Love of Novelty, Innovation Diffusion, and Growth in the Presence of Worker Heterogeneity*

Yuichi Furukawa, Chukyo University

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Abstract

By considering heterogenous workers' love of novelty and their role in endogenous innovation diffusion within a standard innovation-based growth model, we find that a stronger love of novelty and/or a larger population of ordinary workers (who are also called majority workers) leads to a higher rate of innovation diffusion. The higher diffusion rate then leads to a higher long-run rate of economic growth, provided that new technologies, which have not been *diffused*, i.e., are still unavailable to majority workers, generate a moderate amount of knowledge spillovers for innovators. In a case where the spillovers are very efficient, the growth effect is reversed, and becomes negative. We extend our consideration to a two-country version of the model, we also find that the domestic majority workers' population and their love of novelty are conducive to domestic innovation diffusion and world economic growth, but the effects on international specialization and international innovation diffusion are nontrivial. In particular, the effect on international innovation diffusion can be seen to form the shape of an inverted U.

1 Introduction

Economics literature commonly states that culture, along with institutions and geography, is a fundamental determinant of cross-country differences in macroeconomic performance (Acemoglu et al. 2005). An immense volume of literature has long concerned itself with trying to answer questions related to various dimensions of culture, such as religion, values, and family ties (see below for details). Recently, Gören (2017, 2018) reported novel empirical evidence that suggested that individual "love of novelty" is an important aspect of culture responsible for determining macroeconomic performances like economic growth and development.[1]

Some might think the public's openness to new technologies and products enhances innovation and innovation-driven growth. However, the cross-country evidence suggests that love of novelty has an ambiguous effect on per-capita income (Gören 2017).[2] Subsequent studies also show different effects of a stronger love of novelty on different stages

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[1] See also Furukawa et al. (2019) for another piece of empirical evidence.

[2] More precisely, Gören's research addresses novelty-seeking traits, which should be an essential aspect for consideration when examining individual love of novelty. He uses genome data to index a nation's average level of novelty-seeking traits.

of innovation, such as basic and applied research.[3] Although we do need to pay close attention to caveats, particularly the fact that we still have only a few pieces of empirical evidence, each with its own technical limitations, such as causality issues, the evidence to date seems to at least raise a theoretical question that is worthy of consideration: What is the role of individual love of novelty in innovation and innovation-based growth? The answer is not as obvious as it seems.

In this study, we will theoretically characterize the macroeconomic role of the love of novelty. Specifically, we will consider the role of worker heterogeneity in terms of these subjects' innate trait for openness to new technologies. To do so, we introduce the essence of Rogers' (1962) innovation diffusion theory into an innovation-based growth model that features expanding varieties a la Romer (1990). Following Rogers (1962), we may venture that there are different types of agents, who exhibit different levels of an *innate* willingness to accept/adopt new things. We specifically have (i) innovators who innovate new technologies, (ii) early adopters who adopt and use these new (and still uncommon) technologies at work in the production sector, and (iii) the more abundant group, majority workers, who only use relatively old technologies that have already been diffused into the economy (and which should have more user-friendly interfaces as a result).[4] In the model, as is considered in Roger's theory, innovations (i.e., newly innovated technologies) gradually diffuse. To model such gradual diffusion, we emphasize firms (innovators) that assume a proactive role by investing in order to encourage the diffusion of their innovated technologies. From a realistic viewpoint, investment aimed at diffusion should cover a wide range of activities, including process innovation, marketing, advertisement, and so on. When an instance of diffusion investment succeeds, the firm's technology becomes available to majority workers. In such cases, we assume that the investment activity aimed at technology diffusion is stochastic, and we consider a success probability (or a Poisson arrival rate) an increasing function in the firm's investment level (endogenous) and also in majority workers' intrinsic *love of novelty* (exogenous).

The core finding of this study is that when majority workers' love of novelty is stronger (and/or their population is larger), the speed of technology diffusion is higher, and thereby the long-run rate of economic growth is higher, in most cases. This suggests that the public's love of novelty is a fundamental source of technology diffusion and innovation-based growth in the long run. However, if knowledge spillovers from newly innovated technologies (which are yet to be diffused) are very efficient, the effect can be reversed; a stronger love of novelty and/or a larger population size of majority workers can decrease the rate of economic growth, even though it still has a positive effect on the speed of innovation diffusion. This negative growth effect arises because of an endogenous decrease in the ratio of newly innovated technologies to diffused technologies. In our model, the newly innovated technologies play a role as seeds for innovation diffusion, and thus the long-run rate of economic growth can be expressed as a product of the speed of technology diffusion and the amount of *seeds for diffusion* (i.e., new technologies). A smaller amount of seeds has a slowing effect on economic growth, but economic growth can become

[3]While Gören (2018) finds that there is a positive effect on basic research such as scientific knowledge creation, Furukawa et al. (2019) suggests a negative effect on applied research as it relates to inventions that are eligible for intellectual property rights protection (e.g., patents and trademarks).

[4]Rogers (1962) proposes a more detailed set of classification categories: innovators, early adopters, early majority, late majority, and laggards. Thus, our modeling offers a simplified version of his theory, probably without any loss of generality. Note that the essence of his idea is that innovation diffusion gradually occurs through social communications between different individuals who adopt new ideas to different degrees.

dominant when seeds, or new technologies, bring about larger knowledge spillovers.

We then extend the baseline model to a two-country setting simply by allowing for international trade and foreign direct investments.[5] Given this extension, we obtain a new insight on the role of the public's love of novelty from an international perspective. A stronger love of novelty or a larger population of the majority worker in one country leads to a higher speed (rate) of domestic innovation diffusion. Although this increase in the domestic diffusion rate creates more production possibilities for goods originating in the home country, it rather causes a *decrease* in the production share of the home country because firms endogenously choose the production location through foreign direct investments. This crowding-out effect interacts with a growth-enhancing effect as in the baseline (closed-economy) model, possibly to generate a non-monotonic effect on the long-run speed of international technology diffusion from the foreign country to the home country. Specifically, when internationally transferred technologies (i.e., innovated in the foreign country but used in the home country through foreign direct investments) can deliver sufficiently large knowledge spillovers for the home country, the effect of a stronger love of novelty/larger majority worker population on the speed of international diffusion takes the form of an inverted U: in other words, a too strong or too weak public love of novelty in a country can slow down the international diffusion of technologies in the direction of the home country from overseas.

Since we work under the belief that individuals' personal degree of love of novelty is an intrinsic or cultural trait, our analysis treats people's love of novelty as a cultural parameter. Thus, our study contributes to the body of literature on the macroeconomic role of cultural heterogeneity; see Doepke and Zilibotti (2014) for a review. Many theoretical studies on innovation and growth have addressed the role of cultural preference parameters like the time discount rate and the rate of risk aversion. Recent studies such as Galor and Michalopoulos (2012) and Doepke and Zilibotti (2014) consider the joint determination of an endogenous coevolution of entrepreneurial traits (in terms of risk tolerance) and technology. The present paper contributes to this growing body of literature by focusing on worker heterogeneity in terms of workers' innate willingness to welcome and adopt new technologies as new aspects of culture within the framework model of innovation-based growth.[6]

Outside the field of economics, the love of novelty has actually long been a prominent issue across various disciplines, although it is a relatively new concept to economics itself. In psychology, for example, Cloninger (1986) refers to a human personality trait associated with "exhilaration or excitement in response to novel stimuli" as novelty seeking, which is an essential aspect of studying an individual's love of novelty. Subsequent papers have shown that the degree of novelty-seeking varies among individuals (see Chandrasekaran and Tellis 2008, Tellis et al. 2009). Such a view has also been considered in fields such as consumer research (e.g., Hirschman 1980) and business (e.g., Rogers 1962). By focusing particularly on Rogers' (1962) theory, we develop a new innovation-based growth model that incorporates worker heterogeneity and endogenous innovation diffusion.

This paper proceeds as follows: section two sets up a baseline model, section three characterizes the dynamic equilibrium of our model and shows our main results, section four introduces an international perspective through extension and extrapolation, and section five concludes.

[5] We essentially follow Lai (1998) in modeling foreign direct investments and firms' choice of production location.

[6] See Furukawa et al. (2018, 2019) for empirical and theoretical research on *consumers'* love of novelty.

2 A Growth Model of Innovation and Innovation Diffusion with Heterogenous Workers

We introduce a formal theoretical setting for endogenous innovation diffusion a la Rogers (1962) into the innovation-based growth model a la Romer (1990). In doing this, we also consider worker heterogeneity in terms of degrees of workers' innate willingness to adopt new and/or uncommon technology, to which we would like to apply the somewhat imprecise label of "love of novelty." As in the standard model, time is continuous and extends from 0 to ∞. There is a single consumption good, C_t, that is produced by perfectly competitive firms using a number of intermediate goods, $x_t(j)$. Intermediate goods are produced from heterogeneous labor.

2.1 Consumption and Heterogeneous Workers

An infinitely lived representative agent inelastically supplies three different classes of labor: I units of *innovators*, E units of *early adopters*, and L units of *majority workers*, following Rogers' innovation diffusion theory. The key idea is that the three differ in their abilities and attitudes toward new technology. Innovator I, with the strongest love of novelty, will work on research and development (R&D) activities and innovate technologies (for producing intermediate goods). Early adopter E, with the second strongest love of novelty, will adopt such a newly created technology and work on production activities for new intermediate goods. Majority worker L, with a relatively weak love of novelty, can use old and/or common technologies only. As argued in Rogers (1962) and many subsequent studies, the population of early adopters is typically smaller than that of majority workers. Accordingly, we assume $\varepsilon \equiv E/L < 1$.

The representative agent solves a standard dynamic optimization on consumption and saving. The lifetime utility is defined by

$$U = \int_0^\infty e^{-\rho t} \ln C_t dt, \tag{1}$$

where C_t denotes consumption and $\rho > 0$ is the subjective discount rate. We also have an intertemporal budget constraint; we omit to write down the constraint because it is standard. Solving the dynamic optimization,

$$\frac{\dot{C}_t}{C_t} = r_t - \rho, \tag{2}$$

where $r_t > 0$ denotes the (real) interest rate.

2.2 Final Good

The final good is produced by perfectly competitive firms using a number of intermediate goods. We take C_t as the numeraire. There are two kinds of intermediate goods: new and old ones. Let A_t be the number/set of "old" intermediate goods that are already common to all workers in the economy. Let N_t be the number/set of "new" intermediate goods that have freshly been innovated and/or are still uncommon.[7] We consider a constant elasticity of substitution (CES) technology:

$$C_t = \left[\int_{j\in\{A_t\cup N_t\}} x_t(j)^{\frac{\sigma-1}{\sigma}} dj\right]^{\frac{\sigma}{\sigma-1}}, \tag{3}$$

in which $\sigma > 1$ denotes the elasticity of substitution between any two intermediates. These production functions reflect the assumption that sector l has limited access to the set of intermediate goods.

Solving the profit maximization yields the market demand functions as

$$x_t(j) = C_t p_t(j)^{-\sigma}, \tag{4}$$

in which $p_t(j)$ denotes the price of intermediate good j.[8]

2.3 Intermediate Goods

Recalling the considerations stated in the introduction, we recognize two types of labor. Majority workers can work only for old intermediate-good sectors, $j \in A_t$, but early adopters can also work for new intermediate-good sectors, $j \in N_t$. As a result, sectors with $j \in A_t$ hire majority workers, L, and those with $j \in N_t$ hire early adopters.[9] As in the standard growth model, the market structure is one of monopolistic competition. It follows that each sector is occupied by a monopolistic producer (who is originally an innovator, as explained below). We assume a so-called one-for-one technology, converting each one unit of labor into one unit of an intermediate good.

By (4), the price elasticity of demand for any j is constant at $\sigma > 1$, so the monopolistic prices are given by

$$p_t(j) = \begin{cases} \frac{\sigma}{\sigma-1} w_t^L & \text{for } j \in A_t \\ \frac{\sigma}{\sigma-1} w_t^E & \text{for } j \in N_t \end{cases}. \tag{6}$$

Here, w_t^L and w_t^E are wages for majority workers and early adopters. The equilibrium production levels are given by

$$x_t(j) = \begin{cases} C_t\left(\frac{\sigma}{\sigma-1} w_t^L\right)^{-\sigma} \equiv x_t^A & \text{for } j \in A_t \\ C_t\left(\frac{\sigma}{\sigma-1} w_t^E\right)^{-\sigma} \equiv x_t^N & \text{for } j \in N_t \end{cases} \tag{7}$$

and the equilibrium profits are given by

$$\pi_t(j) = \begin{cases} \frac{(\sigma-1)^{\sigma-1}}{\sigma^\sigma} \frac{C_t}{\left(w_t^L\right)^{\sigma-1}} \equiv \pi_t^A & \text{for } j \in A_t \\ \frac{(\sigma-1)^{\sigma-1}}{\sigma^\sigma} \frac{C_t}{\left(w_t^E\right)^{\sigma-1}} \equiv \pi_t^N & \text{for } j \in N_t \end{cases} \tag{8}$$

[7] In this study, for the sake of descriptive simplicity, we use "new" and "old" for N_t and A_t, although N_t could include goods that are not so fresh from the birth but still unavailable for majority workers.

[8] There is one more equilibrium condition to equal the price to the marginal cost:

$$1 = \left[\int_{j\in\{A_t\cup N_t\}} p_t(j)^{1-\sigma} dj\right]^{\frac{1}{1-\sigma}}. \tag{5}$$

[9] We assume a parameter restriction under which the wage for early adopters is alwasy higher than that for majority workers. Thus, there is no incentive for early adopters to use old technologies and work at old intermediate good sectors.

These equations show the standard effect of a higher factor price, w_t^L or w_t^E, that decreases the equilibrium supply and profit, $x_t(j)$ and $\pi_t(j)$.

2.4 Endogenous Innovation and Adoption of New Technologies

Following Romer (1990), we will examine endogenously expanding varieties. There are a number of potential R&D firms, and each R&D firm can invent a new technology to produce a new intermediate good, j, by hiring $1/K_t$ units of innovators I. Here, K_t stands for the knowledge stock of the economy. The R&D firm entering the market would hire some early adopters to produce the new intermediate good, earning a monopolistic profit, $\pi_t(j)$ for $j \in N_t$. Following the standard literature to assume $K_t = A_t + \zeta N_t$, in which $\zeta \in [0, 1]$. When $\zeta = 1$, K_t is equal to the total number of technologies, as in the standard Romer model. When $\zeta < 1$, the knowledge externality from new and uncommon technologies is weaker than that from old and common technologies, which may seem to be a more natural state.

Let V_t^N be the expected present value of a newly innovated technology (or a newly innovated intermediate good). Here we focus on the symmetric equilibrium of R&D firms, so we omit any index for an R&D firm. Free entry in innovation requires

$$V_t^N \leq \frac{w_t^I}{K_t} \text{ with } \left(V_t^N - \frac{w_t^I}{K_t}\right) n_t = 0, \tag{9}$$

in which $n_t \geq 0$ denotes the number of newly innovated technologies for intermediate good production.

2.5 Endogenous Innovation Diffusion

In order to introduce a simple process for innovation (technology) diffusion, we put forward that the successful R&D firm would hire innovators to diffuse newly innovated technology more widely by designing it to be user-friendly. As a result, the new technology becomes diffused and available to all types of production workers, including majority worker L. While economic activities aimed at diffusion should logically include advertisement, marketing, process innovation, and so on, we do not go so far as to specifically label these activities within the scope of this study; it will suffice to simple refer to diffusion activity.

We assume a linear technology:[10] For a short time interval of dt, the firm can successfully diffuse the technology at a probability $\psi\iota_t\ dt$ by hiring $\iota_t/K_t\ dt$ units of innovators. Here, the Romer-type knowledge spillover effect from K_t is also assumed. The parameter ψ determines the efficiency of diffusion from the smaller group of fewer early adopters, E, to the larger, more abundant group of majority workers, L. Although there should be a number of factors affecting the efficiency of diffusion ψ, we intend to focus on ordinary people's openness to or love of novelty. If majority workers, L, have a stronger love of novelty, it is safe to say that the diffusion process of new technologies from E to L becomes smoother and more rapid. Therefore, we may label ψ as the public's love of novelty.

[10] The linear technology we consider here essentially aligns with the concept of quality improving innovation in the canonical quality ladder model (Grossman and Helpman 1991).

If diffusion successfully occurs, the firm with technology j hires majority workers to produce what we call an "old" intermediate good; technology j moves out from the set of new goods, N_t, into the set of old goods A_t. Let V_t^A be the present value of the firm whose technology is already diffused. Then, the optimization problem for a successful R&D firm is given as[11]

$$\max_{\iota_t} \Omega_t^N = \left(\pi_t^N - \frac{w_t^I \iota_t}{K_t}\right) dt + \left((1 - \psi\iota_t dt)\, \dot{V}_t^N dt + \psi\iota_t dt\ V_t^A\right). \tag{10}$$

Following the standard argument,[12] we can ignore the term $(dt)^2$ or $(dt)^3$.[13] Therefore, the first order condition gives rise to

$$\psi V_t^A \leq \frac{w_t^I}{K_t} \text{ with } \left(\psi V_t^A - \frac{w_t^I}{K_t}\right) \iota_t^* = 0, \tag{11}$$

in which ι_t^* is the equilibrium value of ι_t.

Considering the standard asset choice problem, using (11), the Bellman equation for V_t^N is

$$r_t V_t^N = \pi_t^N + \dot{V}_t^N + \underbrace{\iota_t^* \left(\psi V_t^A - \frac{w_t^I}{K_t}\right)}_{=0}. \tag{12a}$$

Since there is no obeisance risk, the Bellman equation for V_t^A is the standard one:

$$r_t V_t^A = \pi_t^A + \dot{V}_t^A. \tag{13}$$

2.6 Evolution of Technology Stocks

Due to endogenous innovation and innovation diffusion, the stock of new/uncommon technologies, N_t, and the stock of old/common technologies, A_t, endogenously grow over time. The inflow to N_t is determined by the number of newly innovated technologies that are successfully adopted by the early adopters E. It is n_t. The outflow from N_t arises from innovation diffusion, whose number is equal to the new technology stock N_t multiplied by the rate ι_t^* of innovation diffusion. Then, the law of motion governing an evolution of new technology stock N_t follows

$$\dot{N}_t = n_t - \iota_t^* N_t. \tag{14}$$

In the meantime, the inflow to A_t is equal to the outflow from N_t, that is, $\iota_t^* N_t$. For simplicity, we do not consider any force generating obsolescence of A_t. Thus, the law of motion governing an evolution of old technology stock A_t follows

$$\dot{A}_t = \iota_t^* N_t. \tag{15}$$

[11] This setting is mechanically the same as the one used in growth models with endogenous firm survival (e.g., Furukawa 2013, Niwa 2018), although existing analyses neither consider endogenous innovation diffusion nor worker heterogeneity. That is to say, the theme of the present paper is completely different from those.

[12] See, e.g., Grossman and Helpman (1991, Chapter 4).

[13] Note this:

$$\iota_t^* \equiv \arg\max_{\iota_t} \Omega_t^N = \left(\pi_t^N - w_t^I\ \iota_t / K_t\right) dt + \dot{V}_t^N dt + \psi\iota_t dt\ V_t^A.$$

2.7 Labor Market Clearing

All markets are cleared in equilibrium at any date, t . In the market for innovators, the labor supply is equal to I, and the demands are from innovation and innovation diffusion:

$$I = \frac{n_t}{K_t} + \frac{\iota_t^* N_t}{K_t}. \tag{16}$$

In the market for early adopters, the labor supply is equal to E, and the demands are from new intermediate-good sectors:

$$E = \int_{j \in N_t} x_t(j)dj = N_t x_t^N. \tag{17}$$

In the market for majority workers, the labor supply is L, and the demands are from old intermediate-good sectors

$$I = \int_{j \in A_t} x_t(j)dj = A_t x_t^A. \tag{18}$$

3 Dynamic Equilibrium: the Role of Public Love of Novelty

In this section, we characterize the dynamic equilibrium of our model. First, we define a key variable: $\omega_t \equiv w_t^E / w_t^L$. This ω_t denotes wage income inequality (between early adopters and majority workers). Thus, ω_t captures a premium on wages for workers who have the innate love of novelty or, to phrase it more simply, a love-of-novelty premium. We combine the labor market equilibrium conditions for E and L, (17) and (18) with the labor demands from (7). It yields the equilibrium relationship between ω_t and the ratio of new technology to old technology, N_t/A_t:[14]

$$\omega_t = \left(\frac{N_t}{\varepsilon A_t} \right)^{\frac{1}{\sigma}}. \tag{19}$$

Recall that $\varepsilon \equiv E/L$ denotes the relative abundance of early adopters in the total population. (19) shows the two standard effects: the price effect (i.e., the negative effect of the resource abundance for E on the relative price ω of E) and the market size effect (i.e., the positive effect of the relative market size for E on the relative price ω of E).[15]

The following lemma assures global stability of the economy and characterizes the long-run ratio of new technology to old technology, N_t/A_t.

Lemma 1 *Define*

$$\eta^* \equiv \varepsilon \psi^{-\frac{\sigma}{\sigma-1}}. \tag{20}$$

Then, N_t/A_t converges to η^* and reaches there in finite time.

Proof. We follow the proof of Proposition 1 in Acemoglu and Zilibotti (2001). Define the following inequality:

$$\frac{N_t}{A_t} > \varepsilon \psi^{-\frac{\sigma}{\sigma-1}}. \tag{21}$$

[14] By assuming $\psi < 1$, we restrict our analysis to the case of $\omega_t > 1$, in which early adopters have no incentive to work for an old-good sector.

[15] See Acemoglu (1998) for a detailed explanation of these two effects.

In this proof, we will prove that under (21), both $n_t = 0$ and $\iota_t^* > 0$ hold.

First, note that in order for N_t and A_t to both expand (that is, $n_t > 0$ and $\iota_t^* > 0$), we need to have $V_t^N = \psi V_t^A$, from the free entry conditions, (9) and (11). Then, combine the two Bellman equations, (12a) and (13), to $r_t V_t^z = \pi_t^z + \dot{V}_t^z$ for $z = N, A$. This implies that $V_t^N = \psi V_t^A = w_t^I / K_t$ is possible if and only if $\pi_t^N = \psi \pi_t^A$. However, it must hold

$$\pi_t^N < \psi \pi_t^A \text{ if (21) holds,}$$

noting (8) and (19). Therefore, as long as (21) holds, $V_t^N < \psi V_t^A = w_t^I / K_t$ holds;[16] $n_t = 0$ and $\iota_t^* > 0$ (that is, $\dot{N}_t = 0$ and $\dot{A}_t > 0$). Under (21), N_t/A_t converges down to η^* and reaches there in finite time.[17] In order to complete, we must consider a similar argument for a case with the opposite inequality in (21). ■

Lemma 1 reveals that N_t/A_t reaches η^* in finite time, and so the economy eventually falls into a balanced growth path on which N_t and A_t grow at the same rate, say g^*. Lemma 1 also shows that the long-run ratio of new to old goods, $N_t/A_t = \eta^*$, increases with the abundance of early adopters, ε, but decreases with the majority workers' love of novelty, ψ.

For the sake of explanation, it is beneficial to define an inverse of η^* by a separate parameter, like

$$\lambda \equiv \left(\varepsilon^{-1}\right) \psi^{\frac{\sigma}{\sigma-1}}. \tag{22}$$

This is the product of the relative population of majority workers, ε^{-1}, and the strength of their love of novelty, $\psi^{\frac{\sigma}{\sigma-1}}$ (the factor facilitating the diffusion process). It captures the total abundance of the love of novelty held by the majority workers as the ordinary people of our economy, so we may simply call λ *public love of novelty.*

To examine the effects of public love of novelty λ, we combine (3) with (17) and (18) to derive the long-run output of the consumption goods as

$$C_t = A_t^{\frac{1}{\sigma-1}} \left(L^{\frac{\sigma-1}{\sigma}} + (\eta^*)^{\frac{1}{\sigma}} E^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}. \tag{23}$$

Thus, the long-run growth rate of consumption is

$$g^c = \frac{1}{\sigma - 1} \frac{\dot{A}_t}{A_t} = \frac{1}{\sigma - 1} g^*. \tag{24}$$

Finally, we will demonstrate that the growth rate, g^*, is determined with the growth of two technological stocks, A_t and N_t. Using (15), we have the expression of long-run growth rate g^* as a product of new technology ratio η^* and innovation diffusion rate ι^*:

$$g^* = \eta^* \cdot \ \iota^*. \tag{25}$$

[16] Note slightly modified definitions on V_t^z:

$$\psi V_t^A \equiv \int_t^\infty e^{-R_s} \psi \pi_s^A ds$$

and

$$V_t^N \equiv \int_t^\infty e^{-R_s} \pi_s^N ds,$$

where $R_s \equiv \int_t^s r_\tau dt$.

[17] We implicitly restrict our analysis to the more natural situation where initially, the new good is not too abundant, such that $N_0 \left(A_0 + N_0\right) < \eta^*$ (or, equivalently, $N_0 < \left(\eta^* / \left(1 + \eta^*\right)\right) A_0$).

This captures two determinants of long-run growth in the model: the aggregate output C_t grows faster (i) when there are more new technologies in the market (higher η^*) and/or (ii) when these technologies are diffused to majority workers more smoothly (higher ι^*). Therefore, the determinants of long-run growth are (i) the seeds for technology diffusion (the relative number of new technologies), η^*, and (ii) the speed of diffusion, ι^*. As explained later, our economy has a trade-off on resources between these two determinants, η^* and ι^*, which plays a role in our main results.

Given that η^* is already characterized in (20) as the inverse of public love of novelty, we derive an expression for the long-run rate of innovation diffusion ι^* by using (14) and (16) with (20) and (25):

$$\iota^* = \frac{\lambda(\lambda+\zeta)}{1+2\lambda} I. \tag{26}$$

From (26), we can show that public love λ of novelty (i.e., the total abundance of the majority workers' love of novelty) facilitates the process of innovation diffusion. Note that λ is supported by the scarcity of early adopters E, the abundance of majority workers L, and the majority workers' love ψ of novelty. First, since the role of early adopters E is to pick up and adopt newly innovated technologies, scarcity in early adopters (smaller E) leads to a smaller demand and profit dyad for the innovation activity of a new technology. Then, in contrast, the role of majority workers L is as the users of a diffused technology, so a larger population L of majority workers or the majority workers' strong love ψ of novelty leads to a larger demand and profit dyad for the diffusion activity. These two effects increase the relative profitability of diffusion investment to innovation investment; as a result, the diffusion rate ι^* increases through the conditions of free entry and market clearing for innovators I.

Proposition 1 *The public love of novelty λ has a monotonically positive effect on the long-run rate of innovation diffusion ι^*.*

Proof. Straightforward from (26). ■

Given that the speed of innovation diffusion ι^* is one of the two key components of long-run growth g^* from (25), Proposition 1 suggests that the public love λ of novelty (larger L and ψ and smaller E) has a direct positive effect on the long-run growth rate, g^*, because it accelerates the speed of innovation diffusion, ι^*. However, given that another component of g^*, i.e., the relative pool size of seeds for diffusion η^*, is inversely related to λ by (20) and (22), the public love λ of novelty also has an indirect negative effect on g^*, noting $g^* = \iota^*\eta^*$. These two opposite effects interact with each other, possibly generating an environment in which the public love of novelty λ is placed in an ambiguous role. The following proposition formally characterizes this effect.

Proposition 2 *The public love of novelty λ has a monotonically positive (negative) effect on the long-run rate g^* of innovation and growth if the knowledge externality from yet-to-be-diffused technologies, $\zeta \in [0,1]$, is weaker (stronger) than* 1/2.

Proof. Substituting (20) and (26) into (25) yields

$$g^* = \left(\frac{\lambda+\zeta}{\lambda+0.5}\right)\frac{I}{2}, \tag{27}$$

with which proving the proposition is straightforward. ■

A perusal of Proposition 2 reveals that there is a trade-off between the two determinants of long-run growth (g^*), which are the seeds for technological diffusion, η^*, and the speed of diffusion, ι^*. The balance of this trade-off is governed critically by the efficiency ζ of knowledge spillovers from new (yet-to-be-diffused) technologies, N_t.

When the spillover effect ζ is weak, the main driver of long-run growth ($g^* = \iota^* \eta^*$) is innovation diffusion ι^* because the diffusion of technologies increases A_t and therefore the knowledge stock $K_t = A_t + \zeta N_t$ is relatively dominant (since ζ is small). With a smaller ζ, the balance of the trade-off on growth possibility between ι^* and η^* is more biased toward ι^*.

However, when the spillover ζ is large enough, the main driver of long-run growth becomes the pool of seeds (new technologies) for technology diffusion η^* because a larger pool size (a larger number of new technologies, N_t) has a stronger effect to increase the knowledge stock $K_t = A_t + \zeta N_t$ (since ζ is high). Here, the key player shifts to the user of new technologies, which is the early adopter who encourages new technologies, N_t, rather than A_t. With a larger ζ, the trade-off between ι^* and η^* is more biased toward η^*.

Remark 1 *An increase in the public love of novelty λ has opposite effects on the two determinants of long-run growth: it increases the speed of technology diffusion ι^*, but decreases the pool size of seeds for diffusion $\eta^* = 1/\lambda$, through an increase in the relative profitability of diffusion to innovation investments. Which determinant is dominant depends on the efficiency ζ of spillovers from new innovations.*

1. *When ζ is smaller, the balance of trade-offs between ι^* and η^* is biased toward diffusion ι^*; changes speeding up the diffusion process enhance long-run growth. Such changes are ones that increase the public love of novelty λ, including increasing the number of majority workers L and the degree of their love of novelty ψ or decreasing early adopters E.*

2. *When, on the other hand, ζ is large enough, the trade-off is biased toward the technology pool η^*; changes encouraging the creation of new technologies enhance long-run growth. Such changes are ones that decrease the public love of novelty λ, including decreasing L and ψ or increasing E.*

4 International Innovation Diffusion under Heterogenous Love of Novelty

In this section, we extend the baseline analysis to incorporate an international context. The reason for this widening of scope is that there is concrete evidence showing that different people or regions typically have different attitudes toward novel things on average (e.g., Rogers 1962, Tellis et al. 2009); thus, love of novelty can be seen as a national characteristic that might affect not only domestic but also international technological diffusion. A question naturally arises: What is the role of cross-country differences in the public love of novelty λ? We then consider a two-country version of our baseline closed-economy model . In doing so, we should capture exactly what is added by the introduction of international factors. Thus, given the extension of context to include an examination of the international, we begin by focusing on a particular situation with $\zeta = 0.5$, in which the growth effects of λ *in the closed economy* (characterized in Propositions 2) cease to exist. Note that g^* becomes $g^* = I/2$ and free from λ when ζ is exactly on the cutoff point, 0.5, noting (27).

Think about two countries, H and F. By a superscript of $i = H, F$, we assign any variables to country i from here on. The two countries are basically identical except for the public love of novelty $\lambda^i = (\varepsilon^i)^{-1}(\psi^i)^{\sigma/(\sigma-1)}$, where $i = H, F$. To introduce international aspects, we assume that all goods are tradable, including the final good, C_t^i, and the intermediates, $\{x_t^i(j)\}$. We also postulate a globally integrated market for financial capital (as the form of ownership for shares of firms), where the world interest rate is denoted as r_t.

We consider the life cycle of a technological innovation, j, to produce an intermediate good as follows. When, first, a firm in one country, say h, innovates a new technology to produce a new intermediate good, j, the innovated technology is adopted only by *local* early adopters, E^H. Then, the firm produces its innovated good j in country H. After the investment aimed at technological diffusion succeeds (with an endogenous arrival rate of ι_t^{H*}), the firm becomes able to produce the good j using majority workers of *either country*, L^H or L^F; then, at each point in time, the firm chooses whether to produce the good j in country H or to shift production location to country F through foreign direct investment (FDI).

As in the standard models, such as Lai (1998), there is no fixed cost for FDI. Therefore, under free trade, the production location for any old good (A^H or A^F) is a country where the profit is higher, and thus, the wage rate for majority workers, w_t^{HL} or w_t^{FL}, is lower in equilibrium. If $w_t^{HL} = w_t^{FL}$, the two countries are indifferent to the firm as a place for production.

Note that in the extended model there are the following six types of intermediate goods: (i) new goods, N_t^H, in country H, which are produced in H; (ii) new goods, N_t^F, in country F, which are produced in F; (iii) old goods, A_t^{HH}, that are originally innovated in country H and produced in country, H; (iv) old goods, A_t^{HF}, that are originally innovated in country H and produced in country F; (v) old goods, A_t^{FF}, that are originally innovated in country F and produced in country, F; and (vi) old goods, A_t^{FH}, that are originally innovated in country F and produced in country H. Denote as A^H (A^F) the number of old goods that are originally innovated in country H (F); $A^H \equiv A^{HH} + A^{HF}$ ($A^F \equiv A^{FH} + A^{FF}$).

As in the baseline model, we consider that the knowledge stock for each country, say country H, depends on its own innovation experience; K_t^H depends on $A_t^H + \zeta N_t^H$. To see the role of international knowledge spillovers, we consider that this too depends on the foreign country's innovation through FDI, which can be represented by A_t^{FH}, i.e., the number of technologies that are innovated in F but produced in H via FDI. Parameterizing the efficiency of international knowledge spillovers with $\xi \geq 0$, we provide a revised definition on K_t^H:

$$K_t^H = A_t^H + \zeta N_t^H + \xi A_t^{FH}. \tag{28}$$

The definition on K_t^F is analogous to (28).

Those types of intermediate goods are all combined by perfectly competitive global firms to produce the single final good, C_t, which is sold to consumers in both countries.

The production function, (3), can be rewritten as

$$C_t = \left[\int_{j \in \{A_t^H \cup N_t^H\} \cup \{A_t^F \cup N_t^F\}} x_t(j)^{\frac{\sigma-1}{\sigma}} dj \right]^{\frac{\sigma}{\sigma-1}} . \tag{29}$$

It is worth showing a revised version of the profit and supply functions: the profit for a firm producing in country H is

$$\pi_t^H(j) = \begin{cases} \frac{(\sigma-1)^{\sigma-1}}{\sigma^\sigma} \frac{C_t}{\left(w_t^{HL}\right)^{\sigma-1}} \equiv \pi_t^{HA} & \text{for } j \in A_t^{HH} \cup A_t^{FH} \\ \frac{(\sigma-1)^{\sigma-1}}{\sigma^\sigma} \frac{C_t}{\left(w_t^{HE}\right)^{\sigma-1}} \equiv \pi_t^{HN} & \text{for } j \in N_t^{HH} \cup N_t^{FH} \end{cases} . \tag{30}$$

Note that the profit for old goods depends only on production location and is free from consideration of the firm's original nationality (regardless of whether A_t^H or A_t^F). The analogous expression for $\pi_t^F(j)$ also holds. The equilibrium supply of intermediate goods is, then, given by

$$x_t^H(j) = \begin{cases} C_t \left(\frac{\sigma}{\sigma-1} w_t^{HL}\right)^{-\sigma} \equiv x_t^{HA} & \text{for } j \in A_t^{HH} \cup A_t^{FH} \\ C_t \left(\frac{\sigma}{\sigma-1} w_t^{HE}\right)^{-\sigma} \equiv x_t^{HN} & \text{for } j \in N_t^{HH} \cup N_t^{FH} \end{cases} . \tag{31}$$

The analogous expression for $x_t^F(j)$ also holds.

4.1 International Equilibrium

To ensure the existence of balanced growth, we naturally focus on an equilibrium in which both countries are engaged in innovation, diffusion, and production. Since any firm can produce old goods in either country, a non-arbitrage condition for location choice requires that the two locations are indifferent to the firms producing old goods: $\pi_t^{HA} = \pi_t^{FA}$ holds in this equilibrium. By definition and (30), the firm values for the old goods and the wages for majority workers must also be equated; $V_t^{HA} = V_t^{FA}$ and $w_t^{HL} = w_t^{FL}$.

It is a straightforward task to show the revised equilibrium conditions in accordance with the two-country environment, but we will only write down the important ones in order to save space (see Appendix A for the detailed derivations). First, the labor market equilibrium condition, (19), becomes

$$\omega^i = \left(\frac{1}{\varepsilon^i} \frac{N_t^i}{A_t^{ii} + A_t^{mi}} \right)^{\frac{1}{\sigma}} \tag{32}$$

for each i. New is the term of A_t^{mi}, i.e., the old goods that are innovated in the foreign country but produced in the home country via FDI. Through the labor market equilibrium, the domestic wage differential between early adopters and majority workers decreases with A_t^{mi}. With the R&D-related conditions, (32) leads to

$$\eta^i = \varepsilon^i \left(\psi^i\right)^{-\frac{\sigma}{\sigma-1}} , \tag{33}$$

which is a country-specific version of (20). Let's define country i's public love of novelty by $\lambda^i \equiv (\varepsilon^i)^{-1} \left(\psi^i\right)^{\sigma/(\sigma-1)}$. Note that along a balanced growth path in the current international setting, both countries grow at the same rate there: $\iota^{H*}\eta^{H} = \iota^{F*}\eta^{F}$ must hold.

Using (32) and (33), we can demonstrate the steady-state values of the domestic diffusion rate of innovation ι^{i*} and the world growth rate g^{*}:[18]

$$\iota^{i*} = \frac{K_t^i}{N_t^i}\frac{\lambda^i}{1+2\lambda^i}I = \lambda^i\left(1+2\xi\phi^i\frac{\lambda^i}{1+2\lambda^i}\right)\frac{I}{2} \tag{34}$$

for each i, and

$$g^{*} = \left(1+\frac{2\xi}{\left(2+1/\lambda^H\right)+\left(2+1/\lambda^F\right)}\right)\frac{I}{2}. \tag{35}$$

Here, $\phi^i \in [0,1]$ is a new and important component in this extension; ϕ^i denotes an international share of the old goods that are produced in one country. We can also derive the steady-state value of the production share ϕ^i of country i for old goods:[19]

$$\phi^i = \frac{\left(2+1/\lambda^i\right)}{\left(2+1/\lambda^i\right)+\left(2+1/\lambda^m\right)} \tag{36}$$

for $(i,m) = (H,F), (F,H)$. Accordingly, we can define a rate of international innovation diffusion as $\tilde{\iota}_t^{mi} \equiv \dot{A}_t^{mi}/A_t^i = \phi^i g^{*}$, capturing a rate in which FDI from country m increases the stock of old goods in country i.

As in the baseline model, the public love of novelty λ^i always has a positive effect on the rate of *domestic* innovation diffusion, ι^{i*}, noting (33), (34), and (36). This diffusion-enhancing effect does not alter in the international environment. The first new result that we can obtain by considering the extension of context to include an international setting is on the international production share, ϕ^i.

Proposition 3 *An increase in the public love of novelty in country i, λ^i, has a negative effect on the production share ϕ^i of the home country, i.*

Proof. Straightforward from (33) and (36). ■

Proposition 3 shows that a stronger public love of novelty in country i, λ^i, leads to a decrease in the production share ϕ^i of the home country, by crowding out some firms producing in country i to the foreign country. The reasoning is as follows. In the first place, as mentioned, a larger λ^i facilitates the domestic diffusion ι^{i*} of new technologies, by increasing the relative profitability of diffusion investment. It increases the number of old goods in country i and thereby increases the labor demand for majority workers in country i. While the wage rates for majority workers are internationally equated *in equilibrium*, this increased labor demand in country i would lead to an increase in the wage rate in country i, w_t^{iL}, *off equilibrium*.[20] Responding to the wage increase, some firms begin to flee from country i to the foreign country, m, by virtue of enjoying a lower wage rate there. With such *capital* flight, the labor demand and the wage rate decrease (increase) in country i (country m), and this trend continues until the wage gap

[18]See Appendix A for derivations. Note that we incorporate $\zeta = 0.5$ from this point on.

[19]In Appendix A (specifically, the last two lemmas there), we provide some conditions under which $0 < \phi^i < 1$ holds for each i. Note that $0 < \phi^i < 1$ always holds when $\zeta = 0.5$.

[20]In our model, a lower wage necessarily implies a higher profit.

ceases to exist, at which point the wages are internationally balanced again. Through this off-equilibrium process, the equilibrium production share ϕ^i of country i decreases.

The second result that we obtain within the international setting pertains to the international diffusion rate of innovation, $\tilde{\iota}^{mi}$.

Proposition 4 *An increase in the public love of novelty in country i, λ^i, has a negative effect on the international diffusion rate $\tilde{\iota}^{mi}$ of innovation from country m to country i if the efficiency ξ of international knowledge spillovers via FDI is equal to or smaller than $2/(2+\eta^m)$. The effect is an inverted U-shape if ξ is higher than $2/(2+\eta^m)$.*

Proof. See Appendix B. ■

Proposition 4 shows that factors speeding up the domestic innovation diffusion ι^{i*}, such as a stronger love of novelty λ^i, can slow down international innovation diffusion (which actually occurs if the spillover effect ξ of international diffusion is sufficiently small). To understand the mechanism, first, recall that the international diffusion rate $\tilde{\iota}^{mi} = \phi^i g^*$ for country i is a product of the production share ϕ^i and the world growth rate. Then, when the public love of novelty in country i is stronger (since, for instance, the population L of majority workers is larger or their love ψ of novelty is stronger), more innovations are domestically diffused within country i (higher ι^{i*}), whereby some productions migrate overseas through the above-mentioned crowding-out effect (lower ϕ^i) as shown in Proposition 3. The decrease in the production share of country i, ϕ^i, can discourage international innovation diffusion from country m to i ($\tilde{\iota}^{mi} = \phi^i g^*$) because some of the productions moving out from i to m have a foreign origin (A_t^{mi}).

However, when the international knowledge spillovers are sufficiently efficient (ξ is sufficiently large), the encouraged diffusion ι^{i*} and resulting increase in old goods in country i (an increase in A_t^i) can strongly contribute to the accumulation of knowledge stock in both countries, noting the last terms with ξ for both knowledge stocks, $K_t^i = A_t^i + \zeta N_t^i + \xi\left(1-\phi^i\right) A_t^m$ and $K_t^m = A_t^m + \zeta N_t^m + \xi \phi^i A_t^i$. Through these terms, there is a positive effect on the world growth rate g^*. Since g^* is another component of international innovation diffusion (recall $\tilde{\iota}^{mi} = \phi^i g^*$ again), there is also a positive effect on $\tilde{\iota}^{mi}$. Therefore, when the efficiency ξ of international spillovers is sufficiently high, this positive effect of higher λ^i on g^* becomes very strong, such that it dominates the negative effect on ϕ^i; in this case, the monotonically negative effect on $\tilde{\iota}^{mi}$ will be bent to form the shape of an inverted U. This is the thinking behind Proposition 4.

Just now, in the above text, we mentioned that a higher λ^i has a positive effect on world economic growth g^*. Since this fact is also important, we will now summarize it as a proposition.

Proposition 5 *An increase in the public love of novelty in either country, H or F, has a monotonically positive effect on the rate of world economic growth g^*.*

Proof. See (33) and (35). ■

We have made the following remark with regard to the extension of context to a two-country, together with Figure 1.

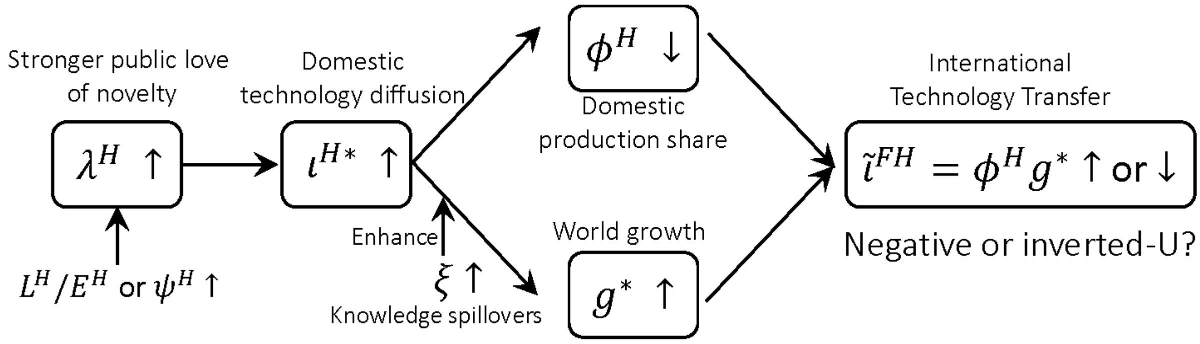

Figure 1: Equilibrium effects in the international economy

Remark 2 *Let us begin by considering an increase in the public love of novelty in one country, say country H. This increase in λ^H, emanating from an increase in the relative population of majority workers L^H/E^H or their love of novelty ψ^H, leads to an increase in the speed of domestic technology diffusion, ι^{H*}, as in the closed-economy model. Then, this rapid technology diffusion in country H has two different effects on the rate of international knowledge spillovers from F to H, i.e., $\tilde{\iota}^{FH} = \phi^H g^*$.*

1. *The increase in ι^{H*} decreases the production share of country H, ϕ^H, through the crowding-out effect (Proposition 3).*

2. *The increase in ι^{H*} increases the world economic growth rate, g^*, by accelerating the accumulation of knowledge stocks for both countries, K_t^H and K_t^F (Proposition 5).*

The second positive effect becomes relatively stronger than the first negative effect when the efficiency ξ of international knowledge spillovers is higher. In fact, as shown in Proposition 4, the effect of an increase in λ^i on $\tilde{\iota}^{FH} = \phi^H g^*$ when ξ is smaller than the cutoff value; however, the effect is an inverted U-shape when ξ is higher than it.

5 Concluding Remarks

We investigate the role of the majority workers' love of novelty in innovation, innovation diffusion, and economic growth in the long run. To do so, we provide a new innovation-based growth model by introducing several types of workers and examining endogenous innovation diffusion from one worker type to another. To consider the role of love of novelty, we particularly focus on worker heterogeneity in terms of these subjects' innate trait of how willing they are to welcome and adopt newly innovated technologies for the production of goods (as it pertains to the somewhat imprecise label of an individual love of novelty).

In the model, we include three different types of labor: innovators (working in R&D), early adopters (working in production with newly innovated technologies), and the much more voluminous group of ordinary workers, who are called majority workers (working in production with relatively old, more user-friendly technologies). An innovated technology endogenously diffuses throughout the economy in such a way that it is first used only by a few people (the early adopters) but eventually becomes available to ordinary people (the majority workers). Two key assumptions are (a) that innovation is diffused to majority workers endogenously owing to R&D firms' investment activity and (b) that the probability of success depends not only on a firm's investment level (endogenous) but also on the strength of the love novelty that majority workers, as ordinary people, possess (exogenous).

We show that a stronger love of novelty and/or a larger population of majority workers facilitates the diffusion of innovated technologies to majority workers, leading, in turn, to a higher speed of innovation diffusion in long-run equilibrium. Since a higher diffusion speed basically contributes to a higher long-run rate of economic growth in our analysis, it suggests that the size of majority workers and their strong love of novelty are a fundamental source of innovation diffusion and long-run economic growth. However, when newly innovated technologies can cause sufficiently efficient knowledge spillovers for R&D firms and/or innovators, the growth effect might be negative.

By extending the contextual scope to a two-country environment with free trade and foreign direct investments, we also show that majority workers' number and degree of love of novelty in any given home country can enhance world economic growth, but it has a negative effect on the international production share of the home country. It can also result in an inverted U-shape effect on the speed of international innovation diffusion (from foreign to home countries) when the foreign-innovated technologies that are used for production in the home country can generate sufficiently efficient knowledge spillovers for home-based R&D firms/innovators. From an international perspective, a country's public love of novelty is a source of world economic growth; however, its effect on international specialization and international technology diffusion can be more complex, potentially also resulting in an inverted U-shape.

We intend to keep our analysis as simple as possible, without losing the core essence. To that end, there are at least three caveats we should mention in order to conclude the paper. First, motivated by existing research in psychology and other fields, we treat ordinary people's love of novelty as a constant parameter because we focus on ordinary people's nature and their innate characteristics, which tend toward a willingness to adopt new technologies. However, people's behavior often changes in response to their new experiences as well as to changes in the macroeconomic environment, and behavior relating to adopting new technologies should be no exception. Therefore, one can understand it is exceedingly interesting to introduce an endogenous factor affecting individuals' love of novelty (e.g., externalities, voluntary search, learning by experience, education, etc.).

The second caveat relates to the fact that population sizes are fixed to reflect, again, our initial motivation (people's love of novelty as an innate trait). However, for the same reason stated as above, human behavior is prone to change, and it is possible for some individuals to move in and out of the category of early adopter. Therefore, one can understand it is deeply interesting to introduce endogenous skill acquisition and occupational choice. For example, people are initially majority workers at birth, but they can familiarize themselves with a newly innovated technology in order to earn a living at a higher wage rate by investing time and/or money in education.

The third caveat is the absence of welfare analysis. From an international context in particular, the domestic/global welfare consequences of ordinary workers' love of novelty should be emphasized due to its significance and its interest value. Unfortunately, the present model is too complex to analytically solve for dynamic welfare. As an inclusive alternative, one could consider a simplified version of the model, which would be eligible for welfare analysis by, for example, going with a more tractable production structure or assuming perfect depreciation of a technology stock. Otherwise, one could rely on computational works and do a calibration analysis. While those issues are worthy of investigation, we leave them up to future research.

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Appendix A

In the extended model, the labor market-related conditions can be expressed as follows. Defining $\omega_t^i \equiv w_t^{iE}/w_t^{iL}$ for each $i = H,\ F$, with (31), (16), (17), and (18) become

$$I = \frac{n_t^i}{K_t^i} + \frac{\iota_t^{i*} N_t^i}{K_t^i}, \tag{A1}$$

$$E^i = N_t^i x_t^{iN} = N_t^i C_t \left(\frac{\sigma}{\sigma - 1} w_t^{iE} \right)^{-\sigma}, \tag{A2}$$

$$L^i = A_t^{ii} x_t^{iA} + A_t^{mH} x_t^{iA} = \left(A_t^{ii} + A_t^{mi} \right) C_t \left(\frac{\sigma}{\sigma - 1} w_t^{iL} \right)^{-\sigma}, \tag{A3}$$

where $(i, m) = (H,\ F),\ (F, H)$. Combining (A2) and (A3) yields

$$\varepsilon^i = \frac{N_t^i}{A_t^{ii} + A_t^{mi}} \left(\omega^i \right)^{-\sigma} \tag{A4a}$$

for $(i, m) = (H,\ F),\ (F, H)$. See (32).

Note that in the present case with $\pi_t^{HA} = \pi_t^{FA}$, the two countries are indifferent as a production location. Given that the profits depend only on the production location (not on a technology's origin/history), thus, the number of old goods, $A_t^{ii} + A_t^{mi}$, that are produced in a particular country, say country i, can be written as a function of the total number of old goods, $\left(A_t^H + A_t^F \right) \equiv A_t$, multiplied by a production share of old goods that are produced in i, denoted as $\phi_t^i \in [0, 1]$:

$$A_t^{ii} + A_t^{mi} = \phi_t^i A_t$$

for $(i, m) = (H,\ F),\ (F, H)$. Clearly, $\phi_t^H + \phi_t^F = 1$. Accordingly, (A4) imply

$$\omega^i = \left(\frac{1}{\varepsilon^i} \frac{N_t^i}{\phi_t^i A_t} \right)^{\frac{1}{\sigma}} \tag{A4b}$$

for $i = H,\ F$.

Let us move to the conditions related to innovation and diffusion investments: (9), (11), (12a) and (13) will be revised to

$$V_t^{iN} = \frac{w_t^{iI}}{K_t^i} \text{ and } \psi^i V_t^{iA} = \frac{w_t^{iI}}{K_t^i}, \tag{A5}$$

$$r_t V_t^{iN} = \pi_t^{iN} + \dot{V}_t^{iN} \text{ and } r_t V_t^{iA} = \max\left\{ \pi_t^{HA}, \pi_t^{FA} \right\} + \dot{V}_t^{iA}, \tag{A6}$$

for $i = H,\ F$. (A5) and (A6) imply $\pi_t^{iN} = \psi^i \pi_t^{iA}$ and thus

$$\omega^i = \left(\psi^i \right)^{-\frac{1}{\sigma - 1}} \tag{A7}$$

for $i = H,\ F$.

Finally, the law of motion in (14) and (15) is revised as

$$\dot{N}_t^i = n_t^i - \iota_t^{i*} N_t^i \text{ and } \dot{A}_t^i = \iota_t^{i*} N_t^i \tag{A10}$$

for $i = H,\ F$.

We will characterize the steady-state equilibrium. Using (A4b) and (A7), we have

$$\frac{N_t^i}{A_t^i} = \varepsilon^i \left(\psi^i\right)^{-\frac{\sigma}{\sigma-1}} \equiv \eta^i \tag{A11}$$

for $i = H,\ F$. See (33). Then, from (A10), $\dot{N}_t^i/N_t^i = \dot{A}_t^i/A_t^i$ implies

$$\frac{n_t^i}{N_t^i} = \iota_t^{i*}\left(1+\frac{N^i}{A_t^i}\right) \tag{A12a}$$

holds in steady state. From (A10), the international balance of growth rates also implies

$$\iota^{H*}\eta^H = \iota^{F*}\eta^F. \tag{A12b}$$

Substituting (A12a) into (A1) yields the steady-state diffusion rate as

$$\iota^{i*} = \frac{K_t^i}{N_t^i}\frac{I^i}{2+\eta^i} = \left(\frac{1}{\eta^i}+\zeta+\frac{\xi^i}{\eta^i}\phi^i\frac{A_t^m}{A_t^i}\right)\frac{I}{2+\eta^i}, \tag{A13}$$

also using (28). By (A12b) and (A13), we have the steady-state production ratio for old goods as[21]

$$\phi^H = \frac{\left(2+\eta^H\right)\left(1+\zeta\eta^F+\xi^F\right)-\left(2+\eta^F\right)\left(1+\zeta\eta^H\right)}{\xi^H\left(2+\eta^F\right)+\xi^F\left(2+\eta^H\right)}, \tag{A14a}$$

$$\phi^F = \frac{\left(2+\eta^F\right)\left(1+\zeta\eta^H+\xi^H\right)-\left(2+\eta^H\right)\left(1+\zeta\eta^F\right)}{\xi^H\left(2+\eta^F\right)+\xi^F\left(2+\eta^H\right)}. \tag{A14b}$$

From (A10), (A13), and (A14), the steady-state innovation rate, $g^* \equiv \dot{A}_t^i/A_t^i = \dot{N}_t^i/N_t^i$ for $i = H,\ F$, is given by

$$g^* = \iota^{i*}\eta^i = \left[\frac{\xi^H\left(1+\zeta\eta^F\right)+\xi^F\left(1+\zeta\eta^H\right)+\xi^H\xi^F}{\xi^H\left(2+\eta^F\right)+\xi^F\left(2+\eta^H\right)}\right]I. \tag{A15}$$

It is easy to verify that $\partial g^*/\partial\eta^H > 0$ if and only if

$$\zeta > \frac{1}{2}\left(\frac{\xi^H\xi^F}{\xi^H+\xi^F}+1\right). \tag{A16}$$

Given that we now work on the equilibrium where both countries produce, we have to ensure $\phi^i \in (0,1)$ for each i. The following parametric condition does so:

$$\frac{1}{1+\frac{\xi^F}{1+\zeta\eta^F}} < \frac{\left(2+\eta^H\right)/\left(1+\zeta\eta^H\right)}{\left(2+\eta^F\right)/\left(1+\zeta\eta^F\right)} < 1+\frac{\xi^H}{1+\zeta\eta^H}. \tag{A17}$$

The following two lemmas state when (A15a) is satisfied.

[21] Here, having in maind s revised version of Lemma 1, we consider an economy that has already reached the steady state, staying there permanently. Thus, A_t^F/A_t^H is constant and simply determined as a function of its initial level A_0^F/A_0^H. We can freely take the steady-state value of A_t^F/A_t^H as an initial condition; we set $A_t^F/A_t^H = 1$.

Lemma 2 *(A17) holds for any* $\left(\eta^H, \eta^F\right) > (0,0)$ *if and only if*

$$2\zeta \in \left(1, 1 + \min\left\{\xi^H, \xi^F\right\}\right); \tag{A18}$$

otherwise, there exists some values of $\left(\eta^H, \eta^F\right)$ *such that the first inequality is violated.*

Proof. The first inequality in (A17) holds for any $\eta^H \geq 0$ if and only if (iff)

$$\begin{aligned} \eta^F &< \frac{\xi^F}{0.5 - \zeta} \text{ in the case of } \zeta \leq 0.5, \\ \zeta &< 0.5\left(1 + \xi^F\right) \text{ in the case of } \zeta > 0.5. \end{aligned}$$

It holds for any $\eta^F \geq 0$ iff

$$\begin{aligned} 0.5 &< \zeta \text{ in the case of } \zeta \leq 0.5\left(1 + \xi^F\right), \\ \eta^H &< \frac{\xi^F}{\zeta - 0.5\left(1 + \xi^F\right)} \text{ in the case of } \zeta > 0.5\left(1 + \xi^F\right). \end{aligned}$$

These two facts mean that: (A) The first inequality in (A17) holds for any $\left(\eta^H, \eta^F\right) > (0,0)$ if and only if $0.5 < \zeta \leq 0.5\left(1 + \xi^F\right)$; otherwise, there exists some values of $\left(\eta^H, \eta^F\right)$ such that the first inequality is violated. This gives a proof for the first half of the lemma.

The second inequality in (A17) holds for any $\eta^H \geq 0$ iff

$$\begin{aligned} 0.5 &< \zeta \text{ in the case of } \zeta \leq 0.5\left(1 + \xi^H\right), \\ \eta^F &< \frac{\xi^H}{\zeta - 0.5\left(1 + \xi^H\right)} \text{ in the case of } \zeta > 0.5\left(1 + \xi^H\right). \end{aligned}$$

It holds for any $\eta^F \geq 0$ iff

$$\begin{aligned} \eta^H &< \frac{\xi^H}{0.5 - \zeta} \text{ in the case of } \zeta \leq 0.5, \\ \zeta &< 0.5\left(1 + \xi^H\right) \text{ in the case of } \zeta > 0.5. \end{aligned}$$

These two facts mean that: (B) The second inequality in (A17) holds for any $\left(\eta^H, \eta^F\right) > (0,0)$ if and only if $0.5 < \zeta < 0.5\left(1 + \xi^H\right)$; otherwise, there exists some values of $\left(\eta^H, \eta^F\right)$ such that the second inequality is violated. The statements (A) and (B) complete the proof. ■

Lemma 3 *Suppose that (A18) is violated. Then there exists an intermediate range of* η^H (η^F) *for which (A17) holds, given* η^F (η^H) *as constant.*

Proof. When $2\zeta \notin \left(1, 1 + \min\left\{\xi^H, \xi^F\right\}\right)$, (A17) has monotonicity in terms of η^H, with which we can explicitly derive the range of η^i in which (A17) holds, given η^m. Noting this fact would suffice to complete the proof. ■

Appendix B

Proof for Proposition 4. With (35) and (36), we have

$$\tilde{\iota}^{mi} = \phi^i g^* = \frac{(2+\eta^i)}{(2+\eta^m)+(2+\eta^i)}\left(1+\frac{2\xi}{(2+\eta^F)+(2+\eta^H)}\right)\frac{I}{2}.$$

Differentiating $\tilde{\iota}^{mi}$ with respect to η^i,

$$\frac{d\tilde{\iota}^{mi}}{d\eta^i} > 0 \Leftrightarrow \left(2+\eta^i\right)\left(2\xi-(2+\eta^m)\right) < (2+\eta^m)\left(2\xi+(2+\eta^m)\right).$$

When $\xi \leq 2/(2+\eta^m)$, the inequality always holds. When $\xi > 2/(2+\eta^m)$, the left-hand side of inequality is monotonically increasing in η^i. As $\eta^i \to 0$, the inequality becomes

$$\left(2\xi-(2+\eta^m)\right) < \left(1+\frac{\eta^m}{2}\right)\left(2\xi+(2+\eta^m)\right),$$

which always holds. As $\eta^i \to \infty$, the inequality is eventually violated. It implies an inverted-U relationship between η^i and $\tilde{\iota}^{mi}$. Given the monotonic relationship of $(\varepsilon^i)^{-1}$ and ψ^i to η^i, it also implies an inverted-U relationship of $(\varepsilon^i)^{-1}$ and ψ^i to $\tilde{\iota}^{mi}$. Note that $(\varepsilon^i)^{-1}$ and ψ^i are negatively related to η^i by (33). ■

Appendix C (not for publication)

This appendix shows saddle-path stability of our dynamical system together with the wage rates for three types of labor, $\left(w_t^I, w_t^E, w_t^L\right)$. To do so, let us think about an economy that has already reached at $t = 0$ the state in which N_t and A_t grow at the same rate, g^*, and $N_t/A_t = \eta^*$ holds for any t. By (2), (8), (13), and (15), we have

$$\frac{\dot{C}_t}{C_t} - \frac{\dot{V}_t^A}{V_t^A} - \frac{\dot{A}_t}{A_t} = \frac{1}{\sigma}\frac{1}{1+\psi\eta^*}\frac{C_t}{A_t V_t^A} - (\rho + g^*), \tag{C1}$$

which also uses the expression of w_t^L in (C2) below and $\omega_t = \psi^{-\frac{1}{\sigma-1}}$ from (19) and (20). From (5), (6), and (19), with $\omega_t = \psi^{-\frac{1}{\sigma-1}}$, we also have the wage rates for production workers as

$$w_t^L = A_t^{\frac{1}{\sigma-1}} \left(\frac{\sigma-1}{\sigma}\right) (1+\psi\eta^*)^{\frac{1}{\sigma-1}}, \tag{C2a}$$

$$w_t^E = \psi^{-\frac{1}{\sigma-1}} A_t^{\frac{1}{\sigma-1}} \left(\frac{\sigma-1}{\sigma}\right) (1+\psi\eta^*)^{\frac{1}{\sigma-1}}. \tag{C2b}$$

By applying the standard argument for saddle-path stability to the one-dimensional dynamical system for $C_t/(A_t V_t^A)$, we can prove the following fact:

$$\frac{C_t}{A_t V_t^A} = \sigma (1+\psi\eta^*)(\rho+g^*) \equiv \tilde{c} \text{ for any } t \geq 0. \tag{C3}$$

Finally, using (11), (23), and (C3), we have the wage rate for innovators as

$$w_t^I = A_t^{\frac{1}{\sigma-1}} \frac{\psi(1+\zeta\eta^*)}{\sigma(\rho+g^*)(1+\psi\eta^*)} \left(L^{\frac{\sigma-1}{\sigma}} + (\eta^*)^{\frac{1}{\sigma}} E^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}. \tag{C4}$$