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Novelty-Seeking Traits and Innovation*

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Abstract

People's desire for novelty is often perceived to encourage innovation. However, our cross-country evidence suggests that the relationship can be negative. To explain this empirical finding, we develop a new R&D-based growth model which incorporates people's novelty-seeking traits. In our model, people's novelty-seeking traits are captured by their extra preference towards new goods; besides, innovation is achieved through new and existing product development as two separate processes of innovation, both requiring costly and time-consuming investment activities. We find that if the level of inherent novelty seeking is higher than some threshold level, then the economy is caught in an underdevelopment trap with less innovation; otherwise, it provides innovation perpetually and achieves long-run growth. Our model shows that the effects of higher levels of inherent novelty seeking on innovation and economic growth can be negative. Our result suggests an essential role of the public's preference for novelty in designing a more favorable economic institution and policy that support innovation and growth.

Keywords: Novelty-seeking traits, DRD4, Innovation, Economic growth

JEL classification: E32, O40, Z10

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1 Introduction

It is generally believed that people's desire for new ideas or novelty seeking traits are important for innovation. For example, Fagerberg (2005, 2013) argues that "'openness' to new ideas, solutions, etc. is essential for innovation" because innovation requires people and firms to "search widely for new ideas, inputs and sources of inspiration." Since innovation is widely recognized as a major driver for long-run growth, one may also think that the people's preferences for novelty are pivotal to economic growth and development.

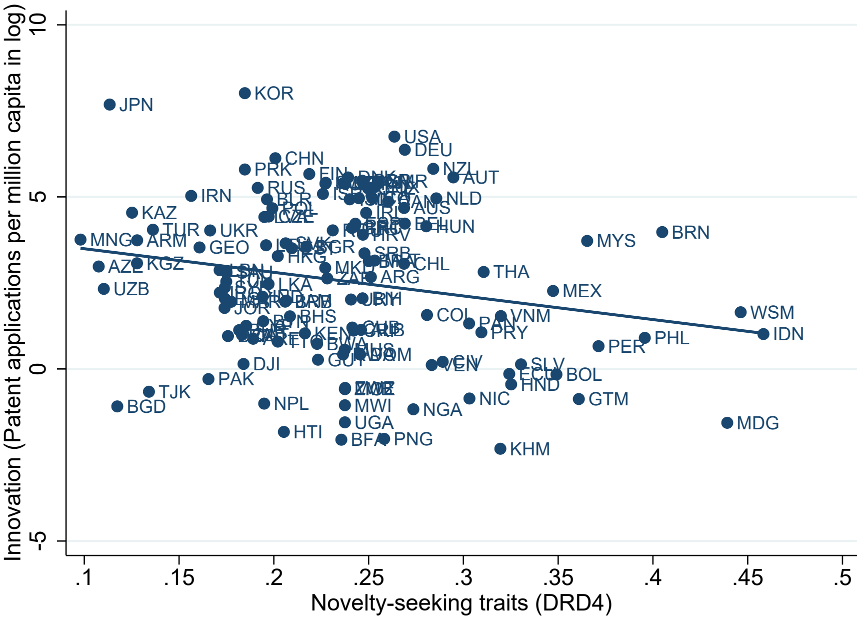

Figure 1: Novelty-seeking traits and innovation: Cross-country relationship. The slope of the fitted line is -6.859 (robust standard error $= 2.627$).

However, as shown in Figure 1, there is a negative and significant relationship between innovation (measured by log Patent applications per million capita)[1] and people's novelty-seeking traits (measured by DRD4, a measure of human personality trait of novelty-seeking behavior).[2] On the other hand, Gören (2017b) documents a robust positive relationship between DRD4 and scientific knowledge creation (measured by number of scientific and technical journal articles per 1,000 people).[3] Recent evidence, thus, suggests that the relationship between the public desire for novelty and innovation (or knowledge creation in general) is not so obvious.

What accounts for these seemingly counter-intuitive relationships? How do individuals' preferences towards new ideas affect innovation and growth? We address these

[1]This is one of the most frequently used indices of innovation; see Bénabou et al. (2016) for example.

[2]The DRD4 variable is taken from Gören (2017a). See Section 2 for more details about these variables and a formal regression analysis that identifies a causal relationship. Note that novelty seeking is a widely-accepted psychological concept that is defined as a human personality trait associated with "exhilaration or excitement in response to novel stimuli" (Cloninger 1986).

[3]To be precise, Gören (2017b) considers journal articles published in the fields of physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.

questions by proposing a new economic framework which helps us understand the costs and benefits of novelty-seeking traits to the aggregate economy.[4]

We consider a so-called expanding varieties model of innovation-based growth (Romer 1990). We begin in Section 3 with a particular class of this model in which the innovators of products enjoy temporary monopoly power (see, for instance, Matsuyama 2001 and Acemoglu et al. 2012); new and old products are explicitly distinguished and have separate roles in equilibrium.[5] We extend this class of growth models in two ways. First, we capture consumers' novelty-seeking traits by considering that they can have extra preference for new goods. Second, we incorporate the conventional understanding that (applied) innovation consists of two separate processes, i.e., new product development and existing product development, both involving time and resource consuming investment activities. In our model, then, ideas are first developed as new products, and they can eventually survive as long-lasting products (or simply "old"products) only if investments in existing product development succeed. Assuming that the success is uncertain, whether a new product ultimately survives and takes root in the economy is also uncertain.[6]

These two features are novel to the literature and help us identify a role of novelty-seeking traits in the economy. Most existing models assume that new products automatically become old without any investment, so that they may not be fully equipped to deal with preference for new products relative to old ones. In a different context, some growth-theoretic papers, as explained below, investigate multiple research processes in innovation, but they mainly focus on different roles of basic and applied innovation. In contrast, our model embodies two separate processes of *applied* innovation, both of which are hence *profitable* unlike basic research. This creates a crucial role for agents' preference for newness of products: Firms involved in innovation would decide between two options, investing in new and existing product development. Through the marketplace, the profitabilities of these two investment activities are determined by the extent to which customers prefer new products to existing products. Putting it simply, the inherent novelty-seeking traits of consumers directly encourage firms to invent new products, but discourage them from improving existing products for survival in market equilibrium. If the latter indirect effect dominates, then the effects of novelty seeking traits could be negative. We prove that this always occurs in dynamic equilibrium.

Our main theoretical finding is that when consumers' extra preference for new products is stronger than some threshold level, their economy is trapped in a situation without innovation and growth in the long run. The intuition is as follows: when consumers are too open to novelty, the demand for and profits related to newly-invented products are large, relative to old goods. Firms invest more resources in inventing new products, leaving fewer resources for making products improve and survive by existing product

[4] Gören (2017b) also presents a simple descriptive model to illustrate his hypothesis by *assuming* the aggregate-level benefits and costs of novelty seeking traits for the level of public knowledge (see equation (2) in his paper), which is quite reasonable because it is based on well-known empirical evidence from genetics. In this study, to complement it, we will search for an economic (i.e., inventive and market based) understanding on the benefits/costs of novelty seeking traits.

[5] See also below for more information on this class of growth models.

[6] This is consistent with the nature of technological progress in history, which often referred to as "technological inertia"(Mokyr 1992). In the history of technological innovation, as Mokyr argues, most societies have exhibited a strong resistance to new ideas, experiencing technological stasis. As a result, newly developed products and technologies often fail to survive, despite their ostensible economic superiority. The survival of a new product or technology is a highly uncertain event, and innovation therefore has ever occurred only cyclically (Mokyr 2000, 2004). Examples include various products and technologies such as steam engines and the internet; see, for instance, Diamond (1997) for more details.

development. Since new and existing product development are both indispensable, it depresses innovation and growth in the long run. If the preference for novelty is weaker than the threshold, the economy can achieve self-sustained innovation and growth in the long run through cycles between periods of new and existing product development.[7] We therefore conclude that the inherent novelty seeking traits may negatively affect innovation and growth in the long run. This result, together with our empirical finding, suggests an essential role of the public's preference for novelty in designing a more favorable economic institution and policy that support innovation and growth.

We also consider some extensions to the baseline model in Section 6. There, we have some results confirming our core finding. Specifically, if we relax the assumption of one-period monopoly to assume long-lived monopoly power as in the canonical R&D-based growth models,[8] new and existing product development can coexist in equilibrium, and the equilibrium rate of innovation can be a monotonically decreasing function in the preference for novelty. Therefore, our theory and empirical evidence, both, suggest that individual novelty seeking traits may negatively affect innovation and economic growth at the aggregate level, in contrast to conventional views.[9]

In the main analysis, we assume that the innovator can enjoy only one-period monopoly. While it is relaxed in Section 6 as mentioned above, this assumption is reasonably justifiable because *in reality* patents last for only some fixed period of time, thereby used in various contexts. For example, the one-period monopoly is built in Acemoglu et al.'s (2012) new and tractable environmental growth model of directed technical change. It also plays an essential role in models of endogenous growth and cycles such as Francois and Shi (1999), Matsuyama (1999, 2001), and Furukawa (2015) and non-growth models of innovation cycles (Shleifer 1986, Deneckere and Judd 1992, Gale 1996). Allowing for more than one period monopoly, from a more general viewpoint, Iwaisako and Futagami (2007) identify an essential role of the temporary nature of monopoly in growth cycles in an innovation-based growth model with *finite* patent length.[10] Our paper extends those papers by considering the role of a new preference parameter for novelty seeking traits in innovation, growth, and cycles.

Our paper is closely related to a growing body of literature on culture and growth. Theoretically, 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.[11] Galor and Michalopoulos (2012) and Doepke and Zilibotti (2014) are two other studies closely related to Galor

[7] In the baseline model, as explained here, an innovative economy is always perpetually cyclical. In Section 6, however, we will show that it can also stably converge to a unique balanced growth path, by considering a natural extension of the baseline model.

[8] See Segerstrom et al. (1990), Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992).

[9] To be more accurate, in the empirical analysis, we use the number of new patents as a proxy for innovation, a widely used proxy. In the theoretical analysis, meanwhile, we refer to the growth of the total number of patents/products as *innovation*, following the literature. These two measures for innovation are standard but may seem to lack consistency. However, we can also show that more novelty seeking traits bring about a smaller (flow) number of new patents in equilibrium. This implies that the theory should be sufficiently consistent with the empirical analysis.

[10] See, for instance, Iwaisako and Tanaka (2017) for endogenous growth cycles in an overlapping generations model.

[11] For example, Ashraf and Galor (2013a) show an inverted U-shaped relationship between genetic diversity within a country and regional economic development.

and Moav (2002). Both of them identify the critical role of entrepreneurial traits in innovation and economic growth by considering an endogenous evolution of the fraction of people who exhibit an entrepreneurial spirit (in terms of risk tolerance) and highlight a positive interplay between novelty-seeking personal traits and economic growth at the country level.[12] Empirically, 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.[13] Gören (2017a) finds an inverted U-shaped relationship between novelty-seeking personality traits and per capita GDP and Gören (2017b) documents a robust positive relationship between novelty-seeking traits and scientific knowledge creation, which should capture a noncommercial aspect of innovation.

The present paper contributes to this literature by (a) providing evidence on the country-level relationship between novelty-seeking personality traits and *innovation* and (b) offering a theoretical model which focuses on consumers' preference for new products (relative to old goods) as another aspect of people's novelty-seeking traits in an innovation-based growth model to help understand the possible negative effect of novelty-seeking on innovation and growth.

Our paper is also related to the literature on two-stage innovation models, most of which distinguish 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). Since we think of two separate activities of *applied* innovation, firms earn profit in both stages of innovation. This differs from existing models, in which there is no profit in early, basic research stages of innovation. Our study, thus, complements the literature by considering two commercial stages of innovation.

The remainder of this paper is organized as follows. Section 2 provides a formal empirical analysis on the relationship between novelty-seeking traits and innovation. Section 3 presents the basic model, and Section 4 characterizes the equilibrium dynamics of the model. Section 5 identifies the critical role of novelty-seeking in innovation and growth in the long run. Section 6 provides some extensions of the baseline model. Finally, Section 7 provides concluding remarks.

2 The Relationship between Novelty-Seeking Traits and Innovation

In Figure 1, we observed an unconditional negative relationship between novelty-seeking traits and innovation. In this section, we perform a more formal regression analysis.

[12]See also Chu (2007), who provides the interesting argument that entrepreneurial overconfidence can cause different rates of economic growth across countries. Moreover, Chu and Cozzi (2011) focus on cultural preferences for fertility. In a broader context, 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 novelty seeking and patent on innovation and long-run growth.

[13]See also Bénabou et al. (2015, 2016), who show that innovation can be negatively associated with people's religiosity.

2.1 Empirical specifications and data description

Our baseline regression model is as follows:

$$Innovation_c = \beta_0 + \beta_1 NoveltySeeking_c + \beta_2 X_c + \varepsilon_c. \quad (1)$$

In this regression, c indexes a country, $Innovation_c$ and $NoveltySeeking_c$, are the innovation measure (log Patent applications per million capita) and the novelty-seeking measure (DRD4) respectively, X_c is a vector of other country-level control variables, and ε_c is the error term.

Patent data come from the World Intellectual Property Organization (WIPO) and population data come from the World Bank. To construct $Innovation_c$, we calculate the average patent applications per million capita for each country between 2010 and 2016 and take log. Data for DRD4 are taken from Gören (2017a); this variable refers to the DRD4 exon III allele frequencies which have been found to be associated with the human personality trait of novelty-seeking behavior.[14]

In the vector of country-level control variables X_c, we include log GDP per capita, log Population, intellectual property protection, years of tertiary schooling, net inflow of foreign direct investment as a percentage of GDP, religiosity (share of religious people and share of people believing in God); these control variables are also used in Bénabou et al. (2016). Data for GDP per capita come from the World Bank; data for the net inflow of foreign direct investment (FDI) as a percentage of GDP from the World Development Index (WDI); the index of patent rights comes from Park (2008); data for years of tertiary schooling come from Barro and Lee (2013). To construct the two measures of religiosity, we use the survey questions F034 and F050 of WVS. More specifically, F034 asks whether the respondent is a religious person (the survey question is: "Independently of whether you go to church or not, would you say you are ..." with possible answers 1 ("A religious person"), 2 ("Not a religious person"), and 3 ("A convinced atheist").) F050 asks whether the respondent believes in god (the survey question is: "Which, if any, of the following do you believe in? ... God" with possible answers 0 ("No") and 1 ("Yes").) Note that the control variables also country-level means between 1990 and 2010 except that the two religiosity measures are means between 1981 and 2002.

Certainly, estimating (1) by OLS only tells us the association between $Innovation_c$ and $NoveltySeeking_c$ rather than causality. When some observable or unobservable factors correlated with both $Innovation_c$ and $NoveltySeeking_c$ are not included in the regression model, endogeneity will likely bias the OLS estimates. To address this concern, we use instrumental variables (IV) estimations. Specifically, Gören (2016) has shown that DRD4 is associated with people's "migratory distance" from East Africa and such biogeographic indicators as latitude, land suitability for agriculture, and pasture land. Gören (2017a) uses these variables as the instruments for the DRD4 measure to study the relationship between novelty-seeking traits and economic development.[15]

In our context, we estimate 2SLS regressions using the following as the first-stage regression and (1) as the second-stage regression:

$$NoveltySeeking_c = \gamma_0 + \gamma_1 IV_c + \gamma_2 X_c + \eta_c, \quad (2)$$

where IV_c is the vector of instruments used by Gören (2017a). To the extent that IV_c is not correlated with the error term ε_c in (1), the instruments should be valid for the DRD4 measure.

[14] For further details about this measure, see Gören (2016) and the references therein.

[15] See Gören (2017a) for the detailed descriptions of these variables.

2.2 Empirical results

Table 1 shows the summary statistics of the sample. Since the variables are constructed using different data sources, the numbers of non-missing values for these variables are different.

In Table 2, we report our OLS regression results. In all specifications, we report robust standard errors in parentheses. In Column (1), we regress $Innovation_c$ on $NoveltySeeking_c$ together with various country-level characteristics, except the religiosity variables. Finally, Bénabou et al. (2016) find that innovation is negatively related to people's religiosity; in Columns (2) and (3), we further control for the share of religious people and the share of people believing in God. In these different specifications, we find that the coefficients of $NoveltySeeking_c$ are negative and statistically significant. These OLS regression results suggest that there is a negative relationship between the two variables.

To address the potential endogeneity problem, we estimate a set of 2SLS regressions. Table 3 reports the second-stage of the 2SLS regression results. Columns (1)-(3) use all the instruments of Gören (2017a), including migratory distance, pasture land (its mean, square, and standard deviation), elevation (its mean, square, and standard deviation), and agricultural suitability (its mean, square, and standard deviation); all instruments are ancestry adjusted; Columns (4)-(6) the ancestry adjusted migratory distance as the only instrument. In both sets of regressions, we still find that the coefficients of $NoveltySeeking_c$ are negative and statistically significant. The corresponding first-stage results are in Table 4.

Between the two sets of results, those in Columns (4)-(6) are preferred because the Kleibergen-Paap rk Wald F-statistics are higher than the corresponding values in Columns (1)-(3). In particular, the F-statistics in various specifications in Panel B are above 10 (i.e., weak identification should not be a problem, Staiger and Stock 1997). In other words, the second-stage results based on the instrument ancestry-adjusted migratory distance should be more reliable.

In terms of economic magnitudes, consider a 10% increase in the DRD4 measure from its mean (about 0.024). The results in Columns (4)-(6) imply that such an increase is associated with decreases in patent applications per million capita by about 20% to 23%. Therefore, the effect is not only statistically significant but also economically significant. To summarize, in this section, we find a robust negative relationship between novelty-seeking traits and innovation. These results motivate our theoretical analysis in the next section.

3 An Innovation-based Growth Model with New and Existing Product Development

This section presents our basic innovation-based growth model, in which innovation occurs endogenously as a product of the firms' profit-seeking R&D investment and thereby the variety of goods increases over time, following Romer (1990). In this section, we at first proceed with the assumption that firms can only enjoy temporary (one period) monopoly power, as in Matsuyama (1999, 2001) and Acemoglu et al. (2012). This is because in this class of models, new products and old products play separate but essential roles in equilibrium, which facilitates the modelling of novelty seeking as will be apparent later. In Section 6, this assumption of one-period monopoly will be relaxed.

To investigate the role of novelty-seeking traits of optimizing agents, our model has two new assumptions: First, we divide the innovation process into two phases, new product development and existing product development, both requiring the R&D investment by profit-seeking firms, based on the conventional view. Then, we assume that the representative agent is endowed with innate novelty seeking traits, so that he/she would prefer new products to old products.[16]

3.1 Consumption and Novelty-Seeking Traits

There is an infinitely lived representative agent who inelastically supplies L units of labor in each period. The representative agent solves the standard dynamic optimization of consumption and saving over an infinite horizon:

$$\max U = \sum_{t=0}^{\infty} \beta^t \ln u(t), \tag{3}$$

where $\beta \in (0,1)$ is the time preference rate and $u(t)$ is an index of consumption in period t. We assume that periodic utility u is defined over differentiated *consumption* goods, each indexed by j.[17] Namely, the agent is endowed with so-called love of novelty preferences. As is standard, we consider a constant elasticity of substitution utility function:

$$u(t) = \left(\int_{j \in A(t) \cup N(t)} (\nu(j,t)\ x(j,t))^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}}, \tag{4}$$

where $x(j,t)$ is the consumption of good j in period t, $\sigma \geq 1$ is the elasticity of substitution between any two consumption goods, and $\nu(j,t)$ is a variable determining the consumer's preference for each good, j. Since new goods can be invented by profit-seeking firms in any period, the consumption goods are naturally categorized into two types: new goods and old goods. Let $N(t)$ be the set of new goods invented in period t and $A(t)$ be the set of old goods. For simplicity of the description, let $A(t)$ and $N(t)$ also denote the number (measure) of goods.

In considering people's innate traits of novelty-seeking, we assume that the representative agent is endowed with "love of novelty" preferences, in addition to the standard love of variety preferences.

Let us first see a benchmark in which the consumer prefers new goods and old goods equally. In this case, all goods should have identical $\nu(j,t)$ for all $j \in A(t) \cup N(t)$. Normalizing this parameter to 1, the consumer's utility function can be written as

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

[16] In this literature, some models have physical capital accumulation (e.g., Matsuyama 2001). To make our analysis tractable, we abstract from this aspect since our focus is on preferences to new products, innovation, and innovation-driven growth.

[17] This follows Grossman and Helpman (1991, ch. 3). In our model, thus, the variety of consumption goods endogenously increases over time, unlike in the original Romer model (in which the variety of intermediate goods increases). Therefore, in the present model, patents are granted for consumption goods, but they are often for intermediate goods in reality. Nevertheless, we adopt the present setting because we are interested in modeling consumers' novelty-seeking traits. Note, however, that we can obtain similar results even if we consider an expanding variety of *intermediate* goods.

Now suppose that the consumer has some *extra* preference, ν, for *novelty* as the state that a good is new. It follows that

$$u(t) = \left(\int_{j \in A(t)} x(j,t)^{\frac{\sigma-1}{\sigma}} dj + \nu \int_{j \in N(t)} x(j,t)^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}}.$$

When $\nu = 1$, the consumer has no preference to novelty, preferring all goods equally. The higher $\nu > 1$, the stronger the consumer's preference to novelty. Therefore, to model the degree of consumer's (inherent) novelty seeking, we assume that

$$\nu(j,t) = \begin{cases} 1 & \text{if } j \in A(t) \text{ (old goods)} \\ \nu & \text{if } j \in N(t) \text{ (new goods)} \end{cases}. \tag{5}$$

Since people in different regions or cultures can have different degrees of novelty seeking on average (Chandrasekaran and Tellis 2008, Tellis et al. 2009), we can regard ν as an intrinsic parameter on the preference that historically and culturally characterizes a society. This theoretical definition of novelty-seeking is also closely related to the empirical counterpart (DRD4), which measures the human personality trait of novelty-seeking behavior.[18]

The infinitely lived consumer solves static optimization in (3); as is well known, we have the demand functions:

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

where the consumer's spending on differentiated goods is:

$$E(t) \equiv \int_{j \in A(t) \cup N(t)} p(j,t)x(j,t)dj, \tag{7}$$

$P(t)$ is the usual price index, defined as:

$$P(t) \equiv \left(\int_{j \in A(t) \cup N(t)} (p(j,t)/\nu(j,t))^{1-\sigma} dj \right)^{\frac{1}{1-\sigma}}, \tag{8}$$

and $p(j,t)$ is the price of good j in period t. Solving dynamic optimization, we also obtain the Euler equation:

$$\frac{E(t+1)}{E(t)} = \beta(1 + r(t)), \tag{9}$$

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

[18] If we allow $\nu < 1$, then consumers can prefer old goods to new goods. Our model would predict that too high or too low ν would discourage innovation. Empirically, one may use data from survey question E046 of the World Values Survey (WVS) as a proxy for ν when it can be less than 1. In particular, this survey question asks respondents to give a score to the statement "Ideas stood test of time better vs New ideas better," and the score ranges from 1 ("Ideas that stood test of time are generally best") to 10 ("New ideas are generally better than old ones"). In other words, lower scores would indicate the case of $\nu < 1$. In unreported OLS regressions, we find that the E046 score and $Innovation_c$ has an inverted-U relationship.

3.2 Production

There is a continuum of firms producing consumption goods $j \in A(t) \cup N(t)$. Each good j, a new or old good, 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 good j, and monopolistically sells them to the consumer. The marginal cost is, thus, 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 of $\sigma = 1$, we introduce an upper bound of the mark-up, say, $\mu > 1$. This upper bound μ is often interpreted as so-called patent breadth in the literature (see, e.g., Li 2001, Goh and Olivier 2002, Iwaisako and Futagami 2013, Chu et al. 2016).[19] As is standard, we assume $\mu \leq \sigma/(\sigma-1)$.[20] Accordingly, each firm sets a monopolistic price at:

$$p(j,t) = \mu w(t) \tag{10}$$

for all j. Using (5), (6), and (10), the output and monopolistic profit for a new good are given by:

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

and

$$\pi(j,t) = \nu^{\sigma-1}\frac{\mu-1}{\mu^\sigma}E(t)\left(\frac{w(t)}{P(t)}\right)^{1-\sigma} \equiv \pi^n(t) \text{ for } j \in N(t). \tag{12}$$

Equation (12) shows that when $\sigma > 1$, the profit for a new good, $\pi^n(t)$, increases with novelty-seeking ν and the total expenditure, $E(t)$, and decreases with the real wage, $w(t)/P(t)$. When $\sigma = 1$ (the Cobb-Douglas case), meanwhile, it becomes independent of novelty-seeking ν, as well as the real wage, $w(t)/P(t)$.

We can also derive the output and monopolistic profit for an old good, from (5), (6), and (10):

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

and

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

The profit $\pi^a(t)$ associated with an old good is always free from novelty-seeking ν.

3.3 Innovation

In this section, we present two stages of innovation: new and existing product development. First, research and development (R&D) firms invent new consumption goods.

[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). We can easily justify the existence of a price upper bound, or patent breadth, by considering potential imitators whose production cost increases with patent breadth, μ. In a different context, μ can also be seen as a result of price regulation (Evans et al. 2003).

[20] Note that, as shown later, our result can hold when $\mu = \sigma/(\sigma-1)$, that is, when there is no upper bound of a mark-up.

Since new goods will be obsolete without any further investments, firms would invest in existing product development. If investments succeed, new goods will survive, called "old" goods.[21]

3.3.1 New Product Development

There is a potentially infinite number of R&D firms. A firm can invent a new good in period t by making an investment of $1/A(t-1)$ units of labor in period $t-1$. We follow Romer (1990) to consider "external effects arising from knowledge spillovers" of the stock of existing technologies, represented by $A(t-1)$. For simplicity, there is no spillover from newly invented goods, since we suppose that they are so new that their information would not be diffused well. Nevertheless, even if we allow for new goods in the stock of existing technologies, the main results will not qualitatively change. Firms that invent new goods earn a monopolistic profit in period t, $\pi^n(t)$.

As we already mentioned, we assume that the monopolistic firm can enjoy only a temporary (one-period) monopoly in the baseline model, following some endogenous growth models such as Francois and Shi (1999), Matsuyama (1999, 2001), and Acemoglu et al. (2012). The free entry condition for new product development can be written as:

$$W^n(t-1) \equiv \frac{\pi^n(t)}{1+r(t-1)} - \frac{w(t-1)}{A(t-1)} \leq 0 \text{ for } t \geq 1 \tag{15}$$

where $W^n(t-1)$ denotes the discounted present value of inventing a new good. Denote as $R^N(t-1)$ the units of labor devoted to new product development in period $t-1$. Then we have

$$N(t) = A(t-1)R^N(t-1). \tag{16}$$

3.3.2 Existing Product Development

Due to the one-period nature of monopoly power, the new goods, $N(t)$, invented in period t can potentially be manufactured by any firms in the subsequent period, $t+1$. The goods are, at this point, no longer new but "existing." We assume that each good becomes obsolete unless investments for survival are made and succeed. We call this second stage of innovation existing product development. Specifically, by investing one unit of labor, an R&D firm engages in existing product development, searching through the set of the new goods, $N(t)$. The firm successfully make $\chi(t)$ units of new goods survive. The firm, then, enjoys a one-period monopoly for those $\chi(t)$ goods, earning the profits of $\chi(t)\pi^a(t+1)$. The free entry condition for existing product development can be given as:

$$W^a(t) \equiv \frac{\chi(t)\pi^a(t+1)}{1+r(t)} - w(t) \leq 0 \text{ for } t \geq 0, \tag{17}$$

in which $W^a(t)$ denotes the discounted present value for existing product development. Concerning $\chi(t)$, we consider a simple technology, $\chi(t) \equiv \kappa N(t)$, in which $\kappa \in (0,1)$ is a

[21] One may relate these two stages to product innovation and process innovation, respectively, given that product innovations are defined as the introduction of a new good and process innovations typically include not only cost reduction activities but also quality improvements of products (see paragraphs 156 and 164 of the Oslo Manual (OECD (2005)).

productivity parameter.[22] With this function, we assume that firms can find more new goods when there are more new goods in the marketplace.

Through this process, the new goods of $N(t)$ are partially converted into the old goods, whose number is expressed as $A(t+1) - A(t)$. Denote as $R^A(t)$ the units of labor devoted to existing product development in period t. Then we have

$$A(t+1) - A(t) = \chi(t) R^A(t) \leq N(t). \tag{18}$$

For simplicity, we assume that none of old goods becomes obsolete, although it is easy to allow for some depreciation for $A(t)$ without rendering any essential change to the result. For descriptive purpose, we define $\rho(t)$ as a macroeconomic rate at which new goods survive to be transformed into old goods:

$$\rho(t+1) \equiv \chi(t) R^A(t)/N(t). \tag{19}$$

In the subsequent period, $t+2$, due to the temporary monopoly again, the "new" old goods, $A(t+1) - A(t)$, can be produced by any firms potentially. We follow Acemoglu et al. (2012), by assuming that monopoly rights will be, then, allocated randomly to a firm drawn from the pool of potential firms. Consequently, in our model, goods are all monopolistically competitively produced in equilibrium.[23]

3.4 Labor Market

As shown in (12) and (14), the real wage $w(t)/P(t)$ is an important component of the profits. It is, thus, beneficial to have

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

which uses $p(j,t) = \mu w(t)$ for any $j \in A(t) \cup N(t)$ with (8). The labor market clearing condition is:

$$L = \int_{j \in A(t) \cup N(t)} x(j,t) dj + R^N(t) + R^A(t). \tag{21}$$

The left-hand side in (21) denotes the labor supply, and the right-hand side denotes the labor demand for production, new product development $R^N(t)$, and existing product development $R^A(t)$ in each period t. It is useful to derive the labor demand from the production sector as

$$\int_{j \in A(t) \cup N(t)} x(j,t) dj = \frac{1}{\mu} \frac{E(t)}{w(t)}, \tag{22}$$

which uses (11), (13), (20), and (21).

[22] From a broader perspective, this κ can relate to firms' absorptive capacity (Cohen and Levinthal 1989).

[23] Alternatively, we could also proceed in such a way that goods are sold at a perfectly competitive price (e.g., Matsuyama 2001). However, we understand that this option will complicate the analysis without garnering any new insights. In addition, the interaction between monopolistic and competitive sectors is interesting but out of our scope. In the present paper, thus, we keep the analysis as simple as possible to highlight the main issue discussed in the introduction.

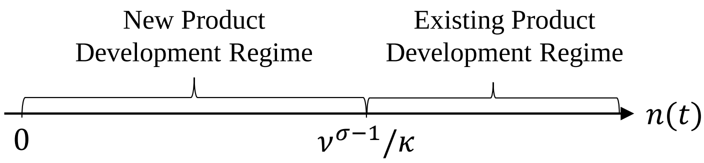

Figure 2: An Illustration for Lemma 1

4 Equilibrium Dynamics

We are now ready to derive the dynamical system that characterizes the law of motion for the equilibrium trajectory of the economy. In doing this, it is beneficial to define $n(t) \equiv N(t)/A(t)$, which is the ratio of new to old goods. By the free entry conditions in (15) and (17), along with (12) and (14), we derive the following lemma.

Lemma 1 *Only new product development takes place in equilibrium when* $n(t) < \nu^{\sigma-1}/\kappa$. *Only existing product development takes place when* $n(t) > \nu^{\sigma-1}/\kappa$.

Proof. Suppose that firms invest in new product development in equilibrium. Then, the free entry condition (15) must hold with equality (giving firms a zero net payoff). With (17), this equality implies $n(t) \leq \nu^{\sigma-1}/\kappa$. Here the profit functions, (12) and (14), have been used with the price index in (20). Where $n(t) < \nu^{\sigma-1}/\kappa$, i.e., (17) holds with inequality, there is no investment in existing product development in equilibrium. Using this fact, one can easily prove the first half of the lemma. An analogous proof can be applied to the second half. ■

The result of Lemma 1 is illustrated in Figure 2. The cut-off level of $n(t)$, $\nu^{\sigma-1}/\kappa$, generates two regimes in the economy. The first corresponds to $n(t) \in (0, \nu^{\sigma-1}/\kappa)$, which we call a new product development regime. The second corresponds to $n(t) \in (\nu^{\sigma-1}/\kappa, \infty)$, which we call an existing product development regime. 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 new and existing product development, more or less, at any point in time. We can easily remove this unrealistic aspect concerning specialization from the model by, as we do in Section 6, allowing the innovator long-lived monopoly or simply introducing an exogenous growth factor. As will be apparent later, either change to the baseline model could provide another interesting analysis but make the analysis less tractable. Thus we adopt the present setting for simplicity.

In each period, t, the value of $n(t)$ should be supposed to be given, since it is a pre-determined (stock) variable. In the hypothetical situation in which $n(t)$ is taken as given, Lemma 1 implies that, for a given $n(t)$, an economy is more likely to engage in new product development if (and only if) the individual novelty-seeking traits, ν, are stronger and/or the productivity for existing product development, κ, is lower. This is because there is a higher relative profit for the invention of a new good, to the investment for existing goods' survival, when the consumer prefers new goods to existing goods more strongly (due to larger ν) and/or the cost for survival investments is higher (due to lower κ). The development of technologies that earn a higher profit is encouraged in market equilibrium. For the analogous reason, an economy is more likely to engage in existing

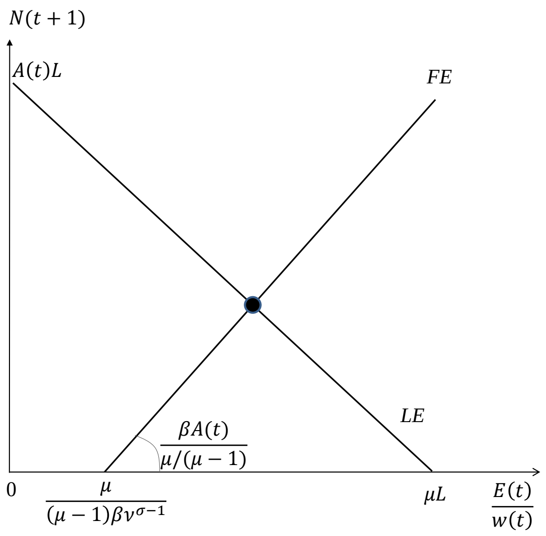

Figure 3: New Product Development Regime

product development when $\nu^{\sigma-1}/\kappa$ is smaller, in which case there is a higher relative profit for survival investments.

4.1 New Product Development Regime

With $n(t) < \nu^{\sigma-1}/\kappa$, by Lemma 1, the economy falls into the new product development regime. With (9), (15), (12), and (20), the free entry condition for invention, $W^n(t) = 0$, becomes:

$$N(t+1) = \frac{A(t)}{\nu^{\sigma-1}}\left[\frac{\beta\nu^{\sigma-1}}{\mu/(\mu-1)}\frac{E(t)}{w(t)} - 1\right], \tag{23}$$

which uses $A(t+1) = A(t)$ (or $\rho(t+1) = 0$). Given $A(t)$, this describes a profit-motive aspect of the inventive activity; the larger the discounted profit from selling new goods $((\beta\nu^{\sigma-1}(\mu-1)/\mu)E(t)/w(t))$, the greater the incentives for firms to invent a new good. The profit for a new good increases as the wage-adjusted expenditure $E(t)/w(t)$ increases and, at the same time, as the consumer's preference for novelty ν increases. Meanwhile, when $n(t) < \nu^{\sigma-1}/\kappa$, no firm has any incentive to invest in existing product development; in such a case, $R^A(t) = 0$. The labor market condition (21), thus, becomes:

$$N(t+1) = A(t)\left[L - \frac{1}{\mu}\frac{E(t)}{w(t)}\right], \tag{24}$$

which uses (16) and (22). Given $A(t)$, the greater the wage-adjusted expenditure $E(t)/w(t)$, the more resources will be devoted to production, leaving less for innovation; this will result in a smaller $N(t+1)$.

Figure 3 depicts (23) and (24), labeled with FE and LE, respectively, which determine the equilibrium number of new goods, $N(t+1)$, and the wage-adjusted expenditure, $E(t)/w(t)$, as a unique intersection. Given the predetermined variable, $A(t)$, the new goods, $N(t+1)$, is increasing in the time preference rate β, the labor force L, and the patent breadth μ. The effect of the elasticity of substitution between goods, σ, is also straightforward. As is standard, σ determines the expenditure share spent on each good. Since $\nu \geq 1$ due to the model's natural property, a higher elasticity of substitution would lead to a higher expenditure share for the new good, resulting in an upward shift of the FE curve in Figure 3. When $\sigma = 1$ (i.e., the case of a Cobb–Douglas preference), any expenditure share is always constant and free from novelty-seeking traits ν. As a result, the new good $N(t+1)$ is increasing in (independent of) the elasticity of substitution σ. All those temporary effects on innovation are natural and standard.

As for the novelty seeking traits ν, a higher ν causes an upward shift in the FE curve. This is simply because the equilibrium profit for new goods, $(\beta\nu^{\sigma-1}(\mu-1)/\mu)E(t)/w(t)$, is higher.[24] The upward shift of the FE curve leads to an increase in $N(t+1)$ in equilibrium. We can formally confirm this effect of ν by solving (23) and (24):

$$N(t+1) = \Theta A(t), \tag{25}$$

where

$$\Theta \equiv \frac{\nu^{\sigma-1}(\mu-1)L - 1/\beta}{\nu^{\sigma-1}\left((\mu-1)+1/\beta\right)}. \tag{26}$$

Equation (25) determines the equilibrium amount of new goods in the new product development regime. The coefficient Θ is increasing in novelty-seeking traits ν as well as the standard parameters β, L, and μ. We can interpret the parameter composite Θ as the potential demand for new goods. We naturally assume $\Theta > 0$ to exclude a trivial case where there is no invention of new goods in any situation, by imposing $\nu^{\sigma-1}\beta(\mu-1)L > 1$, which provides a lower bound of ν as $[1/(\beta(\mu-1)L)]^{1/(\sigma-1)} \equiv \nu_0$. Meanwhile, since $R^A(t) = 0$ and thus $\rho(t+1) = 0$ in the present regime, from (18), the old goods do not grow; $A(t+1) = A(t)$. Therefore, if $\Theta > \nu^{\sigma-1}/\kappa$, it holds that $N(t+1)/A(t+1) \equiv n(t+1) > \nu^{\sigma-1}/\kappa$, whereby the economy moves to the existing product development regime in period $t+1$. Conversely, if $\Theta < \nu^{\sigma-1}/\kappa$, the economy is trapped in the new product development regime. In this situation, $N(t)$ and $A(t)$ are both constant over time, so that there is neither innovation nor growth in the long run.

Lemma 2 *The economy is trapped in the new product development regime if and only if* $\Theta < \nu^{\sigma-1}/\kappa$.

4.2 Existing Product Development Regime

With $n(t) > \nu^{\sigma-1}/\kappa$, by Lemma 1, the economy is in the existing product development regime in period t; $R^A(t) \geq 0$ and $R^N(t) = 0$. Rearranging the labor market condition (21), with (22), yields the survival rate for new goods as:

$$\rho(t+1) = \kappa R^A(t) = \kappa\left(L - \frac{1}{\mu}\frac{E(t)}{w(t)}\right). \tag{27}$$

Analogous to (24), (27) captures the trade-off on resources between the production of goods and the investment in existing product development. With (9), (14), and (17), the free entry condition $W^a(t) = 0$, becomes:

$$\rho(t+1) = \frac{\kappa\beta}{\mu/(\mu-1)}\frac{E(t)}{w(t)} - \frac{A(t)}{N(t)}, \tag{28}$$

[24] See also (12).

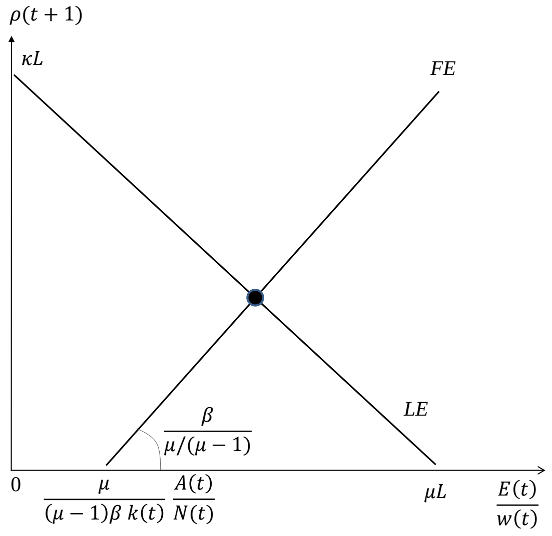

Figure 4: Existing Product Development Regime

which uses $N(t+1) = R^N(t) = 0$ from (16) and $A(t+1) = A(t) + \chi(t)R^A(t) = A(t) + \chi(t)\rho(t+1)/\kappa$ from (18). Naturally, the transformation rate $\rho(t+1)$ increases with the discounted profit from producing the old good $(\beta(\mu-1)/\mu)E(t)/w(t)$. It also increases with the number of new goods $N(t)$, since R&D firms can find more inventions. Figure 4 illustrates how $\rho(t+1)$ is determined by (27) and (28). Solving (27) and (28), we obtain:[25]

$$\rho(t+1) = \frac{1}{1+\beta(\mu-1)} \left(\kappa\beta(\mu-1)L - \frac{A(t)}{N(t)} \right). \tag{29}$$

Using (29), with (18), the growth of old goods follows

$$A(t+1) = A(t)\frac{\beta(\mu-1)}{1+\beta(\mu-1)} \left(1 + \kappa L \frac{N(t)}{A(t)} \right) \tag{30}$$

In the present regime, the new goods do not grow; $N(t+1) = 0$ from (16). This implies $n(t+1) = 0$, which is clearly lower than $\nu^{\sigma-1}/\kappa$. We therefore have the following lemma.

Lemma 3 *The existing product development regime is unstable; the economy here necessarily shifts to the new product development regime.*

5 The Role of Novelty-Seeking Traits in Innovation and Growth

In this section, we will examine the effects of consumers' novelty-seeking traits on innovation and growth in the long run. In doing this, we follow the standard literature

[25]Note that $\rho(t+1) > 0$ always holds, due to $\nu^{\sigma-1}\beta(\mu-1)L > 1$. In order to retain feasibility, we have to ensure that $\rho(t+1) < 1$ holds entirely in the present regime. We do this by imposing $\kappa L < 1 + 1/(\beta(\mu-1))$.

to assume $\sigma > 1$.[26] Lemma 2 shows that in the case with $\Theta < \nu^{\sigma-1}/\kappa$, the economy is fatally caught in the trap with no innovation. In this case, the economy's inventive potential Θ is relatively low, and the consumer's novelty-seeking traits, ν, are relatively strong. On the one hand, the new product development regime is larger due to a high ν. On the other hand, the invention flow $N(t)$ within the regime tends to be low, due to a low Θ. This is why the economy with $\Theta < \nu^{\sigma-1}/\kappa$ can be trapped. To avoid traps, $\Theta > \nu^{\sigma-1}/\kappa$ must hold as shown in Lemma 3. As is common in the standard R&D-based growth model, traps can be avoided only if labor is sufficiently abundant.[27] Specifically, the following lemma holds.

Lemma 4 *The no-trap condition $\Theta > \nu^{\sigma-1}/\kappa$ can hold in equilibrium if and only if*

$$L > [\beta(\mu - 1) + 1 + \kappa]/[\beta\kappa(\mu - 1)] \equiv L_0. \tag{31}$$

Proof. Assuming that

$$D \equiv [\kappa\beta(\mu - 1)L]^2 - 4[\beta(\mu - 1) + 1]\kappa > 0, \tag{32}$$

then $\Theta > \nu^{\sigma-1}/\kappa$ if and only if $\nu^{\sigma-1} \in (\nu_-^{\sigma-1}, \nu_+^{\sigma-1})$ where

$$\nu_-^{\sigma-1} = \frac{\kappa\beta(\mu - 1)L - \sqrt{D}}{2[\beta(\mu - 1) + 1]}, \quad \nu_+^{\sigma-1} = \frac{\kappa\beta(\mu - 1)L + \sqrt{D}}{2[\beta(\mu - 1) + 1]}. \tag{33}$$

From (26), we can see that $\Theta > \nu^{\sigma-1}/\kappa$ if and only if

$$[\beta(\mu - 1) + 1](\nu^{\sigma-1})^2 - \kappa\beta(\mu - 1)L\nu^{\sigma-1} + \kappa < 0. \tag{34}$$

Let $F(\nu^{\sigma-1})$ be the left hand side of the above inequality, which is quadratic in $\nu^{\sigma-1}$. (32) indicates that the determinant of the quadratic equation $F(\nu^{\sigma-1}) = 0$ is strictly positive so that it has real and distinct solutions, which are given by (33). Therefore, $\Theta > \nu^{\sigma-1}/\kappa$ if and only if $\nu^{\sigma-1} \in (\nu_-^{\sigma-1}, \nu_+^{\sigma-1})$.

Recall that $\nu \geq 1$. If $1 > \nu_+^{\sigma-1}$, then $\nu^{\sigma-1} > \nu_+^{\sigma-1}$ for all ν. By the above argument, we must have $\Theta < \nu^{\sigma-1}/\kappa$ for all ν. In other words, it is possible that $\Theta > \nu^{\sigma-1}/\kappa$ holds in equilibrium if and only if $\nu_+^{\sigma-1} > 1$, which is equivalent to (31).[28]

Finally, if (32) does *not* hold, i.e., $D \leq 0$ holds, $F(\nu^{\sigma-1})$ is always positive, so that inequality (34) is always violated. Thus, $\Theta < \nu^{\sigma-1}/\kappa$ always holds in this case. Potentially, we also have to exclude this case; however, (32) always holds if (31) holds. Therefore,

[26] If $\sigma = 1$, the consumption goods are independent goods, so that the expenditure share between new and old goods is constant, free from novelty-seeking ν. Note that under $\sigma = 1$, the condition in Lemma 2 becomes independent of ν.

[27] This is due to the well-known 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: As Boserup (1965) argues, population growth often 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. The empirical finding of Kremer (1993) also suggests that total research output increases with population. Consistent with these views, Lemma 1 shows that population size affects technological progress in the long run. The threshold level of L in (31), L_0, comprises several parameters. Since, for instance, L_0 decreases with κ, the productivity of firms has a role in avoiding traps, which is natural and intuitive.

[28] Note that $\nu_+^{\sigma-1} > 1$ implies that $F(1) = [\beta(\mu - 1) + 1] - \kappa\beta(\mu - 1)L + \kappa < 0 < 0$, which can be rewritten as (31).

(31) is the single condition to avoid the trivial case in which $\Theta < \nu^{\sigma-1}/\kappa$ always holds. ■

This lemma characterizes the parameter range in which the economy has potential for innovating and growing in the long run. Following the standard literature, we assume that (31) holds so as to avoid the trivial case of any economies getting trapped in the no-innovation situation.

The role of novelty-seeking traits ν in achieving $\Theta > \nu^{\sigma-1}/\kappa$ is not obvious, since Θ is increases with ν. On the one hand, higher ν directly makes the invention of new goods profitable relative to the investment in existing product development. As a result of this relative profitability effect, the new product development regime $(0, \nu^{\sigma-1}/\kappa)$ will become large, whereby the economy is more likely to get trapped in the new product development regime. However, higher ν also leads to a larger potential demand Θ, so that there are more new goods $N(t)$ to be created in the new product development regime. This leaves more incentives for firms to engage in existing product development, noting that new goods are the essential source of existing product development. With this positive indirect effect of ν, the economy is more likely to jump out of the new product development region. These two opposite effects interact to create an equilibrium role for ν. The following theorem proves that the direct negative effect dominates in equilibrium.

Theorem 1 *Under the assumption of (31),* $\Theta > \nu^{\sigma-1}/\kappa$ *holds for* $1 < \nu^{\sigma-1} < \nu_+^{\sigma-1}$ *and* $\Theta \leq \nu^{\sigma-1}/\kappa$ *holds for* $\nu^{\sigma-1} \geq \nu_+^{\sigma-1}$.

Proof. Essentially, we need to show that the lower bound of $\nu^{\sigma-1}$ is inside $(\nu_-^{\sigma-1}, \nu_+^{\sigma-1})$, i.e., $\nu_-^{\sigma-1} < 1 < \nu_+^{\sigma-1}$. If this is true, then by the proof of Lemma 4, when $1 < \nu^{\sigma-1} < \nu_+^{\sigma-1}$, we have $\Theta > \nu^{\sigma-1}/\kappa$ and when $\nu^{\sigma-1} \geq \nu_+^{\sigma-1}$, we have $\Theta \leq \nu^{\sigma-1}/\kappa$.

We prove by contradiction and suppose $1 < \nu_-^{\sigma-1} < \nu_+^{\sigma-1}$. From (33), $1 < \nu_-^{\sigma-1}$ implies that:

$$\kappa\beta(\mu-1)L - 2[\beta(\mu-1)+1] > \sqrt{D}. \tag{35}$$

The left hand side of (35) cannot be negative since $\sqrt{D} > 0$ under (31). Therefore, we must have:

$$\kappa\beta(\mu-1)L > 2[\beta(\mu-1)+1]. \tag{36}$$

Since $1 < \nu_-^{\sigma-1}$, $F(1)$ must be positive, i.e., $F(1) = [\beta(\mu-1)+1] - \kappa\beta(\mu-1)L + \kappa > 0$, implying that:

$$\kappa\beta(\mu-1)L < [\beta(\mu-1)+1] + \kappa. \tag{37}$$

Note that $2[\beta(\mu-1)+1] - \{[\beta(\mu-1)+1]+\kappa\} = \beta(\mu-1)+1-\kappa > 0$. Therefore, the inequalities in (36) and (37) cannot hold at the same time. In other words, (35) cannot hold, so that we must have $\nu_-^{\sigma-1} < 1 < \nu_+^{\sigma-1}$. ■

The results of Lemma 4 and Theorem 1 are illustrated in Figure 5. According to Theorem 1, when the novelty-seeking preference ν is low enough, such that $\nu < \nu_+$, $\Theta > \nu^{\sigma-1}/\kappa$ holds. By Lemmata 2 and 3, in this case, the economy moves between the two regimes perpetually. More specifically, in a period, say t, in which the economy is with $n(t) < \nu^{\sigma-1}/\kappa$, it invests in new product development and invents an enough number of new goods for the next period, $N(t+1) > 0$. Then, in period $t+1$, investments are made in existing product development for $N(t+1)$ goods' survival, by which some of new goods successfully survive to become old goods, $A(t+2) > A(t+1)$. In period $t+2$, from Lemma 3, the economy goes back in the new product development regime. This

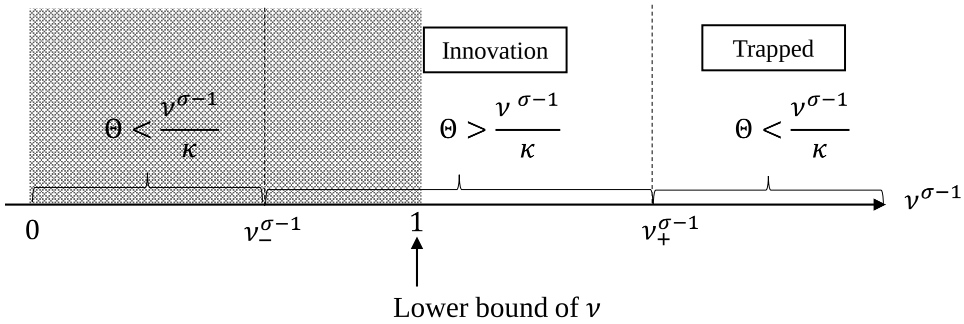

Figure 5: Lemma 4 and Theorem 1: An Illustration.

cycle will repeat itself permanently, whereby both $N(t)$ and $A(t)$ grow over time, going for infinity. There is self-sustained innovation in the long run. The following proposition summarizes our finding.[29]

Proposition 1 *If the infinitely lived consumer's novelty-seeking traits ν are weaker than the threshold level ν_+, the economy achieves innovation perpetually, through cycles between new and existing product development regimes. If the novelty-seeking traits ν are stronger, it is trapped in the situation with no innovation. All in all, inherent novelty seeking negatively affects innovation and economic growth in the long run.*

Proof. Concerning the result on innovation, it is straightforward from Lemmata 1–4. To see the role for growth, we follow the standard definition of an economic growth rate: $\gamma(t) \equiv (u(t+1) - u(t))/u(t)$. By using (4), (11), (13), and (20), we obtain $u(t) = \tilde{u}(t)A(t)^{\frac{1}{\sigma-1}}$, where $\tilde{u}(t) = (E(t)/w(t))\,(1 + \nu^{\sigma-1}N(t)/A(t))^{\frac{1}{\sigma-1}}$ includes the wage-measured expenditure, $E(t)/w(t)$, and the fraction of new goods, $N(t)/A(t)$. When $\Theta < \nu^{\sigma-1}/\kappa$, the trapped economy provides $N(t) = \Theta A(t)$, in which $E(t)/w(t)$ and $A(t)$ are constant over time. The number of consumption goods are constant, and the growth rate $\gamma(t)$ is equal 0, completing the proof. ∎

Our theoretical finding can provide a possible economic explanation for the negative relationship between novelty-seeking traits and innovation that we document in Section 2. With stronger preferences for newness of goods, the traits positively affects innovation by encouraging firms to develop more new goods. However, provided that *existing* product development is also essential to the entire process of innovation, we need some good balance between new and existing product development. Therefore, too strong novelty-seeking traits can depress innovation, by discouraging firms from investing in existing product development for the survival of existing goods.

So far, we refer to the expansion of the consumption-good space as innovation. One might think that it is not exactly the same as what we call innovation in the empirical analysis, in which we measure innovation by the number (flow) of new "patents." While both measures are standard in their respective context, it is easy to fill that gap. In the theoretical model, we may presume that new patents are filed with new product development or existing product development, or both. The amount of new patents can

[29] Recall that the coefficient Θ is increasing in ν. Thus, novelty-seeking traits can have a positive effect on innovation within the new product development regime. However, as shown in the proposition, the effect is negative from a long-run perspective.

be, thus, expressed as a weighted sum of $N(t+1)$ and $A(t+1) - A(t)$. In a trapped economy (with higher ν), noting (25), both $N(t)$ and $A(t)$ are constant over time, in which the number of new patents is also constant. In an innovative economy (with lower ν), $N(t)$ and $A(t)$ alternately increase on an equilibrium path, which continues permanently. The number of new patents increases over time. As a corollary of Proposition 1, we may state that people's inherent novelty-seeking traits can negatively affect the equilibrium number of new patents, through the mechanism we mentioned above.

6 Extensions

In this section, we explore two extensions to our baseline model. First, our economy features only traps and cycles in dynamic equilibrium. By introducing an exogenous growth factor into the baseline model, we will show that the model can have a balanced growth equilibrium as in the standard growth model. Second, for analytical tractability, we assume the one-period nature of monopoly power. We will relax this assumption and allow for a long lived monopoly, whereby the model will be more akin to the canonical R&D-based growth models (Romer 1990, Grossman and Helpman 1991, Aghion and Howitt 1992). In these extensions, our main message still holds: too strong novelty-seeking traits can depress innovation and economic growth in the long run. Note that these extensions also resolve another limitation of the baseline model, by generating a new equilibrium in which new and existing development coexist.

6.1 Balanced Growth and Path Dependence

To allow for a balanced growth equilibrium, we will add minimal elements to the process of innovation. Following Anderlini et al. (2013), we introduce an exogenous growth factor, $\eta(t) \geq 0$, into new product development;[30] the number of endogenously invented goods, $A(t)R^N(t)$, together with the number of exogenously given ones, $\eta(t)$, determine the dynamics of new goods by $N(t+1) = A(t)R^N(t) + \eta(t)$. For the sake of simplicity, we further assume $\eta(t) = \eta N(t)$, with $\eta \in [0,1)$.[31] When $W^n(t) = 0$, thus, the new good $N(t)$ evolves in the new product development regime due to

$$N(t+1) = \Theta A(t) + \eta N(t), \tag{38}$$

which corresponds to (25). When $W^a(t) = 0$, the free entry condition similar to (28) is now

$$\rho(t+1) = \frac{\kappa\beta}{\mu/(\mu-1)} \frac{E(t)}{w(t)} - \frac{A(t)}{N(t)} - \eta\nu^{\sigma-1}, \tag{39}$$

[30]Exogenous growth factors are often assumed in research for a deeper understanding of, not the cause of it but, the role of technological progress in various phenomena; see, for instance, Lucas and Moll (2014) and Benhabib et al. (2017). Given that our goal in the present paper is to investigate the cause of innovation, our extended model still has the endogenous component, $R^N(t)$, more in accordance with Anderlini et al. (2013), who consider both endogenous and exogenous growth factors in the process of technological progress.

[31]If $\eta > 1$, the new good, $N(t)$, autonomously expands without the help of endogenous new product development. Given the focus of our paper, we should restrict the exogenous growth factor to be lower than 1; $\eta < 1$.

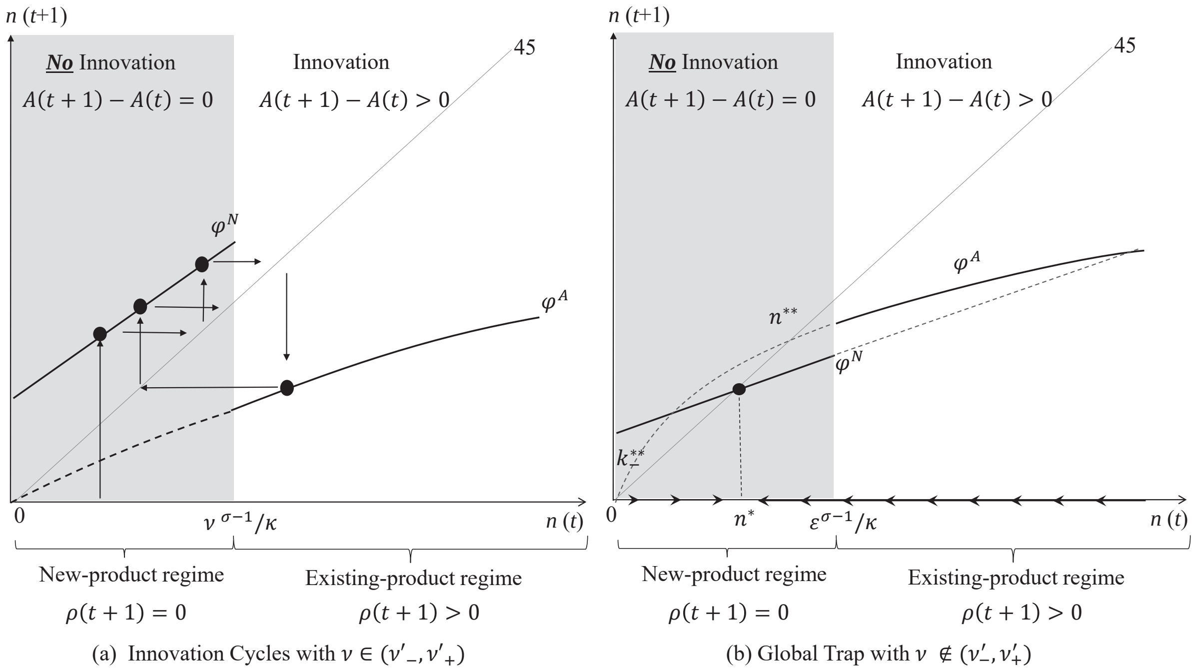

Figure 6: Cycles and Global Traps

which uses $N(t+1) = \eta N(t)$ since $R^N(t) = 0$. From (27) and (39), in the existing product development regime, the old good $A(t)$ evolves due to

$$\rho(t+1) = \frac{1}{1+\beta(\mu-1)}\left(\beta(\mu-1)\kappa L - \frac{A(t)}{N(t)} - \eta\nu^{\sigma-1}\right).^{32} \tag{40}$$

Combining (38) and (40), we can derive the equilibrium dynamic system as:

$$n(t+1) = \begin{cases} \eta n(t) + \Theta \equiv \varphi^N(n(t)) & \text{for } n(t) < \nu^{\sigma-1}/\kappa \\ \frac{\eta(1+\beta(\mu-1))n(t)}{\beta(\mu-1)+(\beta(\mu-1)\kappa L-\eta\nu^{\sigma-1})n(t)} \equiv \varphi^A(n(t)) & \text{for } n(t) > \nu^{\sigma-1}/\kappa \end{cases}, \tag{41}$$

which uses (18).[33] Function φ^N is linear and φ^A is concave, and both are increasing in $n(t)$, each of which has a unique fixed point for $n(t) > 0$, labelled n^* and n^{**}, respectively.

Proposition 1 still holds, but locally; the conditions also change slightly. (A proof requires a tedious sequence of similar calculations, which is omitted here.)[34] Suppose

$$L > \frac{1-\eta}{\kappa}\left(1 + \frac{1}{\beta(\mu-1)}\right) + \frac{1}{\beta(\mu-1)} \equiv L_0',$$

to avoid the trivial case likewise. Then we can revise Lemma 1 as follows: Under the coexistence of endogenous and exogenous innovation, there exists a threshold value of ν, ν_+', such that $\Theta/(1-\eta) > \nu^{\sigma-1}/\kappa$ holds for $1 < \nu < \nu_+'$, and $\Theta/(1-\eta) \leq \nu^{\sigma-1}/\kappa$ for

[32] To ensure feasibility, such that $\rho(t+1) \in (0,1)$ for any $n(t)$, it would suffice to assume $\beta(\mu-1)\kappa L - \left((\beta(\mu-1) + \kappa/\nu^{\sigma-1} + 1\right) < \eta\nu^{\sigma-1} < \beta(\mu-1)\kappa L$.

[33] We also use $A(t+1) = A(t)$ for $n(t) < \nu^{\sigma-1}/\kappa$ and $N(t+1) = \eta N(t)$ for $n(t) > \nu^{\sigma-1}/\kappa$. In order to ensure $n(t+1) > 0$ for any $n(t) > \nu^{\sigma-1}/\kappa$, we impose an upper bound of ν, such that $\nu < [(\kappa/\eta)\beta(\mu-1)L]^{1/(\sigma-1)}$.

[34] A formal proof is available upon request from the authors.

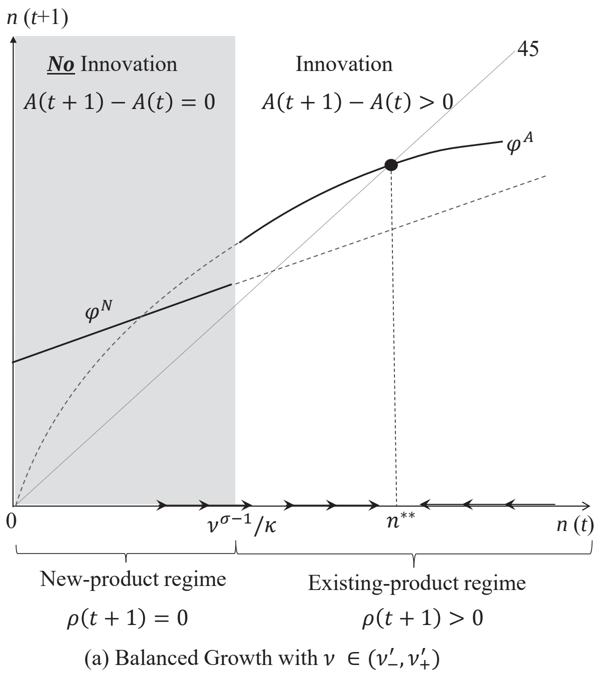

Figure 7: Balanced Growth and Path Dependency

$\nu \geq \nu'_+$.[35] This shows that if (and only if) the consumer's novelty-seeking traits ν are sufficiently strong, there is a *locally* stable trap, n^*. Once the economy falls into the new product development regime, it is trapped and converging to the situation, n^*, in which there is no innovation.

Concerning the existing product development regime, there are two possibilities. First, if n^{**} exists outside this regime, the equilibrium behavior of the economy is quite similar to that in the original model. That is, the economy may achieve innovation and growth perpetually through irregular cycles of new and existing product development, as shown in Figure 6a. Otherwise, it may be fatally caught in the global trap, as shown in Figure 6b.

Second, if n^{**} is included in the existing product development regime, it may work as a globally stable steady state, as shown in Figure 7a. On that point, the number of new goods, $N(t)$, and that of old goods, $A(t)$, grow at the same rate. Therefore, in this case, any path starting from any initial state converges to point n^{**} that gives the economy balanced growth, as in the standard growth model. Figure 7b depicts another interesting case that emerges from the present extension. There are two locally stable steady states; whether the economy converges to a balanced growth path or a 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).

In summary, we demonstrate that the minor change leads to drastically different equilibrium behaviors of the economy such as balanced growth and path dependence; however, the message in our main results does not alter: Stronger novelty-seeking traits negatively affect innovation and growth.

[35]Note that ν'_- and ν'_+ are solutions to the quadratic equation in ν, given by $\Theta/(1-\eta) = \nu^{\sigma-1}/\kappa$, noting $n^* = \Theta/(1-\eta)$. They are quite similar to ν_- and ν_+ in Lemma 1.

6.2 Departing from One-period Monopoly

The purpose of the second extension is to relax the assumption of a one-period monopoly. To achieve this, we consider a stochastic process through which firms can obtain long-lived monopoly power. Specifically, we assume that if an R&D firm that invents a new good in period t invests $z(t)/A(t)$ units of labor in existing product development,[36] it will survive with long-lived monopoly power from period $t+1$ onward at a probability of $s(t+1) = s(z(t)) \in [0,1]$. At the probability of $1 - s(t+1)$, the firm fails to obtain long-live monopoly power, and exits. We consider a simple linear survival function as $s(z) = \psi z$ with $z \geq 0$; see Dinopoulos and Syropoulos (2007) and Eicher and García-Peñalosa (2008) for R&D-based growth models with this kind of endogenous survival of innovations.[37] Here $\psi > 0$ is a productivity parameter. Since $s(z)$ is a probability, $s(z) \leq 1$ must hold, and thus $z \leq 1/\psi$. The law of motion governing the evolution of the old goods $A(t)$ is, thus, given by

$$A(t+1) = A(t) + s(t+1)N(t). \tag{42}$$

The discounted present value of a new good (or a firm inventing a new good) can be described as the following Bellman equation:

$$V^n(t) = \max_{z(t)} \left[\pi^n(t) - \frac{w(t)z(t)}{A(t)} + s(t+1)\frac{V^a(t+1)}{1+r(t)} \right] \tag{43}$$

subject to $s(t+1) = \psi z(t) \in (0,1)$. The discounted present value of a successfully survived firm follows the following Bellman equation:

$$V^a(t) = \pi^a(t) + \frac{V^a(t+1)}{1+r(t)}. \tag{44}$$

Solving optimization in (43), there are three kinds of equilibrium: (i) the value of an old good satisfies

$$\tilde{W}^a(t) \equiv \psi \frac{V^a(t+1)}{1+r(t)} - \frac{w(t)}{A(t)} = 0 \tag{45}$$

for $0 < z(t) < 1/\psi$; (ii) $z(t) = 1/\psi$ holds with $\tilde{W}^a(t) \geq 0$; and (iii) $z(t) = 0$ holds with $\tilde{W}^a(t) \leq 0$. Free entry for new product development ensures

$$W^n(t) \equiv \frac{V^n(t+1)}{1+r(t)} - \frac{w(t)}{A(t)} = 0 \tag{46}$$

for $N(t+1) > 0$.

Here we restrict our analysis to the more interesting interior-solution case, (i), in which new and existing product development coexist; $N(t+1) > 0$ and $1 < z(t) < 1/\psi$. Conditions (45) and (46) imply that the balanced values of new and old goods, $\psi V^a(t) = V^n(t)$, hold as long as $0 < z(t) < 1/\psi$. The following labor market clearing condition closes this extended model:

$$L = \frac{1}{\mu}\frac{E(t)}{w(t)} + \frac{z(t)N(t)}{A(t)} + \frac{N(t+1)}{A(t)}, \tag{47}$$

[36] Alternatively, if we think that an arbitrarily chosen outside firm does this investment, the equilibrium conditions would not alter.

[37] See also Furukawa (2013) and Niwa (2018) for more recent papers. In this section, we use the modelling specification of firms' endogenous survival developed by these two papers.

which is basically analogous to (21) except the fact that the aggregate use of labor for existing product development now depends on each firm's endogenous decision, $z(t)$.

Using (42)–(47), we can show that the equilibrium dynamical system in terms of the rate of innovation, $g(t) \equiv (A(t+1) - A(t))/A(t)$, as follows.[38]

$$1 + g(t+1) = \frac{\nu^{\sigma-1}}{\nu^{\sigma-1} - \psi} \left[(1 + \psi L + \beta\psi) - \frac{\nu^{\sigma-1}}{\nu^{\sigma-1} - \psi} \frac{\beta\psi\,(1 + \psi L)}{1 + g(t)} \right]. \tag{48}$$

Using (48), it is straightforward to prove the following:[39] In the interior case of $0 < z(t) < 1/\psi$, along an equilibrium path, the equilibrium rate of innovation $g(t+1)$ can monotonically decrease with novelty-seeking traits ν for any $g(t) > 0$. It is the case if, say, the productivity of existing product development ψ is smaller than some threshold level. In summary, even in the general case in which monopoly can last longer than one period, the effects of novelty-seeking traits on innovation can be monotonically negative. This confirms our main message that the public's novelty-seeking traits can depress innovation at the aggregate level.

7 Concluding Remarks

In the present study, we explore the relationship between individual novelty-seeking traits and innovation at the aggregate level. We first point out that empirically, the relationship in reality may be more complex than is naturally considered; it may actually be negative. Then, we develop an R&D-based growth model in which the role of novelty-seeking in aggregate innovation can be addressed. The baseline model is kept as simple as possible, along with the assumption of a one-period monopoly. Using this model, we demonstrate a mechanism through which too strong novelty-seeking traits could depress innovation and economic growth in the long run. We also consider two extensions to the baseline model, confirming that the negative effect of novelty-seeking can still hold in a more general setting with, for example, long-lived monopoly power. In the present study, we thereby propose a theory for a possible explanation of the observed negative effect of novelty-seeking traits on innovation.

It is worth noting that the effect of novelty-seeking traits on innovation may differ in different types of innovation. Strictly speaking, our finding indicates that novelty-seeking traits can be harmful for *applied* innovation, in which research outcomes are patentable and profitable. Meanwhile, as we already mentioned, Gören (2017b) finds a robust positive relationship between novelty-seeking traits and *basic* innovation such as scientific knowledge creation (measured by the number of scientific and technical journal articles). These two seemingly contradictory findings could suggest a single implication that the public's novelty-seeking traits have different roles in different stages of innovation.[40]

All in all, our analyses show that the public's inherent novelty-seeking traits significantly influence applied innovation negatively. If we borrow from the term in market quality economics (Yano 2009), the traits are part of the "market infrastructure," which

[38] See Appendix for a proof.

[39] See Appendix for a proof.

[40] One could further think that countries featured by stronger novelty-seeking traits might like to promote applied research relative to basic research, for example by strengthening patent protection. Those with weaker novelty-seeking traits might like to encourage academic researchers to support basic research, by using institutional and/or fiscal policy tools.

is defined as "the entire network of social arrangements in which a market functions including rules, laws, culture, moral, and so on" (Furukawa and Yano 2014). According to the theory, in order for a market to function well, various parts of the market infrastructure must be well coordinated. One policy implication is that a desirable design of innovation-related laws such as a patent law in a particular country should depend on the country's cultural features including novelty-seeking traits. While it might lead to international diversity of optimal economic systems (rather than harmonization), we will leave this question for future work.

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Appendix

Proof for (48):

Solving the maximization problem in (43), the first order condition gives rise to

$$\psi \frac{V^a(t+1)}{1+r(t)} = \frac{w(t)}{A(t)}, \tag{A1}$$

which must hold in the interior-solution equilibrium where $z(t) \in (0, 1/\psi)$. Incorporating (A1) for (43) and (44) yields

$$V^n(t) = \pi^n(t) \tag{A2a}$$

and

$$V^a(t) = \pi^a(t) + \frac{w(t)}{A(t)}, \tag{A2b}$$

respectively.

Together with these conditions on innovation values, we will derive the equilibrium dynamical system of the extended model (for the interior-solution case). First, substituting (A2a) and (A2b) into the balanced value condition $\psi V^a(t) = V^n(t)$, we obtain

$$\frac{E(t)}{w(t)} = \frac{\psi}{\nu^{\sigma-1} - \psi} \frac{\mu}{\mu - 1} \frac{A(t) + \nu^{\sigma-1} N(t)}{A(t)}, \tag{A3}$$

which uses (12), (14), and (20) for the expressions of profits, $\pi^n(t)$ and $\pi^a(t)$. To proceed, we need to assume $\nu^{\sigma-1} > \psi$ since $E(t)/w(t)$ must be positive. Second, substituting (A2a) into the free entry condition (46), we obtain

$$\frac{E(t)}{w(t)} = \frac{1}{\beta \nu^{\sigma-1}} \frac{\mu}{\mu - 1} \frac{A(t+1) + \nu^{\sigma-1} N(t+1)}{A(t)}, \tag{A4}$$

which uses the Euler equation (9), (12) and (20). Finally, incorporating (42) for the labor market equilibrium condition (47), with $s(t+1) = \psi z(t)$, we obtain

$$\frac{E(t)}{w(t)} = \mu \left[L - \frac{1}{\psi} \frac{A(t+1) - A(t)}{A(t)} - \frac{N(t+1)}{A(t)} \right]. \tag{A5}$$

These three conditions, (A3)–(A5), govern the equilibrium dynamic behavior of our economy in the interior case of $z(t) \in (0, 1/\psi)$. Specifically, these determine $E(t)/w(t)$, $A(t+1)$, and $N(t+1)$ as a function in $A(t)$ and $N(t)$.

Since our interest is in the dynamics of the growth rate, $g(t) \equiv (A(t+1) - A(t))/A(t)$, we rewrite (A3)–(A5) as follows. First, we use (A4) and (A5) to express $N(t+1)$ as a function of $g(t)$ and $A(t)$:

$$N(t+1) = A(t) \frac{1}{\psi} \left[\frac{(\psi L + 1)(\beta(\mu - 1))}{\beta(\mu - 1) + 1} - \frac{\beta \nu^{\sigma-1}(\mu - 1) + \psi}{\nu^{\sigma-1}(\beta(\mu - 1) + 1)} (1 + g(t)) \right]. \tag{A6}$$

Using (A3) and (A4), then, we express $1 + g(t)$ as a function in $A(t)$, $N(t+1)$, and $N(t)$:

$$1 + g(t) = \frac{\beta \psi \nu^{\sigma-1}}{\nu^{\sigma-1} - \psi} \left(1 + \nu^{\sigma-1} \frac{N(t)}{A(t-1)} \frac{1}{1 + g(t-1)} \right) - \nu^{\sigma-1} \frac{N(t+1)}{A(t)}, \tag{A7}$$

which uses $A(t) = A(t-1)(1 + g(t-1))$. Substituting (A6) for $N(t+1)$ and $N(t)$ in (A7) yields (48).

Proof for the threshold value of ψ:

Let's define $\tilde{\nu} \equiv \nu^{\sigma-1}/\left(\nu^{\sigma-1}-\psi\right)$ and $\nu^{*} \equiv (1+\beta+\psi L)(1+g(t))/(2\beta(1+\psi L))$ for descriptive convenience. Then, (48) becomes

$$g(t+1) = \tilde{\nu}\left[(1+\beta+\psi L) - \frac{\beta(1+\psi L)}{1+g(t)}\tilde{\nu}\right] - 1. \tag{A8}$$

Differentiating (A8), $g(t+1)$ increases (decreases) with $\tilde{\nu}$ for $\tilde{\nu} \in (0, \nu^{*})$ (for $\tilde{\nu} \in (\nu^{*}, 2\nu^{*})$). Therefore, there is an inverted-U shaped relationship between $\tilde{\nu}$ and $g(t+1)$, and the maximum point is ν^{*}. Since $\nu > 1$, there is an upper bound of $\tilde{\nu}$, such that $\tilde{\nu}_{+} \equiv 1/(1-\psi)$. When ν increases from 1 to ∞, $\tilde{\nu}$ decreases from $\tilde{\nu}_{+}$ to 1. If $\tilde{\nu}_{+} < \nu^{*}$, then there is a monotonically negative relationship between ν and $g(t+1)$. Note that $1 < \tilde{\nu}_{+} < \nu^{*}$ holds for any $g(t) > 0$ if

$$\psi < \frac{-\left((2\beta-1)L+1+\beta\right)+\sqrt{\left((2\beta-1)L+1+\beta\right)^{2}-4(1-\beta)L}}{2L}$$

holds.

Table 1: Summary statistics

Variable	N	Mean	S.D.	Min.	1st quart.	Median	3rd quart.	Max.
$Innovation_c$	134	2.498	2.362	-3.979	0.878	2.585	4.415	8.015
$NoveltySeeking_c$	128	0.236	0.068	0.098	0.194	0.237	0.262	0.458
GDP per capita (log)	131	8.627	1.489	5.599	7.510	8.528	9.920	11.886
Population (log)	134	2.201	1.819	-3.594	1.325	2.309	3.339	7.133
Index of patent rights	98	2.981	0.874	1.342	2.320	2.817	3.670	4.840
Years of tertiary schooling	89	30.827	20.789	0.700	14.420	28.420	46.880	79.640
FDI (as % of GDP)	130	4.679	7.811	0.142	1.614	2.915	4.616	79.164
% religious people	80	0.704	0.196	0.160	0.584	0.730	0.880	0.959
% people believing in God	64	0.850	0.176	0.188	0.779	0.927	0.991	1.000

Table 2: Novelty-seeking traits and innovation: OLS regression analysis

	(1)	(2)	(3)
$NoveltySeeking_c$	-7.444***	-6.276***	-6.426***
	(1.850)	(2.100)	(2.037)
GDP per capita (log)	1.030***	0.736***	0.919***
	(0.210)	(0.256)	(0.248)
Population (log)	0.444***	0.538***	0.428***
	(0.109)	(0.090)	(0.089)
Index of patent rights	0.365	0.442	0.306
	(0.305)	(0.352)	(0.383)
Years of tertiary schooling	0.019*	0.028***	0.023**
	(0.011)	(0.010)	(0.010)
FDI (as % of GDP)	0.020**	-0.009	0.004
	(0.008)	(0.034)	(0.072)
% religious people		-2.171***	
		(0.824)	
% people believing in God			-3.203***
			(0.950)
Constant	-7.636***	-4.673**	-4.083*
	(1.349)	(2.033)	(2.151)
Observations	82	55	41
R^2	0.826	0.829	0.855

Note: The dependent variable is $Innovation_c$. Robust standard errors are reported in parentheses. $*$: significance at 10% level; $**$: significance at 5% level; $***$: significance at 1% level.

Table 3: Novelty-seeking traits and innovation: 2SLS regression analysis

	(1)	(2)	(3)	(4)	(5)	(6)
$NoveltySeeking_c$	-9.201***	-10.548***	-10.613***	-8.773***	-9.410***	-8.330***
	(2.219)	(2.960)	(3.918)	(2.336)	(2.485)	(2.980)
GDP per capita (log)	0.992***	0.738***	0.927***	0.993***	0.738***	0.923***
	(0.209)	(0.250)	(0.258)	(0.210)	(0.250)	(0.251)
Population (log)	0.485***	0.539***	0.439***	0.486***	0.538***	0.433***
	(0.105)	(0.097)	(0.107)	(0.107)	(0.094)	(0.095)
Index of patent rights	0.415	0.449	0.373	0.417	0.447	0.337
	(0.303)	(0.342)	(0.403)	(0.304)	(0.343)	(0.392)
Years of tertiary schooling	0.019*	0.030***	0.024**	0.019	0.029***	0.023**
	(0.011)	(0.010)	(0.010)	(0.011)	(0.010)	(0.009)
FDI (as % of GDP)	0.025***	-0.005	0.038	0.025***	-0.006	0.019
	(0.008)	(0.037)	(0.082)	(0.008)	(0.036)	(0.081)
% religious people		-1.936**			-1.998**	
		(0.815)			(0.815)	
% people believing in God			-2.484**			-2.876**
			(1.157)			(1.154)
Constant	-7.169***	-3.895*	-4.141*	-7.290***	-4.102**	-4.109*
	(1.324)	(2.086)	(2.271)	(1.399)	(2.065)	(2.205)
Observations	81	55	41	81	55	41
Kleibergen-Paap rk Wald F statistic	17.653	15.894	6.520	44.782	36.663	14.556

Note: The dependent variable is $Innovation_c$. Columns (1)-(3) use all the instruments of Gören (2017a), including migratory distance, pasture land (its mean, square, and standard deviation), elevation (its mean, square, and standard deviation), and agricultural suitability (its mean, square, and standard deviation); all instruments are ancestry adjusted. Columns (4)-(6) use the ancestry adjusted migratory distance as the only instrument. Robust standard errors are reported in parentheses. $*$: significance at 10% level; $**$: significance at 5% level; $***$: significance at 1% level.

Table 4: Novelty-seeking traits and innovation: First-stage results of 2SLS regression analysis

	(1)	(2)	(3)	(4)	(5)	(6)
Migratory distance	0.010***	0.014***	0.011***	0.010***	0.012***	0.011***
	(0.002)	(0.002)	(0.003)	(0.001)	(0.002)	(0.003)
Pasture land	0.186	0.755	0.450			
	(0.387)	(0.528)	(0.596)			
Elevation	0.066*	0.076	0.020			
	(0.036)	(0.091)	(0.116)			
Agricultural suitability	0.204	-0.086	0.239			
	(0.186)	(0.263)	(0.388)			
(Pasture land)^2	-0.228	-1.213	-0.760			
	(0.641)	(0.836)	(0.936)			
(Elevation)^2	-0.032**	-0.033	-0.014			
	(0.014)	(0.055)	(0.070)			
(Agricultural suitability)^2	-0.238	0.009	-0.315			
	(0.195)	(0.259)	(0.384)			
S.D.(Pasture land)	-0.338*	-0.675**	-0.461			
	(0.176)	(0.267)	(0.349)			
S.D.(Elevation)	0.001	0.001	0.009			
	(0.027)	(0.043)	(0.052)			
S.D.(Agricultural suitability)	-0.029	0.058	-0.138			
	(0.111)	(0.162)	(0.246)			
GDP per capita (log)	-0.005	0.002	0.008	-0.008	-0.005	-0.003
	(0.009)	(0.013)	(0.015)	(0.010)	(0.013)	(0.013)
Population (log)	0.001	0.007	0.002	-0.005	-0.006	-0.003
	(0.005)	(0.006)	(0.009)	(0.005)	(0.005)	(0.006)
Index of patent rights	-0.002	-0.005	-0.010	0.013	0.018	0.016
	(0.014)	(0.020)	(0.025)	(0.014)	(0.018)	(0.022)
Years of tertiary schooling	0.000	0.000	-0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
FDI (as % of GDP)	0.001***	0.004*	0.011*	0.000	0.001	0.009*
	(0.000)	(0.002)	(0.006)	(0.000)	(0.002)	(0.005)
% religious people		0.068			0.109**	
		(0.048)			(0.044)	
% people believing in God			0.138**			0.135**
			(0.067)			(0.065)
Constant	0.175***	0.047	-0.022	0.213***	0.076	0.001
	(0.055)	(0.079)	(0.093)	(0.068)	(0.095)	(0.106)
Observations	81	55	41	81	55	41
R^2	0.476	0.506	0.521	0.370	0.410	0.411

Note: The dependent variable is $NoveltySeeking_c$. Each column shows the first-stage results of the corresponding column in Table 3. Robust standard errors are reported in parentheses. $*$: significance at 10% level; $**$: significance at 5% level; $***$: significance at 1% level.