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

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,[29] $\mu(t)$ is bounded. If the economy is caught 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 0. 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, that 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 are negatively correlated with some variables that represent the share of people who recognize themselves as being highly receptive to novelty, while moderate receptivity is positively correlated with innovation. To explain the 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). The 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 that 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 into the details of the complex process of innovation. Our proposed model does not contain all of 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 of

[29] See Appendix B for details.

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 research, one can rectify this problem by assuming strictly concave, rather than linear, technologies. Otherwise, allowing for consumers' learning activities with regard to novel prototypes would also work sufficiently. Nevertheless, given its simplicity, we believe that 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).

References

[1] Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hemous. "The environment and directed technical change," *American Economic Review*, 102: 131–166 (2012).

[2] Acs, Z., and M. Sanders. "Patents, knowledge spillovers, and entrepreneurship." *Small Business Economics*, 39: 801–17 (2012).

[3] Aghion, Philippe and Peter Howitt. "A model of growth through creative destruction," *Econometrica*, 60: 323–351 (1992).

[4] Aghion, Philippe, and Peter Howitt. "Research and development in the growth process." Journal of Economic Growth, 1: 49–73 (1996).

[5] Akiyama, Taro. R&D, entrepreneurship, and growth." manuscript (2009).

[6] Alesina, Alberto, and Paola Giuliano. "The power of the family." *Journal of Economic Growth*, 15: 93–125 (2010).

[7] Ashraf, Quamrul, and Oded Galor. "Cultural assimilation, cultural diffusion and the origin of the wealth of nations." *CEPR Discussion Papers* No. 6444 (2007).

[8] Ashraf, Quamrul, and Oded Galor. "The 'Out of Africa' hypothesis, human genetic diversity, and comparative economic development." *American Economic Review*, 103: 1–46 (2013a).

[9] Ashraf, Quamrul, and Oded Galor. "Genetic diversity and the origins of cultural fragmentation." *American Economic Review Papers and Proceedings*, 103: 528–533 (2013b).

[10] Ashraf, Quamrul, and Oded Galor. "The macrogenoeconomics of comparative development." *Journal of Economic Literature*, forthcoming (2017).

[11] Arthur, W. Brian. "Competing technologies, increasing returns, and lock-in by historical events," *Economic Journal* 99: 116–131 (1989).

[12] Barber, Bernard. “Resistance by scientists to scientific discovery,” *Science*, 134: 596–602 (1961).

[13] Bénabou, Roland, Davide Ticchi, and Andrea Vindigni. “Religion and innovation,” *American Economic Review: Papers & Proceedings*, 105: 346–351 (2015).

[14] Bénabou, Roland, Davide Ticchi, Andrea Vindigni. “Forbidden fruits: The political economy of science, religion, and growth.” *NBER Working Paper Series*, 21105. A recent version available at: https://www.princeton.edu/~rbenabou/papers/Religion%20July%202016%20new.pdf (2016).

[15] Beveridge, William Ian Beardmore. *The Art of Scientific Investigation*, Random House, New York (1959).

[16] Boserup, Ester. *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure*, Chicago: Aldine (1965).

[17] Chandrasekaran, Deepa, and Gerard J. Tellis. “Global takeoff of new products: Culture, wealth or vanishing differences.” *Marketing Science* 27: 844-860 (2008).

[18] Chu, Angus C. “Confidence-enhanced economic growth.” *The B.E. Journal of Macroeconomics (Topics)*, 7: Article 13 (2007).

[19] Chu, Angus C, and Guido Cozzi. “Cultural preference on fertility and the growth and welfare effects of intellectual property rights.” *MPRA Paper* No. 31283 (2011).

[20] Chu, Angus C., and Yuichi Furukawa. “Patentability and knowledge spillovers of basic R&D.” *Southern Economic Journal*, 79: 928–945 (2013).

[21] Chu, Angus C., Guido Cozzi, and Silvia Galli. “Does intellectual monopoly stimulate or stifle innovation?” *European Economic Review*, 56: 727–746 (2012).

[22] Chu, Angus C., Guido Cozzi, Shiyuan Pan, and Mengbo Zhang. “Do stronger patents stimulate or stifle innovation? The crucial role of financial development.” *MPRA Paper* No. 73630 (2016).

[23] Cloninger, C. R. “A unified biosocial theory of personality and its role in the development of anxiety states.” *Psychiatric Developments* 4: 167–226 (1986).

[24] Cohen, Wesley M. and Daniel A. Levinthal. “Innovation and learning: The two faces of R&D,” *Economic Journal*, 99: 569–596 (1989).

[25] Cozzi, Guido, and Silvia Galli. “Science-based R&D in Schumpeterian growth.” *Scottish Journal of Political Economy*, 56, 474–491 (2009).

[26] Cozzi, Guido, and Silvia Galli. “Privatization of knowledge: Did the U.S. get it right?” *Economics Working Paper Series* 1307, University of St. Gallen, School of Economics and Political Science (2013).

[27] Cozzi, Guido, and Silvia Galli. “Sequential R&D and blocking patents in the dynamics of growth.” *Journal of Economic Growth*, 19: 183–219 (2014).

[28] Deneckere, Raymond and Kenneth Judd. "Cyclical and chaotic behavior in a dynamic equilibrium model," in *Cycles and Chaos in Economic Equilibrium*, ed. by Jess Benhabib. Princeton: Princeton University Press (1992).

[29] Diamond, Jared. *Guns, Germs, and Steel*, New York: W. W. Norton (1997).

[30] Evans, Lewis, Neil Quigley, and Jie Zhang. "Optimal price regulation in a growth model with monopolistic suppliers of intermediate goods," *Canadian Journal of Economics*, 36: 463–474 (2003).

[31] Francois, Patrick, and Shouyong Shi. "Innovation, growth, and welfare-improving cycles," *Journal of Economic Theory*, 85: 226–57 (1999).

[32] Furukawa, Yuichi. "Leapfrogging cycles in international competition," *Economic Theory*, 59: 401–433 (2015).

[33] Gale, Douglas. "Delay and cycles," *Review of Economic Studies*, 63: 169–98 (1996).

[34] Galor Oded. "From stagnation to growth: Unified growth theory." *Handbook of Economic Growth*, 1A: 171–293 (2005).

[35] Galor, Oded, and Omer Moav. "Natural selection and the origin of economic growth." *Quarterly Journal of Economics*, 117: 1133–1192 (2002).

[36] Gilbert, Richard, and Carl Shapiro. "Optimal patent length and breadth," *RAND Journal of Economics*, 21: 106–112 (1990).

[37] Goh, A.-T., and J. Olivier. "Optimal patent protection in a two-sector economy," *International Economic Review*, 43: 1191–1214 (2002).

[38] Grossman, Gene M., and Elhanan Helpman. *Innovation and Growth in the Global Economy*, Cambridge, MA: MIT Press (1991).

[39] Hirschman, Elizabeth C. "Innovativeness, novelty seeking, and consumer creativity," *Journal of Consumer Research*, 7: 283–295 (1980).

[40] Iwaisako, Tatsuro, and Koichi Futagami. "Patent protection, capital accumulation, and economic growth," *Economic Theory*, 52: 631–668 (2013).

[41] Jones, Charles I. "Time series tests of endogenous growth models," *Quarterly Journal of Economics*, 110: 495–525 (1995).

[42] Kauffman, Stuart. *At Home in the Universe: the Search for the Laws of Self-Organization and Complexity*, New York: Oxford University Press (1995).

[43] Konishi, Kunihiko. "Basic and applied research: A welfare analysis." *Discussion Paper* 15-08, Graduate School of Economics, Osaka University (2015).

[44] Kremer, Michael. "Population growth and technological change: One million B.C. to 1990," *Quarterly Journal of Economics*, 108: 681–716 (1993).

[45] Kuznets, Simon. "Population change and aggregate output," in *Demographic and Economic Change in Developed Countries*, Princeton: Princeton University Press (1960).

[46] Li, C.-W. "On the policy implications of endogenous technological progress," *Economic Journal*, 111: C164–C179 (2001).

[47] Machlup, Fritz. "An Economic Review of the Patent System," *Study No. 15, U.S. Senate Committee on the Judiciary, Subcommittee on Patents, Trademarks and Copyrights*, Washington, D.C.: Government Printing Office (1958).

[48] Matsuyama, Kiminori. "Growing through cycles," *Econometrica*, 67: 335–47 (1999).

[49] Matsuyama, Kiminori. "Growing through cycles in an infinitely lived agent economy," *Journal of Economic Theory*, 100: 220–34 (2001).

[50] Michelacci, Claudio. "Low returns in R&D due to the lack of entrepreneurial skills," *Economic Journal*, 113: 207–25 (2003).

[51] Mokyr, Joel. *The Lever of Riches. Technological Creativity and Economic Progress*, Oxford: Oxford University Press (1990).

[52] Mokyr, Joel. "Evolutionary biology, technological change and economic history," *Bulletin of Economic Research*, 43: 127–149 (1991).

[53] Mokyr, Joel. "Technological inertia in economic history," *Journal of Economic History*, 52: 325–338 (1992).

[54] Mokyr, Joel. "Innovation and its enemies: The economic and political roots of technological inertia," in *A Not-so-dismal Science: A Broader View of Economies and Societies*, ed. by Mancur Olson and Satu Kahkohnen. Oxford: Oxford University Press (2000 (1996, DP)).

[55] Mokyr, Joel. "Invention and rebellion: Why do innovations occur at all? An evolutionary approach," in *Elites, Minorities and Economic Growth*, ed. by Elise S. Brezis and Peter Temin. Emerald Group Publishing (1999 (1997, DP)).

[56] Mokyr, Joel. *The gifts of Athena: Historical origins of the knowledge economy.* Princeton, NJ: Princeton University Press (2004).

[57] Nelson, Richard R. "A theory of the low-level equilibrium trap in underdeveloped economies," *American Economic Review*, 46: 894–908 (1956).

[58] Rogers, Everett M. *Diffusion of Innovations.* New York: Free Press (1962).

[59] Rogers, Everett M., and F. Floyd Shoemaker. *Communication of Innovations: A Cross-Cultural Approach.* New York: Free Press (1971).

[60] Romer, Paul. M. "Endogenous technological change," *Journal of Political Economy*, 98: S71–S102 (1990).

[61] Shleifer, Andrei. "Implementation cycles," *Journal of Political Economy*, 94: 1163–1190 (1986).

[62] Simon, Julian. *The Economics of Population Growth*, Princeton: Princeton University Press (1977).

[63] Tabellini, Guido. "Culture and institutions: Economic development in the regions of Europe," *Journal of the European Economic Association*, 8: 677–716 (2010).

[64] Tellis, Gerard J., Eden Yin, and Simon Bell. "Global consumer innovativeness: Cross-country differences and demographic commonalities." *Journal of International Marketing*, 17: 1–22 (2009).

[65] Yano, Makoto. "The foundation of market quality economics," *Japanese Economic Review*, 60: 1–32 (2009).

[66] Yano, Makoto, and Yuichi Furukawa. "Chaotic industrial revolution cycles and intellectual property protection in an endogenous–exogenous growth model." *MQ Discussions Series* (2013).

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

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

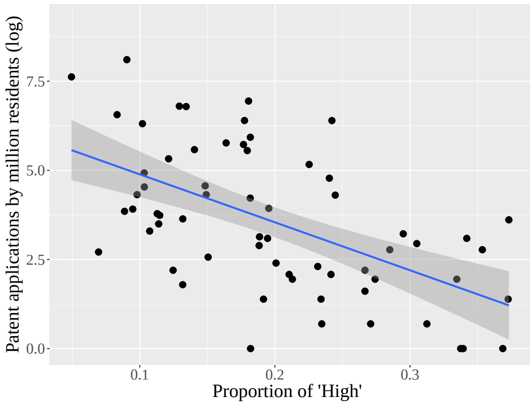
in the invention regime. By (25) and (26), we can have

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

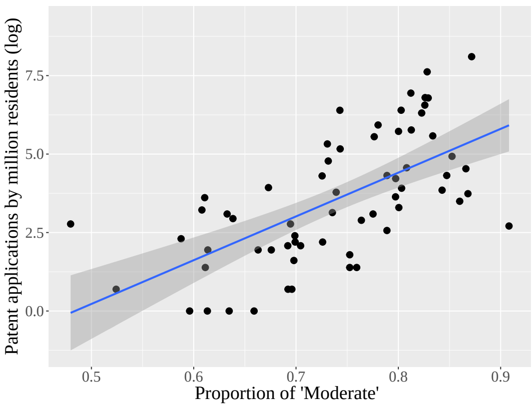
in the introduction regime. Since $A(t)/K(t)$ is constant in the steady state, $E(t)/A(t)$ is also constant there. As for $N(t)/A(t)$, it is easy to show that in the invention regime, $N(t)/A(t)$ converges to a constant level equal to Θ, using (4) and (22). In the introduction regime, $N(t) = 0$, whereby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

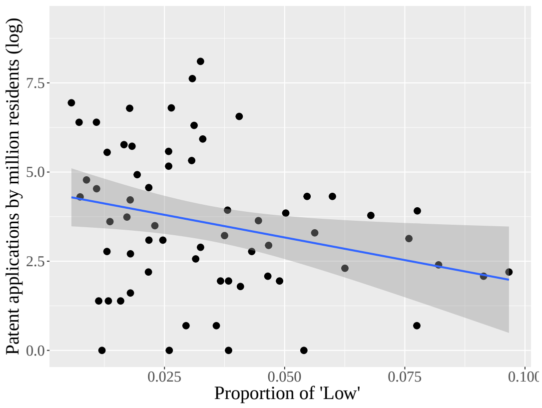
Code	Response	Receptivity
1	Very much like me	High
2	Like me	
3	Somewhat like me	Moderate
4	A little like me	
5	Not like me	
6	Not at all like me	Low
-5	Missing or Inappropriate	
-4	Not asked in survey	*Removed
-3	Not applicable	
-2	No answer	
-1	Don't know	



(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.

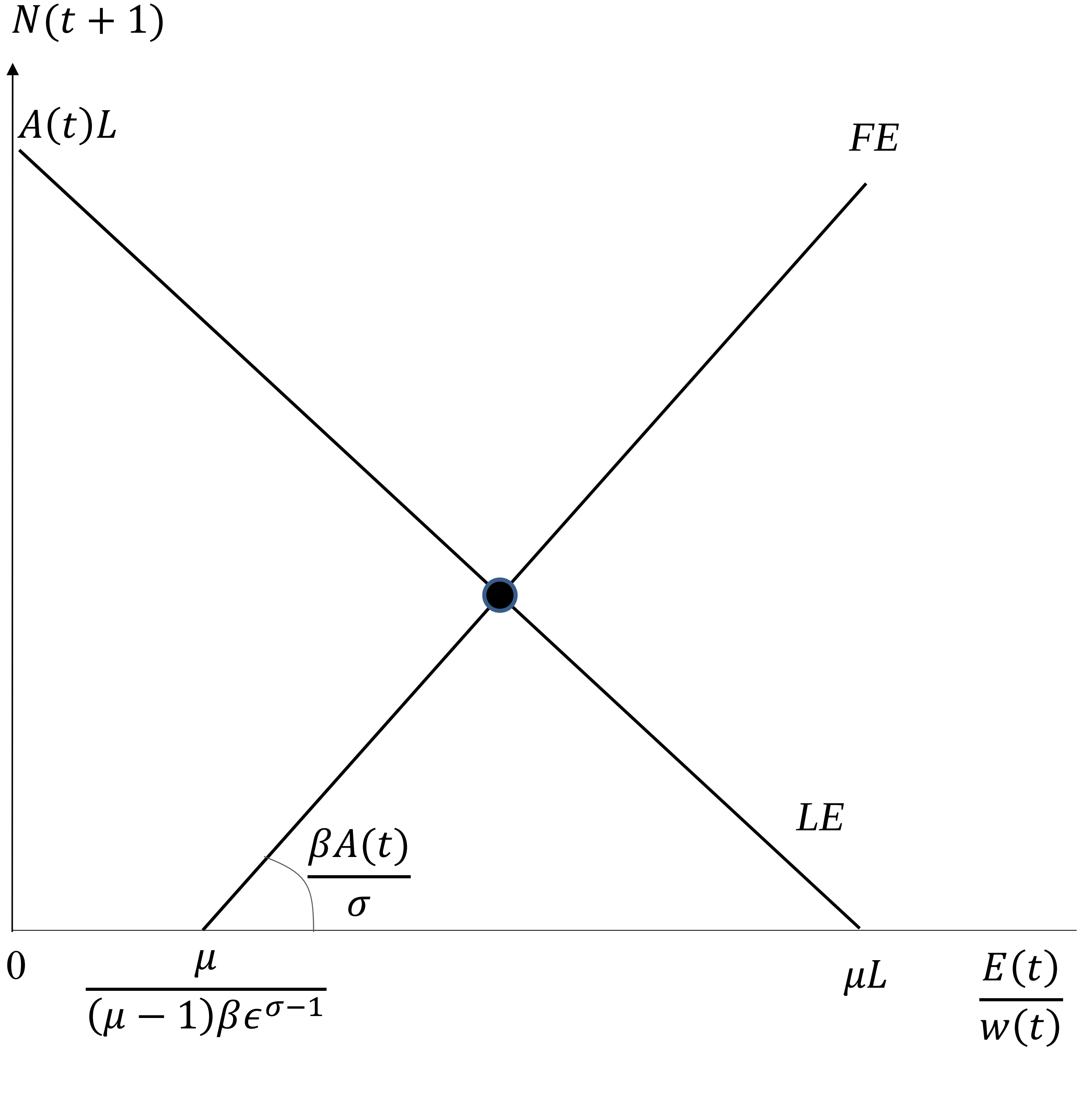


Figure 2: Temporary Equilibrium in the Invention Regime

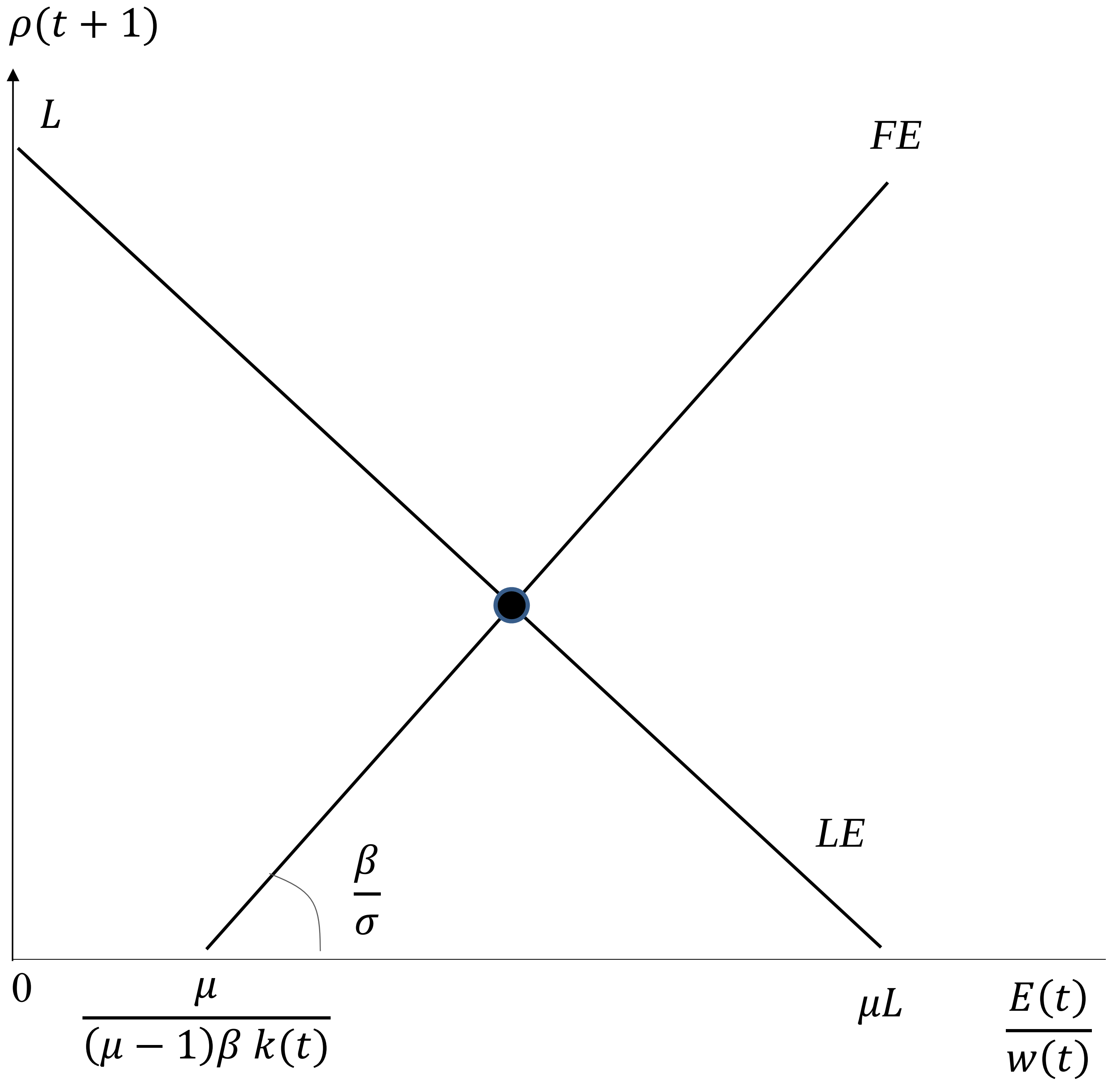


Figure 3: Temporary Equilibrium in the Introduction Regime

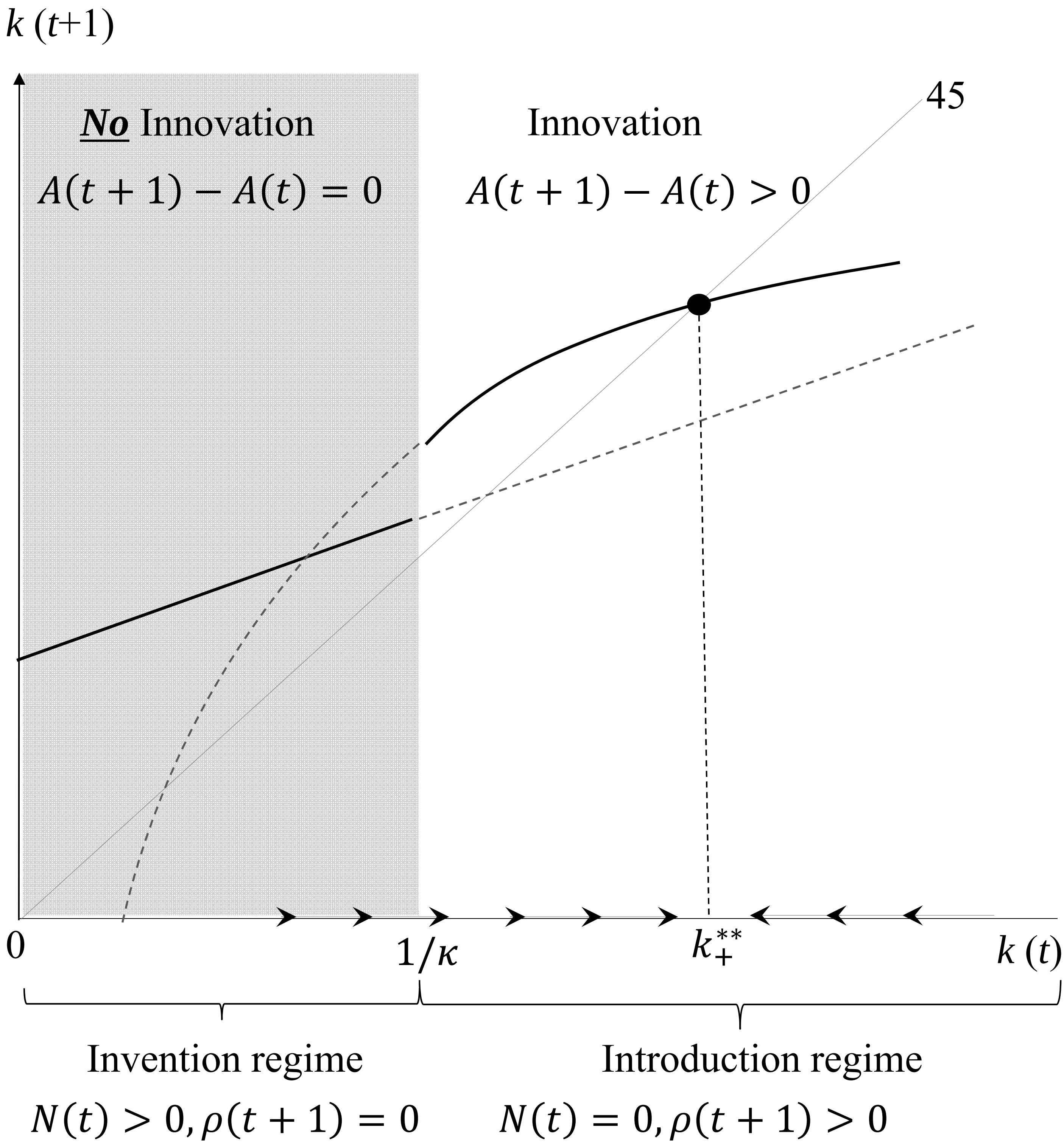


Figure 4: Balanced Growth

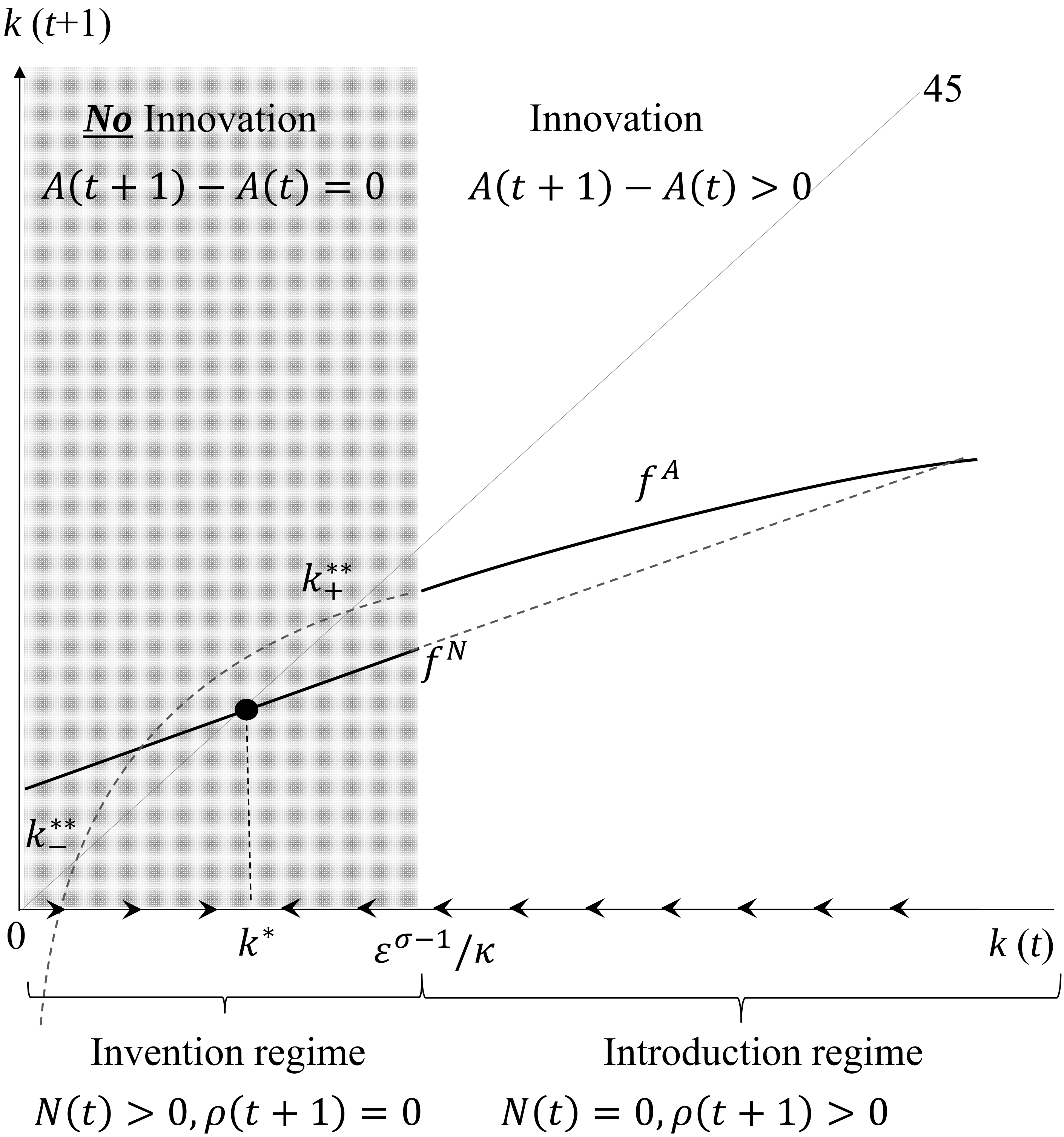


Figure 5a: Global Invention Trap

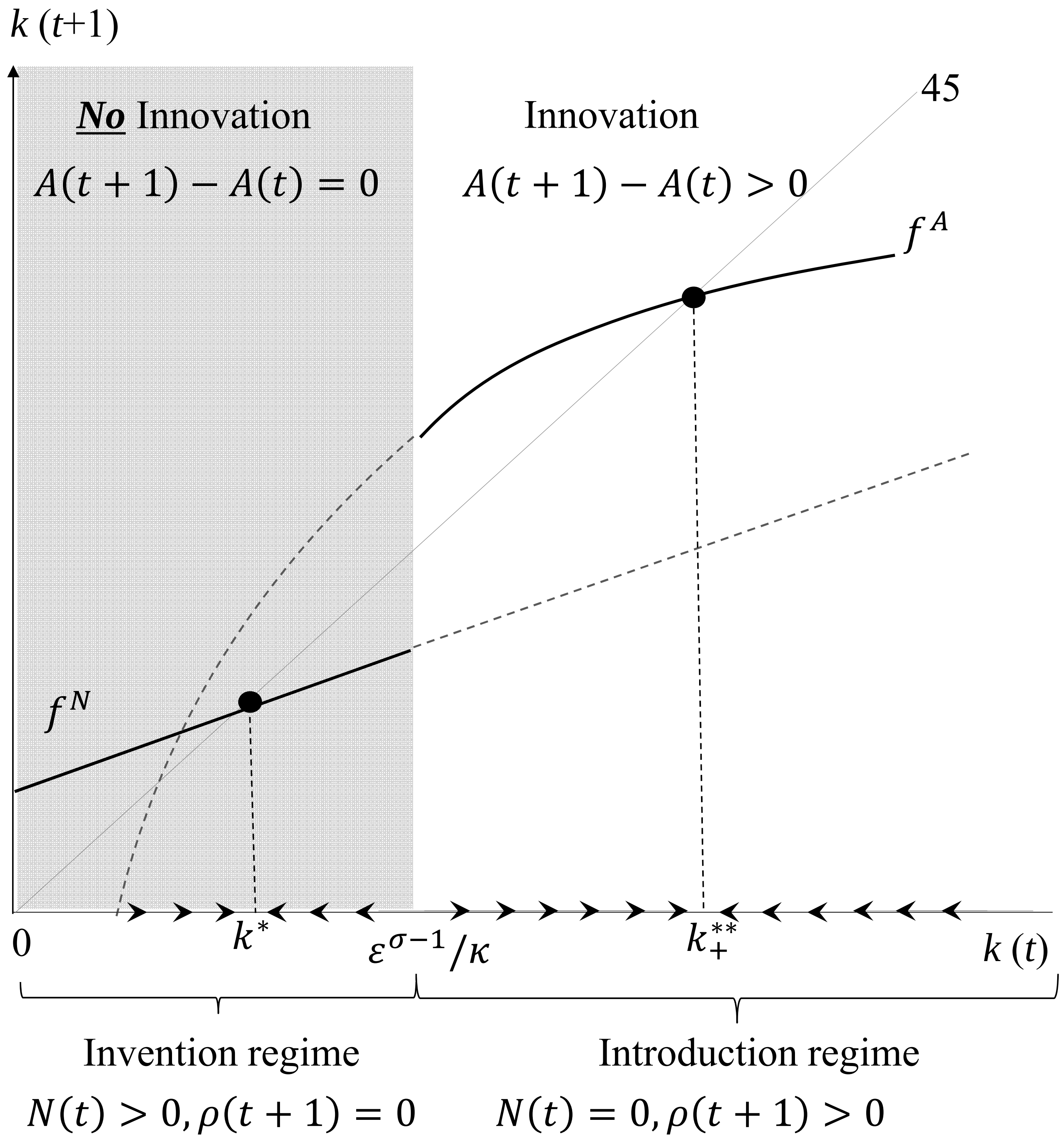


Figure 5b: Traps with Path Dependency

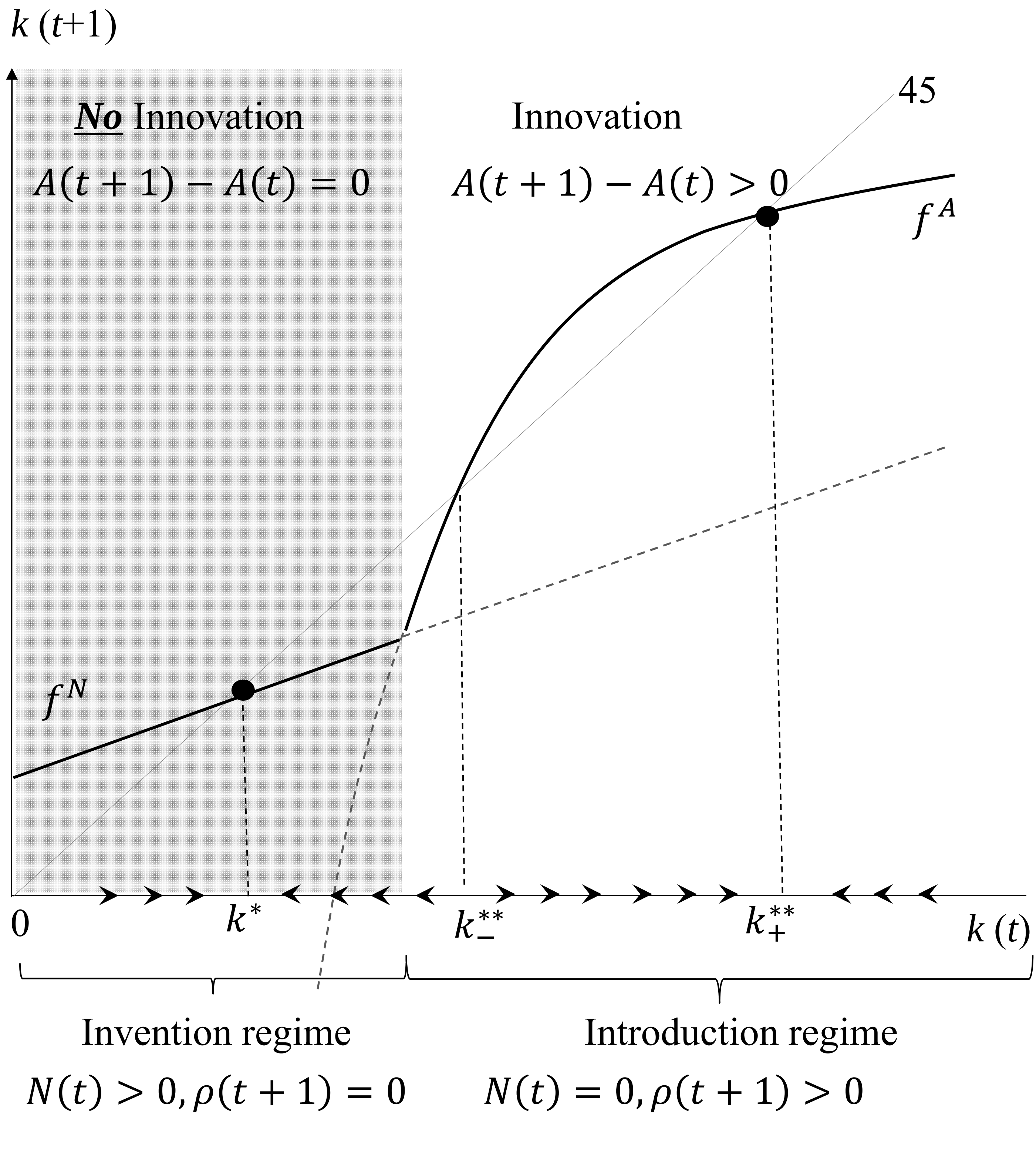


Figure 5c: Traps with Path Dependency II

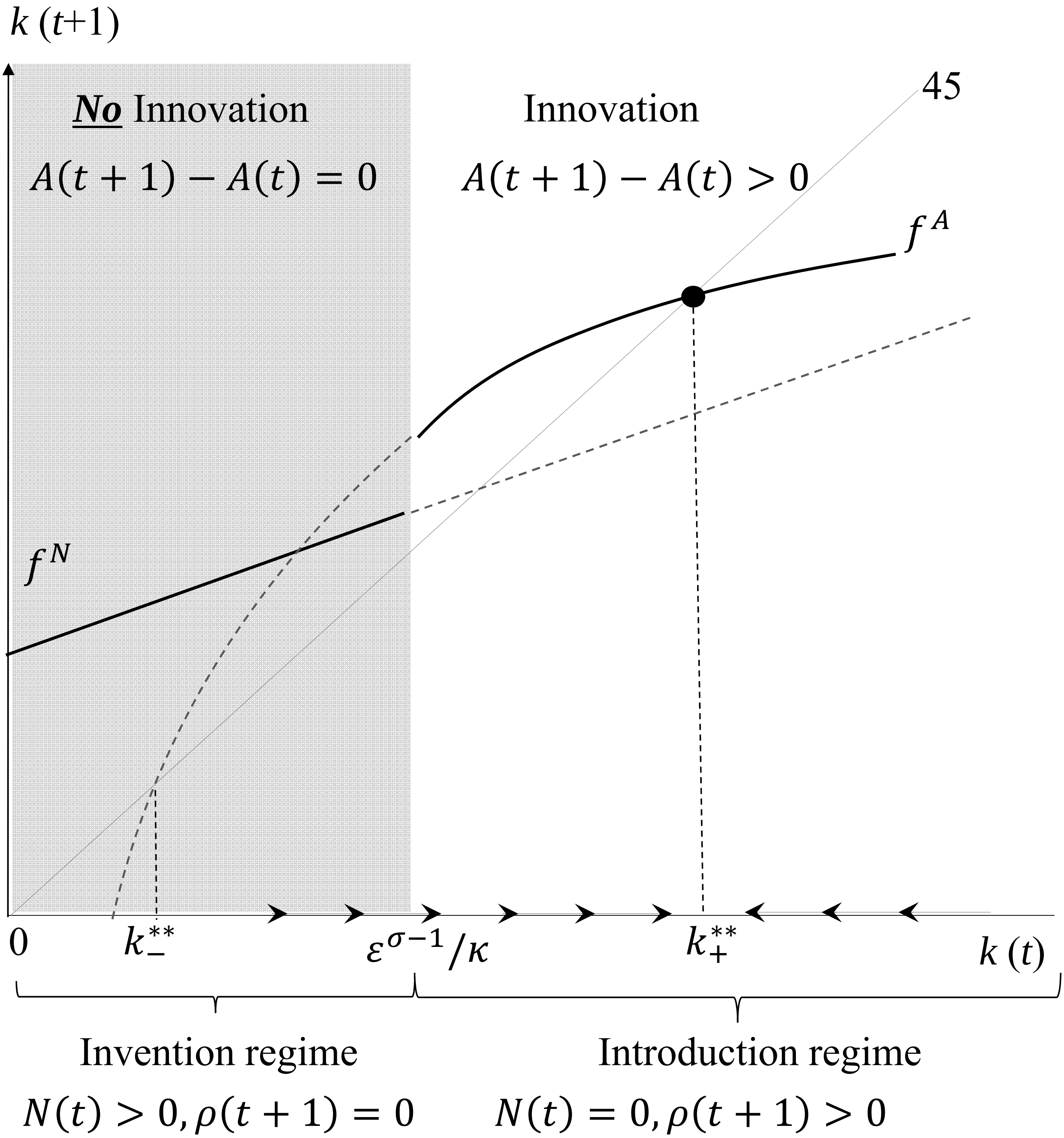


Figure 6a: Balanced Growth

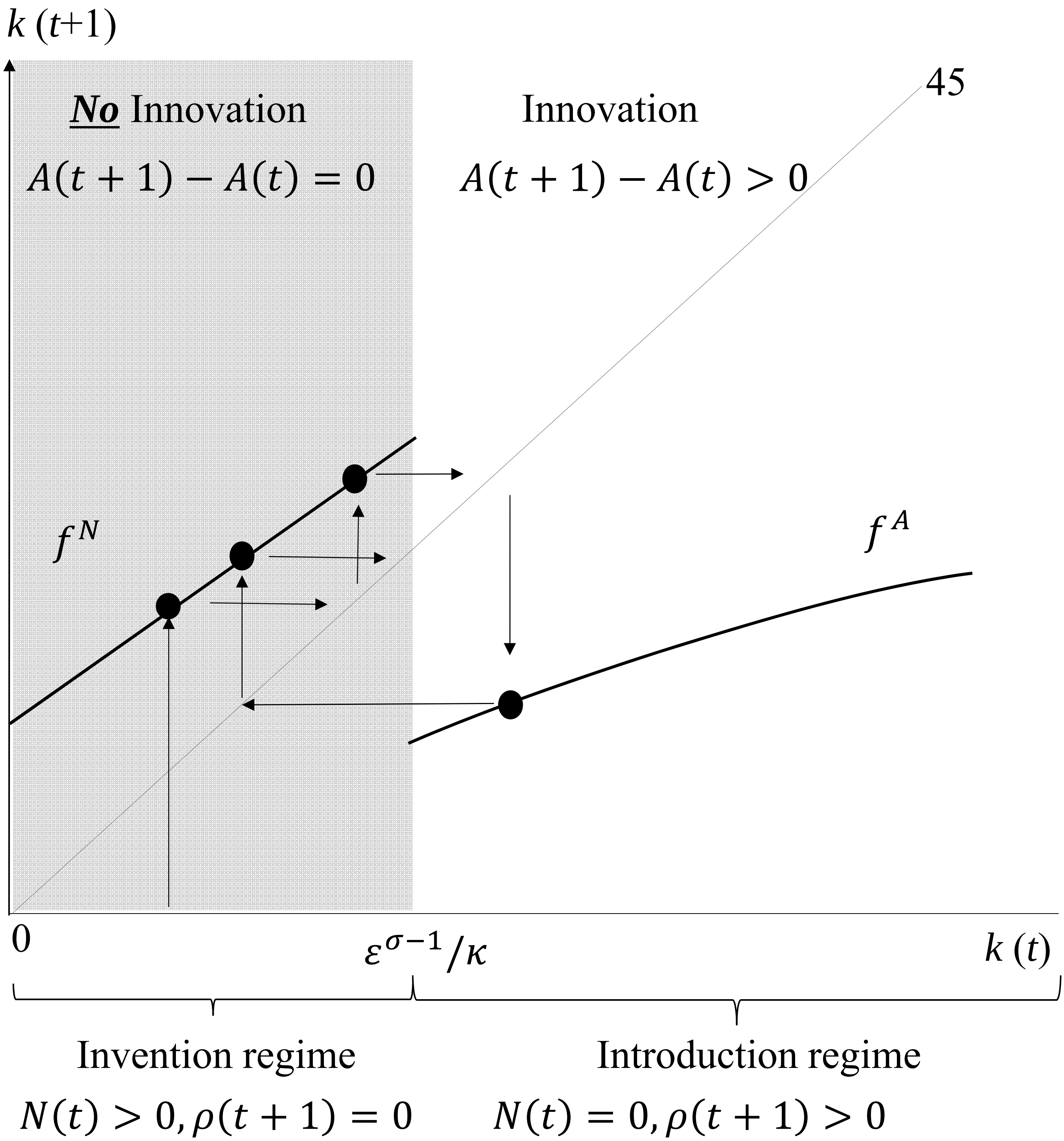


Figure 6b: Innovation Cycles

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

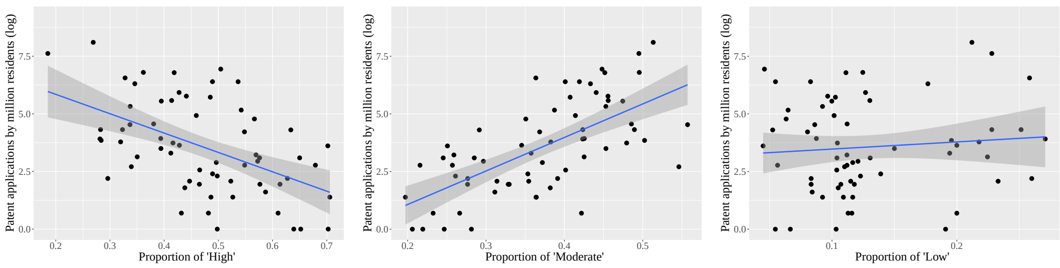
(a) Grouping for Figure 1

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	
-4	Not asked in survey	*Removed
-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	
-4	Not asked in survey	*Removed
-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

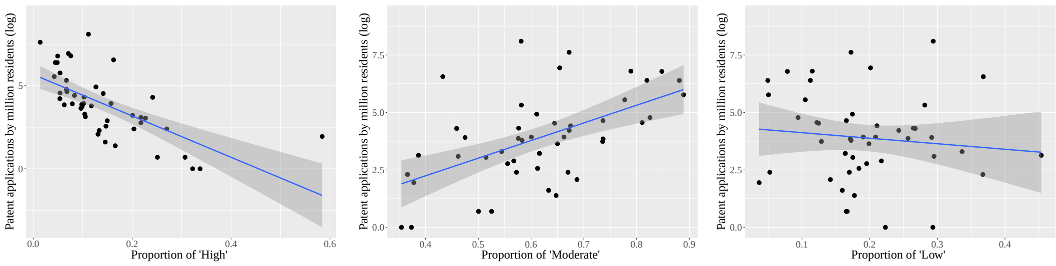
Another option is to use different questions in the World Values Survey. Following Bénabou et al., we perform a similar analysis with Question E046 (New and old ideas). See Table C.2. We consider a person who answered 10 to be the most receptive and 1 the least receptive. For each country, we calculate 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