

# From Adoption to Innovation: State-dependent Technology Policy in Developing Countries\*

Jaedo Choi

Federal Reserve Board of Governors

Younghun Shim

University of Chicago

## Job Market Paper

September 18, 2022

### Abstract

Should governments in developing countries promote technology adoption, or should they support innovation? We use a newly digitized dataset on technology imports and patents in South Korea to answer this question. We find that (i) as firms close the technology gap from foreign firms, productivity growth from adoption decreases compared with innovation, (ii) the adoption fee is higher when the gap is smaller, (iii) when a firm adopts a technology, other firms increase patent citations to the adopted technology, suggesting knowledge diffusion. Based on these findings, we build a two-country growth model where firms can innovate or adopt technology from foreign firms. Since firms are non-atomistic, firms lose market share when they sell the technology to foreign firms. They internalize the loss by charging an adoption fee. Adoption generates knowledge diffusion, which motivates the government to subsidize adoption, but the size of diffusion decreases as the country grows. Then, we estimate the model by matching the empirical findings. Using the estimated model, we evaluate the technology policy in Korea, which started with an adoption subsidy and switched to an innovation subsidy. Our result suggests that the policy generated 5.21% higher welfare than the case without any policy, which is higher than time-invariant policies.

---

\*We are grateful to Ufuk Akcigit, Esteban Rossi-Hansberg, Chad Syverson, and Felix Tintelnot for their invaluable guidance and support. We also thank Rodrigo Adao, Sina Ates, Jonathan Dingel, Jonathan Eaton, Anders Humlum, Furkan Kilic, Samuel Kortum, Fernando Leibovici, Simon Mongey, Hyejin Park, Jeremy Pearce, Marta Prato, B. Ravikumar, Ana Maria Santacreu, Nancy Stokey, and seminar participants at the University of Chicago, Federal Reserve Bank of St. Louis, ESAM2022, AMES2022, YES2022, Workshop on International Trade and Intellectual Property Rights for helpful comments. E-mail: yhshim@uchicago.edu

# 1 Introduction

Samsung group, one of the largest conglomerates in the world, was founded in 1938 as a small company that made noodles. In 1968, Samsung decided to enter the electronics industry, but it did not have the technology necessary to produce an electronic product. To tackle this problem, Samsung aggressively adopted technologies by making technology transfer contracts with Japanese companies such as Sanyo, Sony, and NEC. Using the adopted technology, it produced basic electronic products such as radios, refrigerators, and TVs. However, as Samsung improved its technology level and evolved as a strong competitor, Japanese firms became reluctant to share their technology and charged higher adoption fees. Besides, as Samsung closed the gap with Japanese firms, the productivity growth from adoption became smaller. Therefore, Samsung switched its strategy from adopting foreign technology to innovating its technology. This transition from adoption to innovation also happened at the aggregate level. Figure 1 shows that South Korea (Korea, hereafter) gradually decreased the expenditure share of adoption and increased innovation as it caught up with Japan.

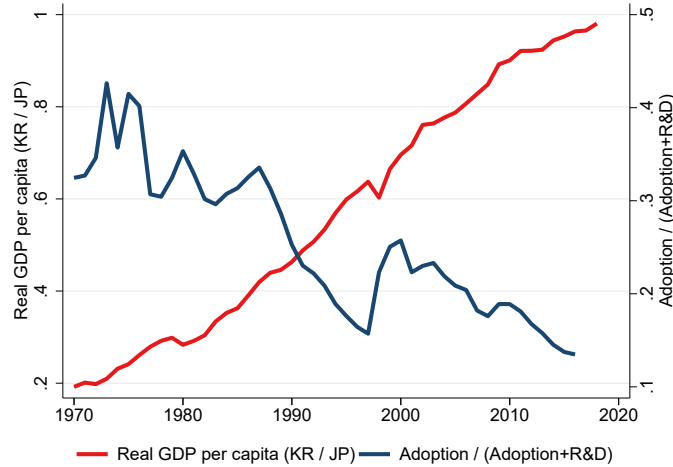


Figure 1: Relative GDP per capita and Expenditure Share of Adoption over time

**Notes:** This figure plots the ratio of the real GDP per capita between Korea and Japan and the adoption expenditure share. Adoption expenditure is (gross) payment to foreign firms for sharing industrial processes, designs, and licensing for patents and trademarks. GDP is from Maddison project (Bolt and Van Zanden, 2020; Cha et al., 2020), R&D and adoption expense are from World Bank DataBank.

This observation leads to the following questions. What is the contribution of technology adoption and innovation to growth? How does the contribution change over different stages of development? What strategic considerations do the adopter and technology seller have regarding the adoption contract? And how does the strategic aspect shape the cost of

technology adoption? What are the externalities of adoption and innovation? What is the role of government policy in terms of adoption and innovation? Should the government promote or delay the transition from adoption to innovation? The answers to these questions are crucial for policymakers to design technology policy in developing countries.

This paper studies the role of technology adoption and innovation over different stages of development and policy implications, providing theoretical, empirical, and quantitative contributions. Theoretically, we build a two-country growth model in which home and foreign firms can increase productivity by innovating or adopting technology from firms in another country. By modeling non-atomistic firms, we capture strategic interactions between the adopter and the seller, generating the endogenous adoption price. Empirically, we overcome the challenge of finding comprehensive microdata of adoption and innovation by constructing a new dataset. We digitize technology import data in Korea, where we can observe Korean firms adopting the technology of foreign firms and the adoption fee payment. This data is merged with firm-level balance sheet data and patent data of both Korean and foreign firms. We document new empirical facts and estimate the model using the simulated methods of moments. Quantitatively, we study the contribution of adoption and innovation over different stages of development. Then, we evaluate the real-world policy implemented in Korea, which started by subsidizing adoption and switched to subsidizing innovation as the country developed.

In the theoretical part, we build a two-country growth model with step-by-step innovation and adoption. This model is a dynamic general equilibrium model where firms are fully forward-looking. It builds on the model in [Akcigit et al. \(2018\)](#) where domestic and foreign firms compete in a global market and improve productivity by innovation. We add endogenous adoption by which the firm improves productivity and pays the adoption fee to the foreign firm. Although many papers have documented the gain from technology adoption, little is known about the cost of the adoption, especially incorporating strategic interaction from the technology seller. We capture the endogenous cost of adoption by modeling the adoption as a mutual agreement of both adopter and seller, and the seller internalizes its future profit loss.<sup>1</sup> Since we have non-atomistic firms, the foreign firm loses future profit when it sells technology to domestic firms. The foreign firm internalizes this loss, and the adoption fee is determined by Nash bargaining between the adopter and the foreign firm. Adoption fee is a function of the productivity gap between foreign and domestic firms. When

---

<sup>1</sup>In [Perla and Tonetti \(2014\)](#), [König et al. \(2020\)](#), the imitator can learn from other firms without their agreement. [Benhabib et al. \(2021\)](#), and [Hopenhayn and Shi \(2020\)](#) also model the endogenous adoption fee, but it is set to share the gain of the adopter, not the loss of the seller. On the other hand, our model captures that the adoption decreases the future profit of the seller, and the adoption fee is also affected by the loss of the seller.

the productivity gap is small, one unit increase in a domestic firm’s productivity decreases a foreign firm’s profit a lot. Therefore, the foreign firm charges a higher adoption fee when the gap is smaller.

Productivity growth from adoption and innovation depends on the current technology gap from the foreign firm. We allow both the adoption and innovation to have the advantage of backwardness ([Gerschenkron, 1962](#)) in which firms can improve productivity easily when they are far from the frontier. To be specific, the expected step size from adoption and innovation decreases with relative productivity. The slope of step size can be different between adoption and innovation, which is estimated from the data.

Also, adoption and innovation generate knowledge diffusion, as the home follower can learn the domestic leader’s technology and improve on top of it when innovating. A leader loses its profit when its domestic follower gets knowledge diffusion. Therefore, this externality potentially creates underinvestment in adoption and innovation. In the case of adoption, the foreign firm internalizes this diffusion and charges higher fees as the adoption contracts can increase both firms’ productivity. It creates a larger discrepancy between the private and social benefits of adoption, which motivates the government to subsidize adoption.

We set the knowledge diffusion to happen stochastically with probability  $0 < \delta < 1$ . This assumption is more general than the previous literature (e.g., [Aghion and Howitt, 1992](#); [Klette and Kortum, 2004](#); [Acemoglu et al., 2018](#)) that assumes other firms can always build on the incumbent’s technology. This makes the level of diffusion flexible, which can be estimated from the data. The level of intertemporal spillover becomes  $\delta$  times the step size from adoption and innovation. Since the step size from adoption and innovation depends on the technology gap from the foreign firm, the level of spillover changes over time. Therefore, the optimal subsidy rate would be different over the different stages of development.

In the empirical part, we contribute to the mostly theoretical literature by providing a new dataset and empirical findings. Compared with the innovation-based growth model, few quantitative papers are studying the adoption-based growth model, mainly due to a lack of data. We contribute to the literature by digitizing the contract-level technology adoption data in Korea from 1962 to 1993. We collect the entire technology import contracts by Korean firms in which we observe the names of the adopter (Korean firm), the seller (foreign firm), and the adoption fee. This data is merged with firm-level financial and patent data both for Korean and foreign firms.

We document three new findings in the empirical analysis. First, productivity growth after innovation and adoption is smaller when the initial productivity gap from the foreign firm is smaller. Moreover, the initial productivity gap matters more for adoption than innovation. It implies that the advantage of backwardness ([Gerschenkron, 1962](#)) is stronger

on adoption than innovation. Second, the adoption fee is higher when the technology gap from the foreign firm is smaller, although the productivity gain is also smaller. It suggests the technology seller endogenizes the adopter's relative position in the adoption fee. Third, when a firm adopts a foreign technology, other non-adopting firms are more likely to cite patents of the foreign firm that sold the technology. It implies knowledge diffusion from the adopter to other firms and pins down the degree of intertemporal spillover in the model.

In the quantitative section, we solve the transition of the model from the initial state where firms in Korea have lower productivity on average to the balanced growth path. Motivated by the fact Korea and Japan had almost equal GDP per capita in 2020, we set the underlying parameter such that the technology gap between the two countries is zero in the long run. Then, we estimate the parameters by matching the simulated moments from the transition period of the model with the data. In particular, we simulate the same regression of the empirical analysis from the model and match the coefficient between the model and the data.

Using the estimated model, we first study the contribution of adoption. We find that the growth contribution of adoption was 77% in 1970, and then it decreased to 10% in 2020. This is because 1) our estimates suggest that the productivity growth from adoption decreases faster than the innovation as the country catches up, 2) adoption fee increases over time, and 3) the government gradually decreases the adoption subsidy rate and increases the innovation subsidy rate. Therefore, firms switch from adoption to innovation over time. Without the policy, firms still transition from adoption to innovation, but the trend is slower.

Then, we evaluate technology policy in Korea since 1973. In 1973, the Korean government began subsidizing adoption by giving a tax credit. Then, it gradually decreased the adoption subsidy rate. On the other hand, it began the R&D subsidy in 1981 and steadily increased the subsidy rate over time. We compare this policy with three counterfactuals. First, we set the adoption subsidy rate as the initial rate (30.89%) and do not change it. Second, we set the innovation subsidy rate as the final rate (32.05%) and do not change it. Third, we shut down both subsidies. The baseline case where we mimic the actual policy generates welfare 5.25% higher than the case without a policy in the consumption unit. Welfare increase from this policy is higher than subsidizing only adoption (3.74%) or subsidizing only innovation (4.1%).

Motivated by this result, we study the optimal timing of switching from adoption to innovation subsidy where the government starts with 30% adoption subsidy and can switch to innovation subsidy in a single year. We find that welfare would have been the largest when the government switched to innovation subsidy in 1982 when GDP per capita in Korea was 37% of GDP per capita in Japan.

## 1.1 Related Literature

First, this paper is related to the endogenous growth literature on technology adoption. While many papers develop innovation-led growth models (e.g., [Romer, 1990](#); [Aghion and Howitt, 1992](#); [Jones, 1995](#); [Klette and Kortum, 2004](#)), several papers study adoption-led growth model particularly in developing country context. [Parente and Prescott \(1994\)](#) and [Comin and Hobijn \(2010\)](#) build adoption-led growth models and show that the barriers to technology adoption can account for a large portion of income disparity across countries. [Perla and Tonetti \(2014\)](#) develop a model where the firm can adopt technology from other domestic firms and the entire growth comes from adoption. [Benhabib et al. \(2021\)](#) and [König et al. \(2020\)](#) allow firms to both innovate and adopt, and study the interaction of two margins. While they focus on the adoption within domestic firms, this paper focuses on the adoption from foreign firms ([Grossman and Helpman, 1991a](#); [Barro and Sala-i Martin, 1997](#); [Comin and Hobijn, 2010](#); [Zilibotti, 2017](#)), [Acemoglu et al. \(2006\)](#), [Comin and Hobijn \(2010\)](#), [Zilibotti \(2017\)](#). In particular, our paper is related to [Acemoglu et al. \(2006\)](#) who study the optimal innovation and adoption policy depending on the distance to the frontier.

Our paper makes theoretical and empirical contributions to this literature. Theoretically, we endogenize adoption costs by modeling both the adopter and the technology seller and capturing the strategic interaction between them. While previous papers capture only the adopter’s incentive, we also capture the seller’s incentive, which is crucial to determining adoption cost. Empirically, this project is one of the first papers that uses comprehensive adoption and innovation data, provides new empirical facts and conduct quantitative analysis.

Second, this paper contributes to the literature on international knowledge diffusion. Several papers develop models where knowledge diffusion is byproduct of trade.<sup>2</sup> [Coe and Helpman \(1995\)](#), [Coe et al. \(1997\)](#), [Eaton and Kortum \(2001\)](#) view knowledge is imbedded in goods and diffused through international trade. Other papers model trade of goods stimulates knowledge transfer. [Grossman and Helpman \(1991b\)](#) assume technology transfer increases with trade volume. In [Alvarez et al. \(2017\)](#), [Buera and Oberfield \(2020\)](#), [Hsieh et al. \(2019\)](#), firms learn by interacting with foreign sellers in domestic market. [Rachapalli \(2021\)](#) assume firms learn about new products from the foreign buyers.<sup>3</sup> Compared with these papers, we focus on technology adoption, which is a deliberate attempt to learn technology from foreign firms and not a byproduct of other activities. Other papers also explicitly model technology adoption. [Eaton and Kortum \(1999\)](#), [Santacreu \(2015\)](#), [Sampson \(2019\)](#), [Lind](#)

---

<sup>2</sup>[Prato \(2022\)](#) studies knowledge diffusion from migration.

<sup>3</sup>For empirical evidence, refer to [Atkin et al. \(2017\)](#), [Aghion et al. \(2019\)](#)

and Ramondo (2022) develop models with trade, innovation, and adoption in multicountry settings. They infer adoption by using international patent, trade, or country-level R&D investment. While these papers use indirect measures of adoption, we utilize a direct measure from technology import data. Santacreu (2022) is an exception, which uses country-level license payment data to study the effect of trade and intellectual property policy. Our work contributes to the literature by using more disaggregated contract-level adoption data instead of country-level data.

Third, this paper contributes to the literature that studies technology policies. For empirical papers, Bloom et al. (2002), Bronzini and Iachini (2014), Dechezleprêtre et al. (2016), Howell (2017), Chen et al. (2021) study the effect of R&D subsidy on innovation and its spillover. de Souza (2021) study the effects of technology substitution policy on labor market in Brazil where the government decrease adoption subsidies and increase R&D subsidies. For quantitative papers, Jones and Williams (2000) show that positive externalities from R&D (non-appropriability of knowledge and intertemporal spillover) dominates negative externalities (business stealing, congestion externalities), which suggests the optimal R&D subsidy rate is positive. Acemoglu et al. (2018), Akcigit et al. (2022) study the optimal R&D policy in a setting with heterogeneous types of firms. Atkeson and Burstein (2019) study the effect of R&D subsidy on growth and welfare by developing a model that nests canonical growth models. Akcigit et al. (2018) study the optimal R&D subsidy and trade policy using a two-country innovation growth model.<sup>4</sup> Liu and Ma (2022) study the optimal R&D resource allocation in a multi sector model with innovation network. While most papers focus on R&D subsidy, we study more general technology policy that includes R&D and technology adoption subsidies.

Fourth, this paper contributes to the empirical literature that studies the effect of technology adoption on firm performance (Atkin et al., 2017; Giorcelli and Li, 2021; Juhász et al., 2020; de Souza, 2021; Humlum, 2019).<sup>5</sup> While most papers in the literature focus on specific technologies or industries, we provide evidence from comprehensive data that captures all of the technology imports in a given period. de Souza (2021) uses similarly comprehensive data on technology adoption and innovation and studies the impact of technology policy that switches from adoption subsidy to innovation subsidy. While he focuses on labor market outcomes based on a static model, we study the impact on growth based on the dynamic model.

Fifth, it is related to a growing literature on the step-by-step innovation model. This literature focuses on the strategic interaction between firms that compete by innovation

---

<sup>4</sup>Bloom et al. (2019) summarize both empirical and theoretical papers on innovation policies.

<sup>5</sup>Refer to (Verhoogen, 2021) for thorough literature review.

(Aghion et al., 2001; Acemoglu and Akcigit, 2012; Akcigit and Ates, 2019; Olmstead-Rumsey, 2022; Liu et al., 2022).<sup>6</sup> In particular, we focus on the competition between domestic and foreign firm similar to Akcigit et al. (2020), Akcigit et al. (2018). We extend this model by allowing endogenous adoption decisions. Specifically, we study the effect of the strategic interaction on the adoption decision and its royalty fee.

Lastly, this paper is related to the literature that studies the growth of Korea. Rodrik (1995) focus on the role of capital accumulation in the growth of Korea. Connolly and Yi (2015) study how trade policy reforms in Korea contributed to growth. Lane (2022), Choi and Levchenko (2021), and Kim et al. (2021) study the effect of temporary industrial policy in the 1970s, when the government subsidized heavy chemical industry. Aghion et al. (2021) study the pro-competitive reforms in Korea after the financial crisis in 1997, which contributed to transforming Korea from investment-based growth to innovation-based growth.

The remainder of this paper is organized as follows. Section 2 describes the model. Section 3 introduces the data. Section 4 shows empirical findings from the data. Section 5 explains the estimation and quantitative results. Section 6 presents policy implications. Section 7 concludes.

## 2 Model

We build a two-country endogenous growth model. This model builds on step-by-step innovation model (Aghion et al., 2001; Acemoglu and Akcigit, 2012; Akcigit and Ates, 2019). The key feature of the model is firms are non-atomistic and internalize other firms' behavior. A finite number of firms compete in each product line and improve productivity by innovation. In particular, we model competition between domestic and foreign firms, which build on Akcigit et al. (2018) and Akcigit et al. (2020).

We take two departures from the literature. First, we allow firms to adopt technology from the foreign firms. This adoption decision is endogenous where the adopter needs to pay adoption fee to the seller and the seller needs to agree on the fee. The adopter internalizes the expected gain from improving productivity. The seller internalizes that the follower can steal the leader's profit using the adopted technology. Adoption fee is determined by Nash bargaining between two firms incorporating both the buyer and seller's incentive. To the best of our knowledge, this is the first paper to consider the loss of the technology seller regarding technology adoption.<sup>7</sup>

---

<sup>6</sup>See Ates (2021) for a thorough literature review.

<sup>7</sup>Other papers endogenizing adoption (licensing) fee such as Benhabib et al. (2021), Hopenhayn and Shi (2020) assume atomistic firms. Therefore, they could capture only the gain from adoption but not the loss



Second, we model knowledge diffusion from innovation and adoption in a flexible way so that the size of diffusion can be estimated from micro data. Most papers in the Schumpeterian growth literature assume that the technology gap between the incumbent and entrant is fixed as one, and the entrant can always build on the incumbent's technology when innovating. This knowledge diffusion generates intertemporal spillover, and the level of spillover is fixed as the entrant always receives the diffusion. Our model allows multiple gaps between the leader and the follower (instead of entrant), and the follower receives knowledge diffusion with probability  $\delta$ . To be specific, the home follower can start from the home leader's productivity level with probability  $\delta$ , and start from its own productivity level with probability  $1 - \delta$ . Therefore, we can estimate the degree of knowledge diffusion from data, which governs the effect of innovation and adoption subsidies.

## 2.1 Environment

### General Setup

Time is continuous. There are two countries  $c \in \{H, F\}$ . We have a continuum of variety goods  $j \in [0, 1]$  which are consumed by household. Also, the goods are tradable across countries with iceberg cost  $D \geq 1$ . Firms need to ship  $D$  unit of goods to export one unit to another country. In country  $H$ , there are two firms in each product line  $j$ . We call the firm with higher productivity as leader and the one with lower productivity as follower. Follower becomes leader when its productivity becomes higher than its competitor. We allow both of them to produce as they produce imperfect substitutes. Both can innovate and adopt to increase productivity. In country  $F$ , we assume that there is a representative firm in each product line  $j$  to simplify the model. Instead of the follower, there is a potential entrant which can enter and replace the incumbent by innovating or adopting in country  $F$ .<sup>8</sup>

### Household

There is a representative household that consumes variety goods, supplies labor, pays lump-sum tax, and owns domestic firms in each country. Household in period  $t$  has the following utility function.

$$U_{ct} = \int_t^\infty \exp(-\rho(s - t)) \ln C_{cs} ds \quad (1)$$

where  $C_{cs}$  is the final consumption at  $s$ ,  $\rho > 0$  is the discount factor. Household maximizes utility subject to the below budget constraint.

---

of the seller.

<sup>8</sup>In this way, we can reduce the number of state variables since we do not need to keep track of gap between two foreign firms.

$$r_{ct}A_{ct} + L_c w_{ct} = P_{ct}C_{ct} + T_{ct} + \dot{A}_{ct} \quad (2)$$

where  $r_{ct}$  is interest rate,  $L_c$  is labor endowment,  $w_{ct}$  is wage,  $P_{ct}$  is the price index of final consumption in country  $c$ ,  $T_{ct}$  is the lump-sum tax that finances innovation and adoption subsidies, and  $A_{ct}$  is the household asset. Asset market is cleared in every period by the following equation.<sup>9</sup>

$$A_{ct} = \int_0^1 \sum_{i=1,2} V_{cijt} dj \quad (3)$$

Right-hand side is the sum of value of all domestic firms.<sup>10</sup>

Final consumption  $C_{ct}$  is the aggregated variety goods as below.

$$C_{Ht} = \exp\left(\int_0^1 \ln((\psi_H^{\frac{1}{\sigma}} y_{H1jt}^{\frac{\sigma-1}{\sigma}} + \psi_H^{\frac{1}{\sigma}} y_{H2jt}^{\frac{\sigma-1}{\sigma}} + \psi_F^{\frac{1}{\sigma}} y_{Fjt}^{*\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}}) dj\right) \quad (4)$$

$y_{H1jt}, y_{H2jt}$  are the output in product line  $j$ , consumed by home household, and produced by the leader and the follower. Leader is the firm with higher productivity than its domestic competitor, and the follower is the other firm with lower productivity.  $y_{Fjt}^*$  is the output produced by the foreign firm, and exported to country  $H$ . The superscript asterisk denotes the goods are exported.  $C_{Ft}$  is defined in a symmetric way as below.<sup>11</sup>

$$C_{Ft} = \exp\left(\int_0^1 \ln((\psi_H^{\frac{1}{\sigma}} y_{H1jt}^{*\frac{\sigma-1}{\sigma}} + \psi_H^{\frac{1}{\sigma}} y_{H2jt}^{*\frac{\sigma-1}{\sigma}} + \psi_F^{\frac{1}{\sigma}} y_{Fjt}^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}}) dj\right) \quad (5)$$

Goods are aggregated by constant elasticity of substitution (CES) aggregator within a product line. Following [Atkeson and Burstein \(2008\)](#), we assume  $1 < \sigma < \infty$  meaning the goods within a product line are imperfect substitutes to each other with the elasticity of substitution  $\sigma$ . Then, they are aggregated by Cobb-Douglas across product lines. Accordingly, the price index  $P_{ct}$  of final consumption is as below.  $\psi_H$  and  $\psi_F$  are the demand shifter for goods produced in  $H$  and  $F$ .

$$P_{Ht} = \exp\left(\int_0^1 \ln((\psi_H^{\frac{1}{\sigma}} p_{H1t}^{1-\sigma} + \psi_H^{\frac{1}{\sigma}} p_{H2t}^{1-\sigma} + \psi_F^{\frac{1}{\sigma}} p_{Ft}^{*1-\sigma}) dj\right) \quad (6)$$

where  $p_{cit}$  is the price of firm  $i$  in domestic market, and  $p_{cit}^*$  is the price when exporting to foreign market.

## Market Structure

<sup>9</sup>We do not allow international capital flows.

<sup>10</sup>In case of country  $F$ ,  $V_{F1jt}$  is the value of the incumbent, and  $V_{F2jt}$  is that of the potential entrant.

<sup>11</sup>From now on, we do not specify variables for the foreign country as long as it is symmetric.

We assume that three firms in each market (home and foreign) participate in Bertrand competition, where they set the price given other firms' pricing decision. As in [Atkeson and Burstein \(2008\)](#), we assume no interaction between home and foreign markets<sup>12</sup> and abstract away from dynamic collusion. Firms recognize that their pricing decision changes the price index and demand of their goods.

### Production

Production function of variety good is linear in labor as below.

$$\mathcal{Y}_{cijt} = q_{cijt} l_{cijt} \quad (7)$$

where  $q_{cijt}$  is the productivity and  $l_{cijt}$  is labor used by firm  $ci$  in product line  $j$  at time  $t$ .  $q_{cijt}$  evolves by the innovation and adoption. The output can be consumed by both home and foreign household as below.

$$\mathcal{Y}_{cijt} = y_{cijt} + D \cdot y_{cijt}^* \quad (8)$$

To export one unit of intermediate good, it needs to produce  $D$  unit of goods due to the iceberg cost.

### Productivity gap

From now on, we omit the time argument when it does not cause confusion. Firms can improve  $h \in \mathbb{Z}$  step and increase productivity by  $\lambda^h$  through innovation or adoption.  $\lambda$  is a fixed step size in the economy. Therefore, we can express the productivity as  $\lambda^n$  in which  $n$  denotes the cumulative number of steps that the firms improved. Then, the productivity gap  $m_F$  between home leader and foreign firm in variety  $j$  can be written as below.

$$\frac{q_{H1j}}{q_{Fj}} = \frac{\lambda^{n_{H1j}}}{\lambda^{n_{Fj}}} = \lambda^{m_F}, \quad m_F \in \mathbb{Z} \quad (9)$$

Likewise, we can get the gap between domestic firm,  $m_D$  as below.

$$\frac{q_{H1j}}{q_{H2j}} = \frac{\lambda^{n_{H1j}}}{\lambda^{n_{H2j}}} = \lambda^{m_D}, \quad m_D \in \mathbb{Z} \quad (10)$$

$m_F > 0$  implies firm has higher productivity than the foreign firm.  $m_D < 0$  implies firm has lower productivity than the domestic competitor. The relevant state of the firm is a vector  $\mathbf{m} = \{m_F, m_D\} \in \mathbb{Z}^2$ .  $\mathbf{m}$  fully characterizes the relative productivities in a given product line. Given the aggregate variables such as wage, consumption share,  $\mathbf{m}$  determines

---

<sup>12</sup>In the equilibrium, there is no arbitrage opportunity since the price ratio between home and foreign good is always less than the iceberg cost.

pricing of the firms, market share, and profit. Productivity gap also determines dynamic decision such as innovation and adoption rates, which will be explained in more details later.

### Innovation

Firms choose innovation rate  $x$  by hiring innovation labor as below.

$$C_{cr}(x) = \alpha_{cr} \frac{x^\gamma}{\gamma} \quad (11)$$

where we assume  $\gamma > 1$  so the innovation cost function is convex.  $\alpha_{cr}$  governs the scale of the required innovation labor. Since it hires labor, the cost is proportional to the wage  $w_c$ . With probability  $x$ , it improves productivity as below.

$$q_{cij}(t + \Delta) = \lambda^n q_{cij}(t), \quad n \sim \mathbb{F}_{\mathbf{m}}(n) \quad (12)$$

where  $\mathbb{F}_{\mathbf{m}}(n)$  is the step size distribution which depends on the current technology gap and is fixed across time and country. We assume  $\mathbb{F}_{\mathbf{m}}(n)$  depends on  $m_F$  which is the productivity gap from the foreign firm.<sup>13</sup> As in [Akcigit et al. \(2018\)](#) and [Olmstead-Rumsey \(2022\)](#), we allow that there is an advantage of backwardness ([Gerschenkron, 1962](#)) and the expected step size is weakly decreasing with  $m_F$ .

Conditional on successful innovation of home leader with step size  $n$ , the gap from the foreign firm and domestic competitor changes to  $(m_F + n, m_D + n)$ . When the domestic competitor innovates with step size  $n$ ,  $m_D$  changes to  $m_D - n$ . When the foreign firm innovates with step size  $n$ ,  $m_F$  changes to  $m_F - n$ .

### Adoption

Home leader, follower, foreign firm choose adoption rate  $a$  by hiring labor<sup>14</sup> as below.

$$C_{ca}(a) = \alpha_{ca} \frac{a^\gamma}{\gamma} \quad (13)$$

Again, we assume that the firm hires labor to adopt, so the cost is proportional to the wage  $w_c$ . With probability  $a$ , the firm meets a foreign firm and make an adoption contract. To simplify the model, we assume that it adopts technology from the foreign firm not from the home leader.<sup>15,16</sup> The adopter pays one-time adoption fee to the foreign firm, and improve

---

<sup>13</sup>We interpret this gap as the distance to the frontier as in [Acemoglu et al. \(2006\)](#). In case of firm in country  $F$ , only the gap from  $H1$  matters.

<sup>14</sup>This labor can be interpreted as researcher who conducts research on the foreign technology, learn, and implement it, which is different from adoption fee to the seller.

<sup>15</sup>In the equilibrium, firms do not adopt from domestic competitor as the total surplus from adoption contract is negative. This is because two domestic firms have no wage difference, and trade cost. It will be explained in detail in Section 2.2.

<sup>16</sup>Firm in country  $F$  adopts only from home leader, not the follower.

productivity. Adoption fee is determined through Nash bargaining between the adopter and the foreign firm, which will be explained in detail in Section 2.2. Conditional on probability  $a$ , the firm improves the productivity as follows.

$$q_{cj}(t + \Delta) = \lambda^n q_{cj}(t), \quad n \sim \mathbb{G}_{\mathbf{m}}(n) \quad (14)$$

$\mathbb{G}_{\mathbf{m}}(n)$  is the step size distribution and it depends on the current gap from the foreign firm  $m_F$ . The expected productivity gain from adoption depends on the current gap. The adopter does not necessarily catches up the foreign firm from only one adoption, which is more flexible assumption compared with other papers in technology diffusion literature (e.g., [Perla and Tonetti, 2014](#); [Benhabib et al., 2021](#); [König et al., 2020](#)). Let  $g_{m_F}(n)$  is the probability of improving  $n$  steps when the gap from foreign firm is  $m_F$ . If we assume  $g_{m_F}(m_F) = 1$ , it nests the case of [Perla and Tonetti \(2014\)](#) and [Benhabib et al. \(2021\)](#).<sup>17</sup> Our assumption is consistent with the empirical facts that the adopter does not import the latest technology but instead imports older and inferior technology.<sup>18</sup> Moreover, if the adoption brings full catching-up, the adoption fee would be always higher when the initial relative productivity of adopter is lower, which is not the case in the data. In the data, the adoption fee is higher when the relative productivity is higher, and this general assumption helps us to match the finding.

Technology adoption differs from the innovation in several ways. First, adoption is only possible when the firm has lower productivity than the foreign firm. In other words,  $g_{m_F}(0) = 1$  for  $m_F \geq 0$ . The expected step size from adoption becomes zero when the gap is larger or equal to zero. Second, the firm cannot leapfrog the foreign leader through adoption, i.e.,  $g_{m_F}(n) = 0$  if  $n > m_F$ . Third, the expected step size from both adoption and innovation decreases with  $m_F$ , but the slopes are different. It implies that the degree of advantage of backwardness can be different for adoption and innovation. Lastly, the adopter needs to pay adoption fee  $\mathcal{F}_{ci,\mathbf{m}}$  to the foreign firm.

### Step size distribution

We use the functional form of step size distribution in [Akcigit et al. \(2018\)](#) and [Olmstead-Rumsey \(2022\)](#). We assume that the step size depends only on the gap from the foreign leader. To make the computation feasible, we impose the maximum technology gap as  $\bar{m}$ . Therefore, the number of potential step size from adoption and innovation is different across

<sup>17</sup>If  $g_{m_F}(1) = 1$ , it nests the case of [König et al. \(2020\)](#) in which adoption (imitation) brings only one step regardless of the current gap.

<sup>18</sup>Or even if the adopter imported the latest technology, it might not be able to implement the technology with full capacity. We can capture this aspect by assuming their realized productivity is still lower than that of the leader.

the initial gap  $m_F$ . For innovation it is  $\bar{n}_r = \bar{m} - m_F$ , and for adoption it is  $\bar{n}_a = \max(0, -m_F)$  as the firm cannot leapfrog the foreign firm through the adoption.

We first define the baseline distribution  $f(n)$ . It is the probability of improving  $n$  steps for the firms that are furthest from the foreign firm with the gap  $-\bar{m}$ .

$$f(n) = c_0 n^{-\eta}, \quad n \in \{1, \dots, \bar{n}\} \quad (15)$$

$c_0$  is decided such that  $\sum_{n=1}^{\bar{n}} f(n) = 1$ . Then,  $f_{m_F}(n)$ , the probability of improving  $n$  step when the current gap from the foreign firm is  $m_F$ , is decided as follows.

$$f_m(n) = \begin{cases} f(1) + \mathcal{A}(m) & \text{for } n = 1 \\ f(n) & \text{for } n \in \{2, \dots, \bar{n}\} \end{cases} \quad (16)$$

$$\mathcal{A}(m) = \sum_{s=1}^{m-1} f(s)$$

$\eta > 0$  ensures that the expected step size decreases with  $m$ , and smaller  $\eta$  leads to a steeper slope as we can see in figure 2. Therefore, we can adjust the degree of advantage of backwardness (Gerschenkron, 1962) by adjusting  $\eta$ .<sup>19</sup> Thanks to the additive feature of the distribution, we only need to pin down one parameter,  $\eta$ . We use the same functional form for both  $g_m(n)$  (adoption) and  $f_m(n)$  (innovation), but use different slope parameter,  $\eta_a$  for adoption and  $\eta_r$  for innovation.

### Potential Entrant

In country  $F$  there is a potential entrant  $F2$  who can innovate and replace the incumbent.<sup>20</sup> The innovation cost of the entrant is the same as that of incumbent as below.

$$C_{Fr}(x) = \alpha_{Fr} \frac{x_{F2}^\gamma}{\gamma} \quad (17)$$

With probability  $x_{F2}$ , they improve the current incumbent's productivity as below and the incumbent exit the market.<sup>21</sup>

$$q_{Fj}(t + \Delta) = \lambda^n q_{Fj}(t), \quad n \sim \mathbb{F}_{\mathbf{m}}(n) \quad (18)$$

### Knowledge Diffusion

The follower has the same structure of innovation and adoption except that it receives

<sup>19</sup>When  $\eta \rightarrow \infty$ , the model becomes step-by-step model with only one step improvement.

<sup>20</sup>For simplicity, we do not allow it to adopt technology.

<sup>21</sup>Note that in foreign country, the potential entrant can always build on the incumbent's technology. This simplifies the computation by reducing the number of state variables.

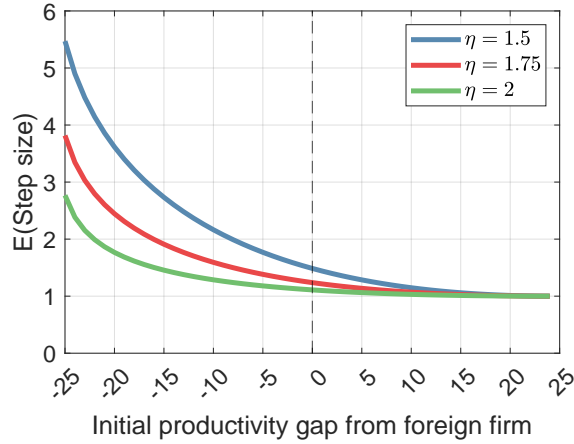


Figure 2: Expected productivity gain from adoption and innovation

**Notes:** X-axis is the productivity gap from the foreign firm, Y-axis is the expected step size from innovation / adoption over different values of  $\eta$  in the model.

knowledge diffusion from the leader stochastically. To be specific, with a fixed probability  $\delta$ , it can build on the home leader's technology and starts from the leader's productivity when innovating or adopting. The step size distribution of the follower is as below.

$$\tilde{f}_{\mathbf{m}}(n) = (1 - \delta)f_{m_F}(n) + \delta f_{m_F+m_D}(n - m_D) \quad (19)$$

where the first term is when there is no diffusion, and the second term is step size distribution with the knowledge diffusion. If  $\delta = 1$ , it becomes equivalent with the common assumption in the quality ladder model literature (e.g., [Aghion and Howitt, 1992](#); [Grossman and Helpman, 1991a](#)) in which the entrants can always build on the incumbent's technology.

The knowledge diffusion generates positive externality from both innovation and adoption. When the leader innovates or adopts, it also increases the future productivity of the follower. However, this knowledge diffusion would hurt the leader's profit in the future. Since the leader takes that into account, it reduces innovation and adoption rate when the knowledge diffusion rate is higher in the economy.

The level of positive externality is governed by  $\mathbb{E}(n) \cdot \delta$  which is the expected step size times the probability of knowledge diffusion. If the step size is larger, it improves more productivity and creates larger spillover to the follower. And the expected step size is weakly decreasing with the initial productivity gap from the foreign firm as we assume in equation (15),(16). Therefore, the size of externality decreases as country catches up the foreign country.

Lastly, we allow that there is an exogenous productivity spillover. With probability  $\phi$ , the technology is shared by all three firms and they have the same productivity.<sup>22</sup>

### Government Policy

We allow two subsidies - adoption and R&D subsidy. The government subsidizes a fraction of the adoption cost as  $s_{cat}\mathcal{F}_{cijt} + s_{cat}\alpha_{ca}\frac{a_{cijt}^\gamma}{\gamma}w_c$ . The government also subsidizes a fraction of innovation effort as  $s_{crt}\alpha_{cr}\frac{x_{cijt}^\gamma}{\gamma}w_c$ . The expenses for two subsidies are financed by the lump-sum tax from the household. Government holds a balanced budget in every period as below.

$$T_{ct} = \int_0^1 \sum_{i=1}^2 (s_{cat}\mathcal{F}_{cijt} + s_{cat}\alpha_{ca}\frac{a_{cijt}^\gamma}{\gamma}w_c + s_{crt}\alpha_{cr}\frac{x_{cijt}^\gamma}{\gamma}w_c) dj \quad (20)$$

### Labor Market Clearing

In each country labor market clears by the following equation.

$$L_{ct} = \int_0^1 \sum_{i=1}^2 (l_{cijt} + \alpha_{ac}\frac{a_{cijt}^\gamma}{\gamma} + \alpha_{rc}\frac{x_{cijt}^\gamma}{\gamma}) dj \quad (21)$$

Left-hand side is the supply of labor which is fixed over time, and right-hand side is the demand of labor. First term is labor demand from the production, second term is from innovation, and the last term is from adoption.

### Trade balance

We assume that trade is balanced between two countries in every period. In other words, the sum of import, adoption fee expense should be equal to the sum of export, and the adoption fee revenue as below.

$$\int_0^1 (p_{Fjt}^* y_{Fjt}^* + \sum_{i=1}^2 a_{Hijt} p_{Hijt}) dj = \int_0^1 (\sum_{i=1}^2 p_{Hijt}^* y_{Hijt}^* + a_{Fjt} p_{Fjt}) dj \quad (22)$$

## 2.2 Equilibrium

In this section, we define a Markov perfect equilibrium in which strategies of the firms depend only on the payoff relevant state  $\mathbf{m}$ , the productivity gap vector. Then, we characterize the balanced growth path equilibrium where the aggregate productivity, output, wage, consumption grow at the same rate, and the distribution of productivity gap, interest rates, relative price are constant over time.

### Household

---

<sup>22</sup>The example of exogenous spillover is the leakage of technology or the expiration of patent.



A representative household maximizes utility from the equation (1) given the budget constraint from the equation (2). It generates the followign Euler equation.

$$\frac{\dot{C}_{ct}}{C_{ct}} = \rho - (r_{ct} - \frac{\dot{P}_{ct}}{P_{ct}}) \quad (23)$$

### Production and Profits

Production and profit of intermediate goods are determined by the wage in two countries, trade cost, and productivity gap  $\mathbf{m}$ . Firms in each product-country participate in Bertrand competition. Since the final consumption is Cobb-Douglas of the variety goods, household spends the same amount of expenditure  $P_c C_c$  on each product line  $j$ , which leads to the following equation.

$$\sum_{i=1}^2 p_{Hij} y_{Hij} + p_{Fj}^* y_{Fj}^* = P_H C_H \quad (24)$$

where  $p_{Hij}, y_{Hij}$  is the price and quantity of the goods produced by the firm  $Hij$ , consumed in country  $H$ , and  $p_{Fj}^*, y_{Fj}^*$  is the price and output of the goods produced by  $F$  and exported to  $H$ .

By solving the household utility maximization problem given the variety price, the market share of each firm  $s_{Hij}, s_{Fj}^*$  in home market are as below.

$$s_{Hij} = \frac{\psi_H p_{Hij}^{1-\sigma}}{\sum_{i=1}^2 \psi_H p_{Hij}^{1-\sigma} + \psi_F p_{Fj}^{*1-\sigma}}, \quad s_{Fj}^* = \frac{\psi_F p_{Fj}^{*1-\sigma}}{\sum_{i=1}^2 \psi_H p_{Hij}^{1-\sigma} + \psi_F p_{Fj}^{*1-\sigma}} \quad (25)$$

And the demand  $y_{cij}, y_{cij}^*$  is as follows

$$y_{Hij} = \frac{p_{Hij}^{-\sigma}}{\sum_{i=1}^2 p_{Hij}^{1-\sigma} + p_{Fj}^{*1-\sigma}}, \quad y_{Fj}^* = \frac{p_{Fj}^{*- \sigma}}{\sum_{i=1}^2 p_{Hij}^{1-\sigma} + p_{Fj}^{*1-\sigma}} \quad (26)$$

Given this demand function, we can solve the firm's problem and get the optimal prices are the following.

$$p_{Hij} = \frac{1 - \frac{\sigma-1}{\sigma} s_{Hij}}{\frac{\sigma-1}{\sigma} (1 - s_{Hij})} \frac{w_c}{q_{Hij}}, \quad p_{Fj}^* = \frac{1 - \frac{\sigma-1}{\sigma} s_{Fj}^*}{\frac{\sigma-1}{\sigma} (1 - s_{Fj}^*)} \frac{D \cdot w_F}{q_{Fj}} \quad (27)$$

The profit functions from country  $c$  are the following

$$\pi_{Hij} = \frac{s_{Hij} (1 - \frac{\sigma-1}{\sigma})}{1 - \frac{\sigma-1}{\sigma} s_{Hij}}, \quad \pi_{Fj}^* = \frac{s_{Fj}^* (1 - \frac{\sigma-1}{\sigma})}{1 - \frac{\sigma-1}{\sigma} s_{Fj}^*} \quad (28)$$

The equilibrium in foreign market is defined in a symmetric way. The firm makes profit

from two sources: domestic market and foreign market. Finally, the total profit of firm in country  $c$ , position  $i$ , product line  $j$  is the following

$$\Pi_{cij} = \pi_{cij} P_c Y_c + \pi_{cij}^* P_{-c} Y_{-c} \quad (29)$$

If we combine the equation (25) and (27), we can solve the price, market share, and profit as functions of the productivity gap, relative wage, trade costs, and household expenditure  $P_H C_H$ ,  $P_F C_F$ . Therefore, given the aggregate variables, productivity gap  $\mathbf{m}$  fully determines the static variables of the firms.

### Value function

Note that given the aggregate variables, firm profit depends only on the productivity gap and the innovation and adoption decision only changes the gap, we can represent value function as a function of the productivity gap vector  $\mathbf{m} := \{m_F, m_D\}$ . For the domestic firms,  $m_F$  is the gap from the foreign leader, and  $m_D$  is the gap from the domestic competitor. For foreign firms,  $m_F$  is gap from the home leader, and  $m_D$  is the gap of home leader from home follower. For example, if the productivity of home leader is  $\lambda^3$ , that of home follower is  $\lambda^2$ , and that of foreign firm is  $\lambda^1$ , then the gap vector for the home leader is  $\{2, 1\}$ , for the home follower is  $\{1, -1\}$ , and for the foreign firm is  $\{-2, 1\}$ . We will use  $\mathbf{m}$  instead of  $j$  as state variable.

The value function of the home leader  $H1$  with gap  $\mathbf{m} = (m_F, m_D)$  is as follows.

$$\begin{aligned}
& r_{Ht}V_{Ht}(\mathbf{m}) - \dot{V}_{Ht}(\mathbf{m}) \\
&= \max_{x_{H1mt}, a_{H1mt}} \underbrace{\Pi_{Ht}(\mathbf{m})}_{\text{profit}} - \underbrace{(1 - s_{Hrt}) \alpha_{Hr} \frac{(x_{H1mt})^\gamma}{\gamma} w_{Ht}}_{\text{innovation cost}} - \underbrace{(1 - s_{Hat}) \alpha_{Ha} \frac{(a_{H1mt})^\gamma}{\gamma} w_{Ht}}_{\text{Adoption cost}} \\
&+ x_{H1mt} \sum_n f_{m_F}(n) \underbrace{[V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m})]}_{\text{Gain from innovation}} \\
&+ a_{H1mt} \sum_n g_{m_F}(n) \left[ \underbrace{[V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m})]}_{\text{Gain from adoption}} - \underbrace{(1 - s_{Hat}) \mathcal{F}_{H1mt}}_{\text{adoption fee}} \right] \\
&+ x_{H2mt} \sum_n \tilde{f}_{m_F - m_D}(n) \underbrace{[V_{Ht}(m_F, m_D - n) - V_{Ht}(\mathbf{m})]}_{\text{loss from follower innovation}} \\
&+ a_{H2mt} \sum_n \tilde{g}_{m_F - m_D}(n) \underbrace{[V_{Ht}(m_F, m_D - n) - V_{Ht}(\mathbf{m})]}_{\text{loss from follower adoption}} \\
&+ (x_{F\mathbf{mt}} + \tilde{x}_{F\mathbf{mt}}) \sum_n f_{-m_F}(n) \underbrace{[V_{Ht}(m_F - n, m_D) - V_{Ht}(\mathbf{m})]}_{\text{loss from foreign firm innovation}} \\
&+ a_{F\mathbf{mt}} \sum_n g_{-m_F}(n) \left[ \underbrace{[V_{Ht}(m_F - n, m_D) - V_{Ht}(\mathbf{m})]}_{\text{loss from foreign leader adoption}} + \underbrace{\mathcal{F}_{F\mathbf{mt}}}_{\text{adoption fee}} \right] \\
&+ \underbrace{\phi(V_{Ht}(\mathbf{0}) - V_{Ht}(\mathbf{m}))}_{\text{Exogenous spillover}}
\end{aligned} \tag{30}$$

The first line of value function includes the operating profit, which is defined in equation (28) and (29). Then, the firm spends innovation and adoption costs.  $s_{Hrt}$  and  $s_{Hat}$ , are innovation and adoption subsidy rate, respectively. Next two lines show the gain from innovation and adoption where the step size  $n$  follows the distribution  $f_{m_F}(n), g_{m_F}(n)$ . The adoption fee is determined later in equation (32). The next two lines represent the change of value from home follower's innovation and adoption. The following two lines denote the foreign firms' (both incumbent and entrant) innovation and adoption. Note that the adoption can only happen for the firms with lower productivity. For example, if  $m_{F1} < 0$ , which means the home leader has lower productivity than the foreign firm, the adoption rate of foreign firm is always zero. The last line has the exogenous spillover, which is governed by the parameter  $\phi$ . Value function of home follower, foreign firm, foreign entrant are defined symmetrically, in equation (42), (43), (44) in Appendix A.1.

### Adoption Fee

Adoption fee is one time payment which summarizes all future profit gain of the adopter and loss of the seller. The bargaining is only between the adopter and the seller and we

assume that they cannot make the contract contingent on future behavior. For example, we do not allow the foreign firm to prohibit the adopter's exporting in the foreign country.<sup>23</sup> Also, we do not allow the foreign firm to promise not to sell the technology to another domestic firm. This assumption can be microfounded if we assume that the foreign firm cannot commit its future behavior. Lastly, we do not allow one foreign firm bargain with two domestic firms at the same time. With probability  $a$ , the adopter meets the foreign firm and their outside option is zero, which is not having the contract.  $\mathcal{F}_{H1\mathbf{m}}$ , the adoption fee of the leader is determined by the following equation.

$$\begin{aligned} \mathcal{F}_{H1\mathbf{m}} = & \operatorname{argmax}_{\mathcal{F}_{H1\mathbf{m}}} \left( \sum_n g_{m_F}(n) V_H(m_F + n, m_D + n) - \mathcal{F}_{H1\mathbf{m}} - V_H(\mathbf{m}) \right)^\xi \\ & \cdot \left( \sum_n g_{m_F}(n) V_F(-m_F - n, m_D + n) + \mathcal{F}_{H1\mathbf{m}} - V_F(-m_F, m_D) \right)^{1-\xi} \end{aligned} \quad (31)$$

where  $0 \leq \xi \leq 1$  is the bargaining power of the adopter.  $\sum_n g_{\mathbf{m}}(n) V_c(m_{F1} + n, m_D + n)$  is the expected value of the adopter after the adoption in which it improves gap from all firms as  $n$  steps.  $V_c(\mathbf{m})$  is the value of firm in country  $c$  with gap  $\mathbf{m}$ , which is defined in equation (30). Net value from adoption is the new value minus the price  $\mathcal{F}_{H1\mathbf{m}}$  and its outside option is the current value  $V_H(m)$ . Likewise, the expected value of the seller after the adoption is  $\sum_n g_{\mathbf{m}}(n) V_{-c}(-m_F - n, m_D + n)$  where it has lower value from the decreased relative productivity, but receives adoption fee  $\mathcal{F}_{ci\mathbf{m}}$ . The outside option is the current value  $V_F(-m_F, m_D)$ .

When we solve the equation (31), we get the following price equation.

$$\begin{aligned} \mathcal{F}_{H1\mathbf{m}} = & (1 - \xi) \left( \sum_n g_{m_F}(n) V_H(m_F + n, m_D + n) - V_H(\mathbf{m}) \right) \\ & - \xi \left( \sum_n g_{m_F}(n) V_F(-m_F - n, m_D + n) - V_F(-m_F, m_D) \right) \end{aligned} \quad (32)$$

Adoption fee of home follower and foreign firm are defined in a similar way in equation (45), (46) in Appendix A.2. Adoption fee is higher if the leader loses more or the follower gains more from the adoption. It depends on the two forces: the degree of advantage of backwardness and the competition effect. From the advantage of backwardness, the productivity growth from adoption is larger when the initial productivity gap is larger. This means the follower gains more, and the leader loses more when the follower adopts technology. It makes the price is higher when the productivity gap is larger. On the other hand, the profit gain from productivity improvement increases when the initial gap is smaller.

Figure 3 shows the example of profit function over the technology gap from the foreign

---

<sup>23</sup>This is indeed very rare in the data where only 1.3% of the contracts restrict the adopter's future export.

leader while fixing other gaps. We can see that the profit increase is small when the follower is far from the leader i.e.,  $m_F$  is small. The slope of profit function increases as the firm gets closer to the leader. Therefore, the willingness to pay for technology adoption is larger when the gap is smaller, which makes the price increase with  $m_F$ .

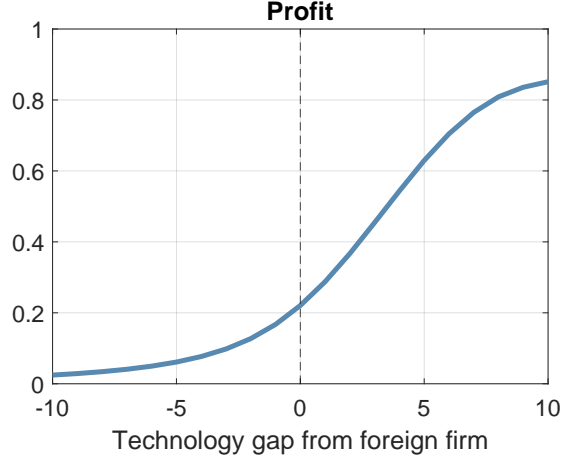


Figure 3: Profit function over technology gap

**Notes:** X-axis is the productivity gap from the foreign firm and Y-axis is the profit of the firm when we fix the gap between domestic firms as zero.  $\sigma = 8, D = 1.2, \lambda = 1.1$

### Room for trade of technology

Note that an adoption contract is not always possible. If the total surplus from the contract is negative, then no adoption fee makes the adoption contract possible. Several cases increase the total surplus, making a room for trade of technology. First, when the wage in the follower's country is lower, the foreign firm's technology can be used more efficiently in home country and makes a positive total surplus. Second, when the trade cost is high, two markets are more separated and it is more effective to produce in home country and sell to household in home country. Thus, selling technology can increase the total revenue, which increase total surplus from the adoption contract. This creates an interaction between trade policy and adoption. Since the adoption fee decreases and adoption rate increases with import tariff, the government may want to increase import tariff when it wants to increase the adoption rate. Lastly, when the foreign firm sells technology, potential entrant also loses its future profit, but the foreign firm does not internalize it. Even if selling technology decrease the foreign country's overall welfare, the foreign firm can still sell the technology since it internalizes only the private profit. This motivates a foreign government to prevent technology selling to another country, which we will discuss more in detail in Section 6.

### Optimal Innovation and Adoption rate

The optimal innovation rate of home leader with gap  $\mathbf{m}$  is as below.

$$x_{H1\mathbf{m}t} = \left\{ \frac{1}{(1 - s_{Hrt})\alpha_{Hr}w_{Ht}} \sum_n f_{m_F}(n)[V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m})] \right\}^{\frac{1}{\gamma-1}} \quad (33)$$

Likewise, the optimal adoption rate of home leader with gap  $\mathbf{m}$  is as follows.

$$a_{H1\mathbf{m}t} = \left\{ \frac{1}{(1 - s_{Hat})\alpha_{Ha}w_{Ht}} \sum_n g_{m_F}(n)[V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m}) - (1 - s_{Hat})\mathcal{F}_{H1\mathbf{m}t}] \right\}^{\frac{1}{\gamma-1}} \quad (34)$$

The optimal innovation and adoption rate of home follower, foreign incumbent, and entrant is in (47), (48), (49) in Appendix A.3.

### Distribution of Technology Gap

The distribution of technology gap is the state variable in the economy. We use the gap from the home leader's perspective as the aggregate state variable and denote  $\mathbf{m} = (m_F, m_D)$  where  $m_F$  is the home leader's gap from the foreign firm, and  $m_D$  is from the home follower. We define  $\mathbb{T}_i(\mathbf{m}, n)$  as the probability of firm  $i$  improves productivity  $n$  steps when the aggregate state variable is  $\mathbf{m}$ .

$$\begin{aligned} \mathbb{T}_{H1}(\mathbf{m}, n) &= f_{m_F}(n)x_{H1t}(m_F, m_D) + g_{m_F}(n)a_{H1t}(m_F, m_D) \\ \mathbb{T}_{H2}(\mathbf{m}, n) &= \tilde{f}_{m_F - m_D}(n)x_{H2t}(m_F - m_D, -m_D) + g_{m_F - m_D}(n)a_{H1t}(m_F - m_D, -m_D) \\ \mathbb{T}_F(\mathbf{m}, n) &= f_{-m_F}(n)x_{Ft}(-m_F, m_D) + g_{-m_F}(n)a_{H1t}(-m_F, m_D) \end{aligned} \quad (35)$$

Let  $\mu_{\mathbf{m}t}$  the share of product lines with gap  $\mathbf{m}$  in time  $t$ . The law of motion of  $\mu_{\mathbf{m}t}$  is as follows.

$$\begin{aligned}
\dot{\mu}_{Ht}(m_F, m_D) = & \\
& \sum_{n=1}^{m_F+\bar{m}} \mathbb{T}_{H1}(m_F-n, m_D-n, n) \mu_{Ht}(m_F-n, m_F-n) \\
& + \sum_{n=1}^{m_D} \mathbb{T}_{H2}(m_F, m_D+n, n) \mu_{Ht}(m_F, m_D+n) \\
& + \sum_{n=m_D+1}^{m_F+\bar{m}} \mathbb{T}_{H2}(m_F-(n-m_D), m_D-n, n) \mu_{Ht}(m_F-(n-m_D), m_D-n) \\
& + \sum_{n=1}^{-m_F+\bar{m}} \mathbb{T}_F(m_F+n, m_D) \mu_{Ht}(m_F+n, m_D) \\
& + \mathbb{1}(\mathbf{m} = \mathbf{0}) \cdot \phi - \left( \sum_{c=\{H,F\}} \sum_{i=1}^2 (x_{Himt} + a_{Himt}) + \phi \right) \mu_{Ht}(\mathbf{m})
\end{aligned} \tag{36}$$

First two lines are the added mass from home leader's innovation and adoption. The third and fourth lines are from home follower's innovation and adoption where the follower did not leapfrog the leader. The fifth and sixth lines are also from home follower but they leapfrog the leader in this case. The next two lines are from foreign incumbent and entrant, which have the same structure as the domestic firms. The next line indicates the added mass from the exogenous spillover, which is added to  $\mathbf{m} = (m_F, m_D) = (0, 0)$ . Last line represents the subtracted mass from innovation and adoption, exogenous spillover. In the balanced growth path,  $\dot{\mu}_{\mathbf{m}t} = 0$  for all  $\mathbf{m}$ .

Note that each product line has different productivity even if they have the same gap  $\mathbf{m}$ . Let  $Q_{\mathbf{m}t}$  is the average productivity of the leader with gap  $\mathbf{m}$  as below.

$$Q_{\mathbf{m}t} = \sum_{\mathbf{m}} q_{H1jt} \mu_{\mathbf{m}t} \tag{37}$$

**Definition 2.1.** A Markov perfect equilibrium is an allocation

$$\{r_{ct}, w_{ct}, p_{cijt}, p_{cijt}^*, y_{cijt}, y_{cijt}^*, l_{cijt}, x_{cijt}, a_{cijt}, \mu_{\mathbf{m}t}, Q_{\mathbf{m}t}, C_{ct}, A_{ct}, T_{ct}\}_{t \in [0, \infty), j \in [0, 1], c \in \{H, F\}, i \in \{1, 2\}, m \in \{-\bar{m}, \dots, \bar{m}\}}$$

1. Given  $r_{ct}$ , household choose  $C_{ct}, A_{ct}$  to maximize sum of discounted utility
2. Given  $\{p_{cijt}, p_{cijt}^*\}$ , household choose  $y_{cijt}, y_{cijt}^*$  to minimize expenditure
3. Given  $\{w_{ct}, \mathbf{m}_{jt}\}$ , firms in product line  $j$  choose  $p_{cijt}, p_{cijt}^*, l_{cijt}, l_{cijt}^*$  to maximize profit
4. Given  $\{r_{ct}, w_{ct}, \mathbf{m}_{jt}, \mathcal{F}_{cijt}\}$ ,  $x_{cijt}, a_{cijt}$  solve firm's dynamic problem
5. Given  $\{r_{ct}, w_{ct}, \mathbf{m}_{jt}, x_{cijt}, a_{cijt}\}$ ,  $\mathcal{F}_{cijt}$  solves Nash Bargaining between buyer and seller.

6. Given  $\mu_{\mathbf{m}0}, Q_{\mathbf{m}0}, \{\mu_{\mathbf{m}t}\}_{t \in [0, \infty)}, \{Q_{\mathbf{m}t}\}_{t \in [0, \infty)}$  is consistent with  $x_{cijt}, a_{cijt}$
7.  $w_{ct}$  clears labor market in each country
8.  $r_{ct}$  satisfies household Euler equation.
9.  $T_{ct}$  balances government budget in every period.

**Definition 2.2.** Balanced growth path is the equilibrium defined in Definition 2.1 with  $w_{ct}, y_{ijt}, y_{ijt}^*, C_{ct}, T_{ct}, Q_{\mathbf{m}t}$  grow at a rate  $g$ , and  $p_{cijt}, p_{cijt}^*, l_{cijt}, l_{cijt}^*, x_{cijt}, a_{cijt}, \mu_{\mathbf{m}t}$  are constant over time.

### Inefficiency in the model

The model has several forces that makes the competitive equilibrium not efficient. First, all firms have positive markup that makes the output is less than the social optimal. Second, innovation and adoption has positive externality from knowledge diffusion and exogenous productivity spillover. While firms try to avoid generating spillover to other firms as it decreases their profit, social planner cares about the productivity of both firms. Furthermore, in case of adoption, the foreign firm internalizes the externality of adoption when it determines the adoption fee. Since the value function incorporates future profit which is affected by both the leader and follower, the adoption fee increases with the knowledge diffusion. It amplifies the discrepancy between the private and social value of adoption, which makes the underinvestment problem of the adoption be more severe than the innovation. Lastly, the innovation and adoption have business stealing effect. The innovation and adoption incentive includes both improving productivity and stealing the market share of another firms. However, social planner only cares about the aggregate productivity and output. If the step size from innovation or adoption is small, firms might improve technology with only marginally while spending a substantial amount of resources on the innovation or adoption. This potentially creates overinvestment in both innovation and adoption.

## 3 Data

### 3.1 Technology adoption data

We construct a contract-level technology import dataset. To be specific, we collect and digitize the contracts from the National Archives of Korea and supplement them with [Korea Industrial Technology Association \(1995\)](#).<sup>24</sup> These have the universe of technology import

---

<sup>24</sup>We extend the data used in [Choi and Shim \(2022\)](#) which is until 1982 to 1993 and add adoption fee information. We also obtain some contracts in 1994-1995 but do not capture all of them since firms do not have to report them.



Table 1: Example of Technology adoption Data

Buyer	Seller	Length (year)	Date	Technology	Contents	Fee
Samsung	Nippon Electronic (Japan)	10	78.2.24	Color TV	Know-how Transfer, Licensing	Fixed \$800,000
LG	Hitachi (Japan)	9	78.4.1	Color TV	Know-how Transfer, Licensing	Fixed \$100,000 Royalty 3%
Haengnam Electronics	EPH (US)	2	78.12.18	Alumina	Know-how Transfer	Fixed \$131,000

in 1962-1993 since the domestic firms were required to submit the related documents to the government when they import technology from a foreign country.<sup>25</sup> As a result, we collected 8,512 contracts from 2,902 unique firms.<sup>26</sup> Figure B.1, B.2 show the snapshot of contracts where we can see the contents and payment of the contract.

Korea Industrial Technology Association (1995) classifies contracts into five categories - sharing information, technical guidance, patent licensing, trademark licensing, and etc. We consider the first two as know-how transfer, and third and fourth as licensing. Know-how transfer includes sharing blueprint, design specification, production details, and training the Korean employees. 53% of contracts involve only know-how transfer, 41% involve both know-how and licensing, and 4% involve only licensing. 95% of contracts are in manufacturing in which the distribution is in Table B.1.

Furthermore, we collect the name of the Korean firm (buyer) and foreign firm (seller), date and length of the contract, description of the technology, contents of the contract, and the adoption fee which consists of fixed fee and royalty rate. Table 1 shows the example of collected data. In terms of origin of country, Japan accounts for 50%, the US accounts for 26.3%, and Germany, France, the UK account for 13.1% in sum. Table B.2 shows the distribution of countries in adoption contracts. In terms of adoptoin fee, 61.38% of contracts have royalty payment and 76.56% have fixed fee, 37.97% have both. Average royalty rate is 3.26%, average fixed fee is 7.84 million dollar which account for 9.31% of yearly sale on average, and length of contract is 5.13 year. Figure 4 shows both the number and the average price of adoption contract increased over time.

<sup>25</sup>Korean firms are strictly required to report all of transactions involving foreign currencies under the Foreign Capital Inducement Act. To be specific, it reported details of technology import to Economic Planning Board.

<sup>26</sup>We exclude contracts within the same multi-national firm. For example, Korean IBM paid the fee to US IBM. We exclude these transactions, which account for 3% of the whole sample.

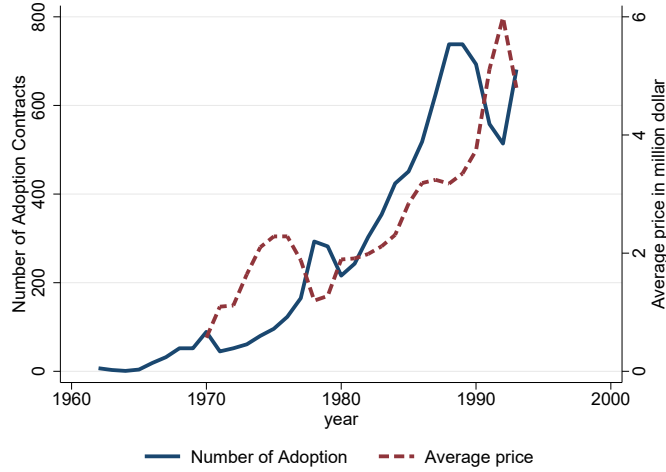


Figure 4: The number of adoption contracts and Average price over time

**Notes:** Average price is the total adoption payment divided by the number of adoption contract in each year. Price is adjusted as 2015 dollar value.

## 3.2 Firm-level Balance Sheet Data

### Korean Firms

We use two sources of data to construct firm-level balance sheet data for Korean firms. First, we digitize firm-level data from Annual Reports of Korean Companies made by the Korea Productivity Center. It is firm survey data that covers more than 50 employees.<sup>27</sup> We can observe firm sales, total assets, fixed assets, number of employees, profit, start year, business ID, and sector between 1970 and 1983. Second, we use KIS value data starting from 1980, which covers firms with assets of more than 3 billion Korean Won (2.65lmn 2015 USD).<sup>28</sup> By using business ID and firm name, we merge these two data.<sup>29</sup> Then, we merge this balance sheet data with the technology adoption data by using firm names. On average, 6.26% of firms adopted technology in each year.

### Foreign Firms

We use Compustat data for the foreign firms where we can capture the listed firms. We append Compustat North America which starts from 1950 with Compustat global which starts from 1988. For variables, we use firm sales, employment, sector. Then we merge it with technology adoption data using firm name and country.

<sup>27</sup>It accounts for 70% of the value-added share in manufacturing.

<sup>28</sup>The 1981 Act on External Audit of Joint-Stock Corporations require that all the publicly traded firm and other firms larger than the asset threshold have to report their balance sheet information.

<sup>29</sup>We also use history of firm names in case firm had changed its name mainly from [www.saramin.co.kr](http://www.saramin.co.kr)

### 3.3 Patent Data

#### Korean Patent Office Data

To measure the innovation of Korean firms, we use patent data from Korean Intellectual Property Office. We download the data from Korean Intellectual Property Rights Information Service, following the procedure in [Lee et al. \(2020\)](#). The data starts since 1945 and captures a universe patent registered in Korea, both by a domestic and foreign firm. We merge this data with firm-level data by using business ID and then use fuzzy matching on firm names.

#### United States Patent Office Data

Also, we use the United States Patent Office data (USPTO, hereafter) to measure the innovation of foreign firms. It starts in 1975 and covers all the patents registered in the US. We use crosswalk by [Bena et al. \(2017\)](#) to merge USPTO with global and North America Compustat. We also merge USPTO data with the technology adoption data by using the name of the foreign firm. Detailed procedure of matching foreign firm names with USPTO data can be found in Appendix B.3.

One caveat of Korean patent data is that it does not have citation data until 1990s. When we study the citation pattern of Korean firm, we use USPTO instead of Korean Patent data since USPTO has citation for all period. We use crosswalk between Korean patent office firm ID and USPTO ID made by [Lee et al. \(2020\)](#).

### 3.4 Summary Statistics

Table 2: Average of variables of Adopting and Non-adopting Firms

Average	Adopting	Non-adopting
Share	6.21%	93.79%
Emp	2,618.11	478.99
Total Asset	576.56	45.88
Sales	570.19	65.98
Sales per emp	0.21	0.16
Patenting	0.16	0.02

**Notes:** We calculate the average value of variables for the firms in 1971-1993. Total asset, sales and sales per employment are in million dollar.

Table 2 shows the summary statistics between adopting and non-adopting firms in 1971-1993. We define adopting firms when they have at least one adoption contract in a given year. 6.21% of total firms adopt technology. They have bigger size in terms of employment,

total asset. Also, they on average have larger sales and have larger sales per employment. Lastly, we compare the patenting dummy variables between two groups. Adopting firms are more likely to apply for a patent.

In general, foreign technologies were adopted by larger and more productive firms in Korea. This is consistent with our model assumption that have two incumbents in each product line. Figure C.1 plots the distribution of variables between two groups after controlling for sector-year fixed effects.

## 4 Empirical Analysis

### 4.1 Productivity Growth over the Initial Productivity Gap

Our model suggests that the expected productivity growth depends on the distance to the foreign firm. To estimate the slope of step size distribution, we run a regression as below.

$$\log\left(\frac{\text{Sales}/\text{emp}_{i,t+5}}{\text{Sales}/\text{emp}_{i,t}}\right) = \beta \cdot \text{gap}_{it} + \Gamma \cdot X_{it} + \alpha_{s(i)} + \delta_t + \epsilon_{it} \quad (38)$$

$\log\left(\frac{\text{Sales}/\text{emp}_{i,t+5}}{\text{Sales}/\text{emp}_{i,t}}\right)$  is the growth rate of labor productivity after innovation or adoption.  $\text{gap}_{it}$  is  $\log(\text{Sales per emp of Korean firm}/\text{Sales per emp of Foreign firm})$  in the year of the adoption or innovation. Since we do not have corresponding foreign firm for innovation, we first use imputed gap from the adoption event for the same firm, and then use the maximum sales per employment of the foreign firm within the industry sector and year.  $X_{i,t}$  includes control variable such as capital intensity growth which is defined as the growth rate of fixed asset per employment also in 5 years. Lastly, we control sector and year fixed effects. Note that we exclude firms that both innovate and adopt in the same year.

Table 3 shows the result of the regression. First column runs the regression with productivity growth after adoption, second column with the one after innovation, and third column pulls both innovation and adoption with interaction term. The coefficient is negative for both adoption and innovation, which implies the advantage of backwardness (Gerschenkron, 1962). This rationalizes the negative correlation between the expected gain and the relative productivity in the model.

Moreover, the absolute value of coefficient is larger for adoption than innovation suggesting the slope is steeper for the adoption. The difference is statistically significant as the coefficient of interaction term in the third column is significant. In the model,  $\eta_a, \eta_x$  that govern the slope of step size distribution will be estimated to match the coefficient from this regression.

Table 3: Sales per Employment Growth over the Initial Productivity Gap

	Adoption	Innovation	Both
Productivity gap (t)	-0.120*** (0.0208)	-0.0457*** (0.0144)	-0.0562*** (0.0133)
gap x adoption			<b>-0.0576***</b> (0.0195)
adoption			-0.00758 (0.0310)
N	919	439	1,362
Adjusted R2	0.4276	0.4013	0.4224
Standard errors in parentheses, * $p < 0.10$ , ** $p < 0.05$ , *** $p < 0.01$			

**Notes:** This table shows the result of regression in equation (38). Productivity gap is the log ratio of sales per employment between the adopting firm and the foreign technology seller. Since we do not have information for the foreign firm when the Korean firm is innovating, we use the maximum of  $\log(\text{sales} / \text{emp})$  of foreign technology seller in the same sector. First column includes only adopting firms. Second column uses only innovating firms that applied at least one patent in a given year. We exclude firms that have both adoption and innovation. Third column includes all the firms. In all regression, we control the growth rate of fixed asset / employment in 5 years. Standard errors are clustered at the Korean firm level.

## 4.2 Productivity Gap and Adoption Fee

We study the relation between the productivity gap and the price of adoption contract. Figure 5 plots the relative productivity of Korean firms and the adoption fee. Adoption fee is estimated by sum of fixed fee and royalty rate times total sale.<sup>30</sup> The relative productivity is measured by logged sales per employment of Korean firm (buyer) divided by that of the foreign firm (technology seller) at the time of adoption contract. We use global Compustat data to get sales per employment of foreign firm.<sup>31</sup>

The positive correlation suggests when the Korean firm is closer to the foreign firm, the seller is compensated more by adoption fee. Through the lens of our model, the seller loses more profit when the productivity gap from the buyer is smaller. This is because the profit is more sensitive with productivity gap when the gap is close to zero. And the adoption fee reacts more with the technology gap when the competition between two firms are stronger. We also run the regression with only fixed fee, and royalty rate as robustness checks. Table

<sup>30</sup>Royalty payment is usually a share of revenue by using the adopted technology. Since we do not have disaggregated sales data, we use firm-level total sale as the revenue. Also, contract often specify that it is net sale after tax and other expenses, but we abstract away from it. We run the regression with royalty rate and fixed fee separately as a robustness check.

<sup>31</sup>For samples that do not have information of foreign firms, we use maximum sales per employment within sector-year.

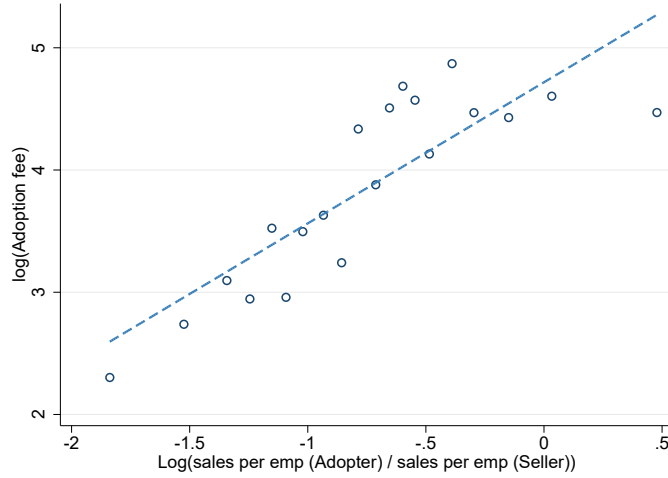


Figure 5: Price of adoption contract and the productivity gap between Korean firm (buyer) and foreign firm (seller)

**Notes:** This figure is binscatter plot where each dot has multiple contracts. Y-axis is the adoption fee (in 1 million won), which is fixed fee + royalty rate  $\times$  sales  $\times$  contract years. The X-axis is the log ratio of sales per employment between Korean firm (buyer) and the foreign firm (seller). We control sector and year fixed effects.

4 shows that both fixed fee and royalty rate have positive correlation with the productivity gap.

To see whether the degree of competition matters for the correlation, we use finer level in patent data. If two firms are in the same technology field (IPC 3 digit level) in patent data, we consider two firms are in strong competition since they are competing in the same product market. To be specific, we list ten most frequent patent classes. Then, we make a dummy variable whether more than half of patent classes in the adopter's list are also included in the seller's list. 27% of our sample have overlap in more than half of their most frequent patent classes.

The positive correlation between the adoption fee and the buyer's relative productivity is indeed stronger when the two firms are in the same technology field. Table 4 shows that the interaction term between gap and overlap of the sector has a significant and positive coefficient. Therefore, when the two firms are in the same field, the technology gap matters more in the adoption price. This suggests that competition effect is important in deciding adoption fee.

A NEW SECTION WILL BE ADDED HERE : FROM ADOPTION TO INNOVATION AT THE FIRM LEVEL

Table 4: Regression of adoption price with technology gap

	Fixed fee	Royalty	Total Fee	Total Fee
Gap	0.117** (0.0503)	0.124*** (0.0465)	0.627*** (0.0545)	0.561*** (0.0598)
Gap x overlap				0.292*** (0.111)
Overlap of field				0.530*** (0.162)
N	1,436	1,029	1,022	1,022
Adjusted R2	0.1106	0.0634	0.4062	0.4116
Sector FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ 

**Notes:** Fixed fee and Total fee are logged. Total fee is sum of fixed fee and royalty rate times sales times contract years. Gap is the log ratio of sales per employment between the Korean firm (buyer) and the foreign firm (seller). Overlap is whether more than half of the adopter’s ten most frequent patent classes are also included in the seller’s list.

### 4.3 Knowledge Diffusion from Adoption

We study whether there is knowledge diffusion from the adopted technology to other firms that did not directly adopt the technology. We use patent citation to measure knowledge diffusion following the innovation literature (Jaffe et al., 1993; Cai and Li, 2019; Aghion et al., 2019). Specifically, if a Korean firm cites a foreign firm’s patent, we assume that the Korean firm gets knowledge diffusion from the foreign firm. The ideal experiment would be to pick two identical foreign firms and make one sell the technology to a Korean firm while the other does not. Then, if there is a spillover from the adopted technology, Korean non-adopters would increase patent citation to the foreign technology seller compared with the other one.

To mimic the ideal experiment, we use a matching-based event study, following Jaravel et al. (2018), Humlum (2019), and Prato (2022). We match two foreign firms, one of which sold technology (treated) while the other did not (control). We use minimum distance matching<sup>32</sup> in terms of logged patent stock while exactly matching on the country, year, and the main patent field (IPC 3 digit).<sup>33</sup> Table 5 shows the descriptive statistics of two groups

<sup>32</sup>We use kmatch function in STATA.

<sup>33</sup>We use the most frequent 3 digit IPC class in each foreign firm.

and p-values. The event year is when the firm sells technology to Korean firm for the first time, and we assign the same event year as a placebo year for the control firms. Then, we compare the probability of citation from Korean never-adopters to the foreign firms around the event year. Note that we exclude the citations from adopters to measure spillovers. Specifically, we estimate the below equation.

Table 5: Descriptive statistics of technology seller and Placebo group

	Technology seller	Placebo	P-value
log (cumulative patent)	4.25 ( 2.24 )	4.46 ( 2.33 )	0.22
log (cumulative citations)	1.77 ( 0.49 )	1.80 ( 0.46 )	0.39
N	374	374	

**Notes:** Both variables are the cumulative numbers at the year of first (placebo) technology adoption. P-value is p-value for the null hypothesis that the difference between technology seller and matched group is zero.

$$Y_{it} = \sum_{k=-5}^{10} \beta_k^{\text{Seller}} \mathbf{1}_{\{L_{it}^{\text{Seller}}=k\}} + \sum_{k=-5}^{10} \beta_k^{\text{All}} \mathbf{1}_{\{L_{it}^{\text{All}}=k\}} + \alpha_i + \gamma_t + \epsilon_{it} \quad (39)$$

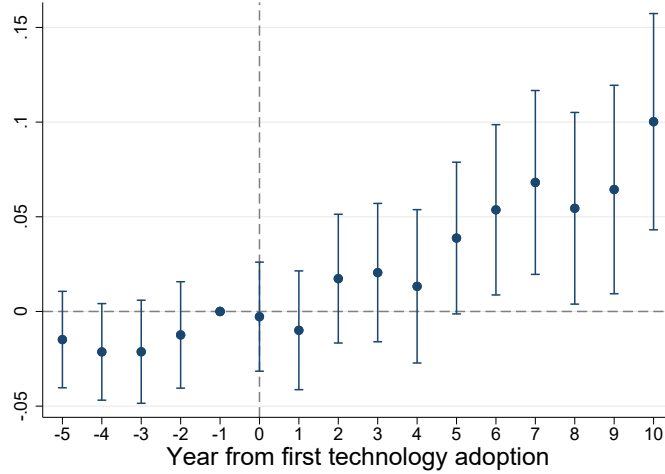


Figure 6: Event study result of patent citations

**Notes:** The figure plots  $\beta_k^{\text{Seller}}$  in equation (39), which captures the difference between the foreign firm that sold technology to Korean firm and the foreign firm that did not in terms of the probability of citation received from the Korean never-adopters. Vertical line is 95% confidence interval. The coefficient in one year before the adoption is normalized as zero. Standard error is clustered at the foreign firm level.



where  $Y_{it}$  is citation dummy variable which is equal to one if any Korean never-adopters cite a patent of the foreign firm  $i$  in year  $t$ , and zero if not.  $L_{it}^{\text{All}}$  is the number of years from the first (placebo) adoption and  $L_{it}^{\text{Seller}}$  is the same variable but applies only to the technology seller (treated).  $\alpha_i$  is the foreign firm fixed effects,  $\gamma_t$  is year fixed effects, and  $\epsilon_{it}$  is the error term. Therefore,  $\beta_k^{\text{All}}$  captures common trend around the event year, and  $\beta_k^{\text{Seller}}$  captures the difference between treated and control firms. We cluster standard error at the technology field level (3 digit IPC) and year.

Figure 6 plots  $\beta_k^{\text{Real}}$  in which there is an increase in the number of patent citations to the technology seller compared with control firms. It suggests that Korean firms build on the adopted technology when they innovate, which implies a positive externality of the adoption. We do not find a clear pre-trend before the first technology adoption, supporting that the difference is not driven by the different trends between two groups. This result would identify knowledge diffusion parameter  $\delta$  in the model. Details of model counterpart is in Section 5.1.2.

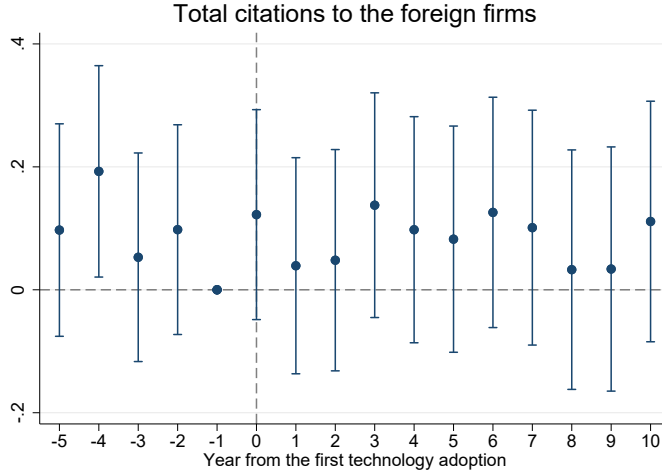


Figure 7: Event study result of patent citations (placebo)

**Notes:** The figure plots  $\beta_k^{\text{Seller}}$  in equation (39), which captures the difference between the foreign firm that sold technology to Korean firm and the foreign firm that did not in terms of logged number of citations that firm  $i$  received from all the other countries except Korea. Vertical line is 95% confidence interval. The coefficient in one year before the adoption is normalized as zero. Standard error is clustered at the foreign firm level.

A potential identification threat is an unobserved shock to the foreign firm that increase adoption probability and the number of citations received. For example, Sony's technology turns out to be superior, and Korean firm become more likely to adopt from Sony and also citation to Sony increased after the adoption year. As a placebo test, we run the same regression with the number of citations received from all the other countries except Korea.

figure 7 shows that there is no clear difference between treated and control groups in terms of total citations, which bolsters the credibility of the event study result. To study the intensive margin as well, figure C.3 plots the difference of the inverse hyperbolic transformation of the number of citations. Table C.1 shows the entire coefficient with standard errors for both extensive and intensive margin.

To summarize the results, we run simpler difference-in-difference specification in which we include dummy variable which is equal to one if the year is after the first (placebo) technology adoption. The regression equation is as below.

$$Y_{it} = \beta^{\text{Seller}} \cdot \mathbf{1}(L_{it}^{\text{seller}} > 0) + \beta^{\text{All}} \cdot \mathbf{1}(L_{it}^{\text{All}} > 0) + \alpha_i + \gamma_t + \epsilon_{it} \quad (40)$$

Table 6 shows the result in which the coefficient of post adoption is 0.0284 within 5 years. This suggests that the Korean non-adopting firms increase probability of citation by 2.84 percentage point.

Table 6: Patent Citations to Foreign Firm after Adoption

	Citation (dummy)
Post Adoption	0.0284** (0.0117)
N	6,820
Adjusted R2	0.3927
Firm FE	yes
Year FE	yes
Standard errors in parentheses	
* $p < 0.10$ , ** $p < 0.05$ , *** $p < 0.01$	

**Notes:** This table displays the estimates of  $\beta^{\text{seller}}$  in equation 40, which is the difference is probability of citations from Korean non-adopting firms to the foreign technology seller after the first technology adoption. We restrict the sample from 5 years prior to post 5 years from the first technology adoption. Standard errors are clustered at the foreign firm level.

## 5 Quantitative Exercise

### 5.1 Estimation

We estimate the model in two steps. First, we use values either from other studies or directly from the data for a subset of parameters. The remaining parameters are jointly estimated by the simulated method of moments (SMM). To be specific, we initiate the simulation in

which  $m_F$ , the productivity gap from foreign firm follows  $N(d, 1)$ , and  $m_D$ , the gap from the home follower follows uniform distribution. And we solve transition until it converges to the balanced growth path. Along the transition, we calculate moments from the model. Then, we choose parameter to minimize the distance between the moments from the model and data in 1970-1990.

### 5.1.1 External Calibration

We use discount rate  $\rho = 0.02$ , which is common value in the literature. R&D and adoption cost curvature parameter  $\gamma$  is set to be 2 to follow the estimate in the innovation literature. (Refer to [Acemoglu et al., 2018](#), for the discussion.) We impose  $\sigma = 8$  following [Anderson and Van Wincoop \(2004\)](#). For iceberg trade cost, we use  $D = 1.5$  following [Atkeson and Burstein \(2008\)](#). We set labor supply  $L_H = 1$  as normalization, and  $L_F = 2$  to match Japan's relative population size.  $\bar{m}_F$  is the maximum technology gap from foreign firm and set to be 25 for computational reason.<sup>34</sup>  $\bar{m}_D$  is set to be 5.

For government policy  $s_{Hat}, s_{Hrt}$ , we use tax credit for adoption and innovation. As an adoption subsidy, Korean government exempted corporate tax for the expense of adoption fee to foreign firms since 1973.<sup>35,36</sup> To be specific, firm gets full tax credit from the fixed fee and royalty payment for the first 5 years of the adoption contract, and half tax credit for the following 3 years. In 1981, the policy changed to give tax credit only for 5 years. In 1991, the policy limit the coverage of adoption tax credit to "advanced technology". In the data, 42% of adoption contract gets tax credit since 1991, and we interpret this as the firms get 42% of tax credit from adoption cost. Lastly, in 2010, the government stopped giving tax credit to adoption cost. Using the corporate tax and formula from [Bloom et al. \(2002\)](#), we calculate the adoption subsidy rate over time.

Likewise, the government also subsidized innovation by giving R&D tax credit. It started in 1981 with tax credit rate as 10%. In 1990, it increased tax credit rate to 15%, and in 2009, increased the rate to 25%. We again calculate the innovation subsidy rate by the formula from [Bloom et al. \(2002\)](#). The tax credit rate is from [Choe and Lee \(2012\)](#).<sup>37</sup>

We include  $s_{Hat}, s_{Hrt}$  into the model while assuming perfect foresight of the agents. In

---

<sup>34</sup>We increase  $\bar{m}$  until the point in which it does not affect key results.

<sup>35</sup>In the 1970s, there was also sector-specific adoption subsidy which subsidizes input cost of adoption-related business as we studied in [Choi and Shim \(2022\)](#). We abstract away from this sector-specific subsidy in this paper.

<sup>36</sup>We collected the adoption tax credit law over time from <https://glaw.scourt.go.kr>

<sup>37</sup>We use tax credit rate of middle and small sized firms because the tax credit for big firms is more complicated. In particular, the government gives 50% tax credit for the increment of R&D for the big firms, which is hard to calculate as innovation subsidy rate.

other words, firms know the plan of policy change in advance. For country  $F$ ,  $s_{Fat} = 0, s_{Frt} = 0$ .<sup>38</sup>

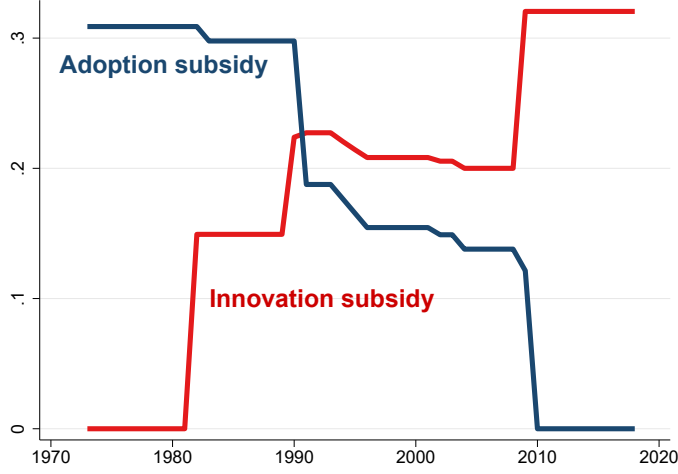


Figure 8: Innovation and adoption subsidy rate in Korea

**Notes:** Tax credit rate is from <https://glaw.scourt.go.kr>, R&D tax credit rate is from Choe and Lee (2012). We calculate innovation and adoption subsidy rate using the formula from Bloom et al. (2002).

### 5.1.2 Internal Calibration using Method of Moments

Since the period of data is the catching-up period in Korea, we calibrate the model on the transition. To be specific, we start the economy in year 1970 with the initial technology distribution in which firms in home country have lower productivity and solve the transition until it converges to a balanced growth path. We compare the moments in the initial periods of simulation with the moments from the data in Korea, 1970-1990. The detailed explanation is in Appendix D.2.

We assume  $\alpha_{Fr} = \alpha_F \cdot \alpha_{Hr}$ ,  $\alpha_{Fa} = \alpha_F \cdot \alpha_{Ha}$ . Since the structure of firms is different in two countries, we adjust cost parameter of innovation and adoption to get the average productivity gap in the balanced growth path can be zero.

The remaining ten parameters  $\Theta = \{\lambda, \alpha_r, \alpha_a, \alpha_F, \eta_a, \eta_r, \xi, \delta, d, \phi\}$  and ten empirical moments. We choose  $\Theta$  to minimize the distance between empirical moments  $M_i^D$  and moments from model  $M_i(\Theta)$  as follows.

$$\min_{\Theta} \sum_{i=1}^{10} \left( \frac{M_i^D - M_i(\Theta)}{\frac{1}{2}(M_i^D + M_i(\Theta))} \right)^2 \quad (41)$$

<sup>38</sup>Since we calibrate  $\alpha_{Fa}, \alpha_{Fr}$  different from home country to make two countries symmetric in the long run, abstracting away from policy in country  $F$  does not change the result a lot.

We document the ten empirical moments and discuss relevant parameters that we identify from the moments.

#### **Adoption fee / yearly sale**

The adoption fee over yearly sale from adoption contract is 22.4% on average.<sup>39</sup> Likewise, we calculate the adoption fee over annualized sales in the model, and compare two moments. The key parameter is  $\xi$  which governs the bargaining power of the adopter.

**Slope of sales / emp growth over productivity gap** In table 3, we regress the sales per employment growth from adoption and innovation over the initial productivity gap. The coefficient for adoption is -0.12 and for innovation is -0.046. This coefficient informs the curvature of expected productivity gain from adoption and innovation in the model.

To be specific, we run the same regression in the model. We simulate 100,000 adopting / innovating firms by using the distribution of productivity gap conditional on adopting / innovating. For each simulated firm, we calculate the sales per employment growth from adoption and innovation. Then, we regress it with the initial sales per employment gap from the foreign firm. Then, we compare the regression coefficient in the model and the data in table 3. The key parameters are  $\eta_x, \eta_a$  which govern the slope of step size distribution from adoption and innovation (Figure 2).

**Patent citation increase from non-adopters after adoption** To replicate the result in figure 6, we develop a simple model of patent citation. In the model, home follower can receive knowledge diffusion from adopted technology. We assume that when they get knowledge diffusion and innovate, they need to cite the foreign firm's patent. Then the increased citation from domestic follower (non-adopters) to the foreign firm is  $x \cdot \delta$ , where  $x$  is the innovation rate, and  $\delta$  is the probability of getting knowledge diffusion. Therefore, we match  $x \cdot \delta = 0.0284$ . The key parameter is  $\delta$ .

**Long-run Growth rate** The growth rate of Japan since 2010 is 1.5%, and we consider it as the growth rate in the balanced growth path. GDP Growth rate increases with the level of  $\lambda$  which is the unit productivity growth from innovation and adoption.

**R&D, adoption / value added in manufacturing** The R&D expenditure over the value added in manufacturing is 2.97%, and that of adoption is 1.48%.<sup>40</sup> These inform the scale parameter of innovation cost,  $\alpha_r$  and the scale parameter of adoption cost  $\alpha_a$ . From equation (33), we can calculate the innovation expenditure function, which decreases with  $\alpha_r$ . Likewise,  $\alpha_a$  decreases adoption rate, and adoption expenditure which is adoption rate times adoption fee.

<sup>39</sup>In case the firm pays the fee in multiple years, we simply sum all the payment.

<sup>40</sup>These are average in 1985-1990. R&D expense in manufacturing is from [Ministry of Science and Technology \(1990\)](#), adoption expense is from [Korea Industrial Technology Association \(1995\)](#), value added in manufacturing is from Input-Output table provided by Bank of Korea.

**GDP gap in 1970 and 2020** The initial log ratio of GDP per capita<sup>41</sup> between Korean and Japan is 1.64 in 1970. This informs  $d$ , the average productivity gap between  $H$  and  $F$  in the initial period. We assume that the productivity gap from the foreign firm follows  $N(d, 1)$ . The GDP gap becomes 0.019 in 2020. This informs  $\phi$ , which is the exogenous spillover parameter. When we have higher  $\phi$ , convergence is faster and GDP gap after 50 years is smaller.

**Productivity gap in the long run** Since we assume there are two incumbents in Korea while one incumbent in Japan, two countries have different innovation / adoption rate even if they have the same cost parameters. Therefore, we adjust the cost function of Japan to have symmetric productivity level in the balanced growth path. We target the long-run productivity gap as zero. The key parameter is  $\theta_F$ . When  $\theta_F$  is higher, then the long-run productivity is higher in  $F$ .

Table 7: Estimation result

Parameter	Description	Value	Source
<i>Externally Calibrated</i>			
$\rho$	Time preference	0.02	Long-run interest rate
$\sigma$	Elasticity of Substitution	8	Anderson and Van Wincoop (2004)
$\psi_H$	Demand Shifter of Home good	0.25	Equal share
$\psi_F$	Demand Shifter of Foreign good	0.5	Equal share
$L_H$	Labor in home country	1	normalization
$L_F$	Labor in foreign country	2	population in Japan
$D$	Trade cost	1.5	Atkeson and Burstein (2008)
$\gamma$	Innovation / adoption cost curvature	2	Acemoglu et al. (2018)
<i>Internally Calibrated</i>			
$\lambda$	Unit step size	1.049	
$\eta_a$	Slope of step size from adoption	1.133	
$\eta_r$	Slope of step size from innovation	1.752	
$\alpha_a$	Adoption cost	3.371	
$\alpha_r$	Innovation cost	2.642	Jointly Estimated through SMM
$\xi$	Bargaining power of adopter	0.367	
$\delta$	knowledge diffusion	0.256	
$d$	Initial productivity gap	-24.010	
$\alpha_F$	Relative cost in $F$	5.891	
$\phi$	Exogenous spillover	0.029	

## 5.2 Estimation Result

Table 7 shows the result of estimation and table 8 shows the fitness of the model. Overall, the estimated model match both the micro and macro moments.  $\lambda$  is 1.049, which means

<sup>41</sup>GDP per capita is price level adjusted measure.

Table 8: Moments

Moment	Model	Data
Adoption fee / annual sale	0.229	0.224
$\beta^a$ : productivity growth with gap (adoption)	-0.119	-0.120
$\beta^i$ : productivity growth with gap (innovation)	-0.045	-0.046
$\Delta$ Patent citation after adoption	0.023	0.028
Long-run growth rate	0.014	0.014
Adoption / value added in manufacturing	0.013	0.015
R&D / value added in manufacturing	0.027	0.030
GDP gap in 1970	1.644	1.649
GDP gap in 2020	0.038	0.019
Long-run productivity gap	0.002	0.000

one step improvement increases 4.9% of labor productivity.  $\eta_x > \eta_a$  implies the slope of step size distribution of adoption is larger than that of the innovation. This is because from the regression (38), sales per employment is more sensitive with the initial productivity gap for adoption than innovation. On the other hand,  $\alpha_a > \alpha_r$ , which means the cost parameter of adoption is larger. This is because the adoption expenditure share is smaller than that of innovation, so the adoption rate is smaller than the innovation in the model.  $\xi$ , the bargaining power parameter is 0.367, which implies that the adopter takes roughly one third of total surplus from the adoption.  $\delta$ , the probability of getting knowledge diffusion is 0.256, which is much lower than one.  $d$ , the initial productivity gap is  $-24.01$ , which means the productivity of foreign firms is 2.6 times larger than the Korean firms.  $\alpha_F$  is 5.891, which implies  $F$  has higher cost for innovation and adoption. This is because the entrant in  $F$  has always higher incentive to innovate.  $\phi$  is 0.029, so the firms are getting exogenous spillover with 2.9% every period.

### 5.3 Quantitative Result

First, we document how the firm behaves according to the productivity gap. The left panel of figure 9 plots the adoption and innovation rate over the productivity gap.<sup>42</sup> Both increase as the firm gets closer to the foreign firm. Since the slope of the profit function (figure 3) becomes steeper as the productivity gap increases, the incentive to improve productivity also increases. Therefore, both the innovation and adoption rates increase. The right panel of 9 shows that the adoption fee increases as the relative productivity of the firm becomes higher. This is because both the gain for the adopter and loss for the leader increase with the productivity gap.

<sup>42</sup>We take the average of first 20 years on the transition.

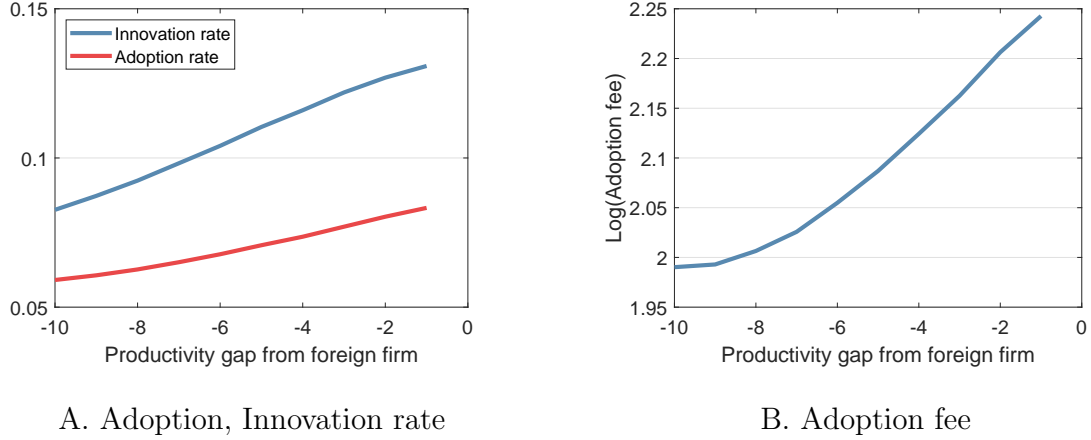


Figure 9: Adoption, Innovation Rate, and Adoption Fee over Productivity Gap

**Notes:** Both graphs plot the average value of the first 20 years on the transition. We fix the gap between two domestic firms as zero.

Second, we document how the economy converges to the balanced growth path from the initial productivity distribution. Figure 10 plots the relative GDP per capita and adoption expenditure share, which is the same as the figure 1 in the Introduction. While Korea converges to Japan, the expenditure share of adoption decreases in the model as well. This is because 1) the adoption fee increases as Korea catching up, 2) productivity growth from adoption become smaller compared with innovation<sup>43</sup> 3) the government gradually decreases adoption subsidy rate and increases innovation subsidy rate as we can see in the figure 8.

While the policy partially generates the decreasing trend of adoption expenditure share, the model still produces a strong trend of decreasing adoption expenditure share without the policy change. Dashed lines in figure 10 show the transition without policy. We can see that the adoption expenditure share decreases over time even without the policy change, but it is more flat than the baseline case. Also, the convergence is slower than the baseline case.

Untargeted Moments will be added here

## 5.4 Contribution of Adoption and Innovation

To study the contribution of adoption, we first shut down the adoption channel in the model by increasing the adoption cost to the infinity, and second we calculate the contribution of adoption and innovation on GDP growth in each period.

The left panel of figure 11 shows the average productivity gap over time in the baseline

<sup>43</sup>This is because  $\eta_x > \eta_a$ , and there is no productivity growth from adoption when the firm has higher productivity than the foreign firm.



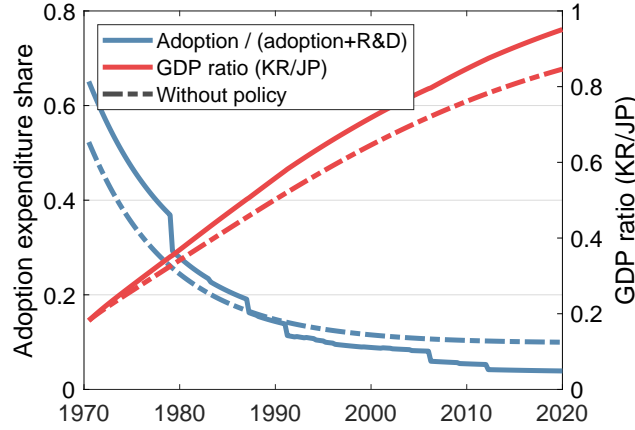


Figure 10: Relative GDP and adoption expenditure share with and without policy

**Notes:** We plot the adoption fee expenditure / (adoption fee + innovation cost) and real GDP per capita of  $H$  divided by that of  $F$  over time. Solid lines are the baseline cases with policies, and the dashed lines are the cases without policies.

case, and the case where we shut down the adoption. It shows that the convergence is much slower without adoption. This is because adoption provides better way to reduce the gap from the foreign firm, especially in the early period of development. The right panel of figure 11 compares  $\log(\text{GDP})$  over time with the baseline case and the case without adoption. We can see Korea loses a substantial portion of GDP when we shut down GDP. In particular, growth rate is much higher in the early period with adoption. Welfare in 100 years is 13.81% higher in the baseline case, which is equivalent to have 14.22% higher consumption in every period.

Next, we directly decompose the growth contribution of adoption and innovation over time. To be specific, we simulate the next period GDP with innovation only, and with adoption only and get the growth rate separately. Then, we calculate growth share of adoption and innovation.

Figure 12 shows the contribution of adoption on growth is 77% in 1970, and it decreases to 10% in 2020. In other words, the main driver of growth is technology adoption from foreign countries in the early stage of development, and it shifts to the innovation. Again, the policy change has contributed to this decreasing trend, but the model still has decreasing pattern even without any policy.

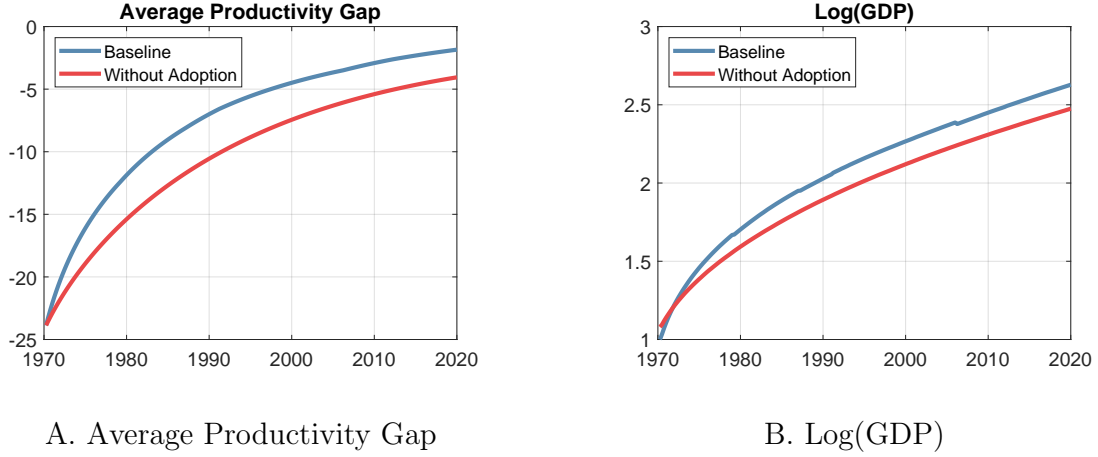


Figure 11: Counterfactual without Adoption

**Notes:** Baseline case is with adoption channel and subsidies. Without adoption is when we shut down the adoption channel and subsidies.

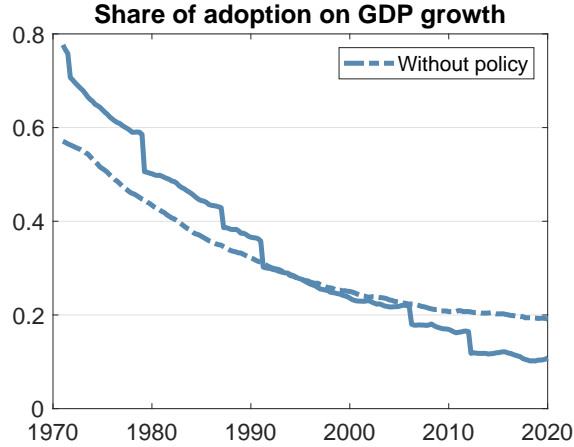


Figure 12: Contribution on GDP growth of adoption and innovation

**Notes:** Growth share of adoption is Growth rate from adoption / (growth rate from adoption + growth rate from innovation). Solid line is the baseline case with policy and the dashed line is without policy.

## 6 Policy Analysis

In this section, we first discuss the policy implication of the model. Then, we evaluate the technology policy implemented in Korea since 1970 where it started as adoption subsidy and switch to innovation subsidy. Next, we study the optimal timing of switch from adoption to innovation subsidy. Lastly, we study the effect of trade policy and its interaction with

innovation and adoption.

## 6.1 Policy Implication of the Model

As we discussed in Section 2, competitive equilibrium of our model is not efficient because adoption and innovation have externalities. They have positive externalities because the entrants can receive knowledge diffusion and build on the current technology level. This spillover discourages the incumbents from innovating and adopting, which creates underinvestment of them. On the other hand, the innovation and adoption by entrants have negative externalities by stealing the profit of incumbent. The relative size of positive and negative externality depends on the step size of innovation and adoption (Aghion and Howitt, 1992). The larger step size creates larger positive externalities from technology improvement while keeping the negative externality unchanged. Therefore, the social value of adoption and innovation depends on the relative step size.

The advantage of backwardness makes the average step size of adoption and innovation decrease as the firm gets closer to the foreign firms. Since our empirical analysis suggests the advantage of backwardness is stronger for adoption, the average step size decreases more than that of innovation. It leads to the step size of adoption being larger than the innovation at the early stage of development, and it becomes smaller when the economy is close to the frontier. Since the social value follows the step size, the optimal subsidy will be larger for adoption than innovation initially. Then, the optimal adoption subsidy rate decreases, and the optimal innovation subsidy rate increases as the economy converges.

## 6.2 Evaluation of Technology Policy in Korea

As a baseline case, we include both adoption and innovation subsidies over year from the data as in figure 8. We compare the baseline with three alternative scenarios. First, there is no subsidy at all. Second, the government subsidizes only adoption with 30.89%, which is the initial value in the baseline. Lastly, the government subsidizes only innovation with 32.05%, which is the final value in the baseline.<sup>44</sup>

The left panel of figure 13 shows the relative GDP compared with the case without any policy over time. When we subsidize adoption only, it brings higher growth rate at the early stage. It brings higher GDP compared to the case without policy. However, the relative GDP does not grow exponentially, implying that subsidizing only adoption does not generate significantly higher long-run growth rate. On the other hand, when we subsidize

---

<sup>44</sup>To decompose the contribution of the actual adoption and innovation subsidies, we compare the baseline case with the cases when we shut down either adoption or innovation subsidies, or both in Figure E.2.

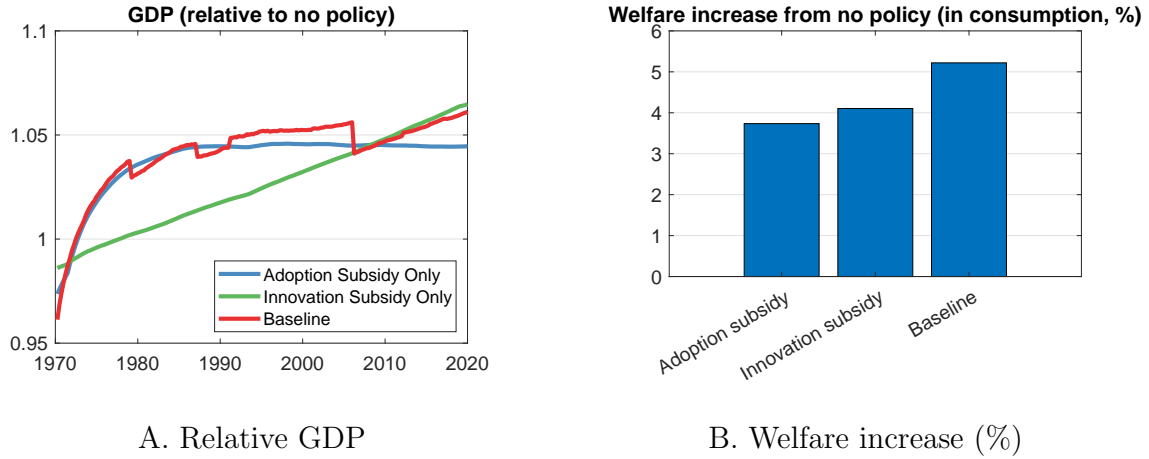


Figure 13: Results of the Counterfactual Analysis

**Notes:** This figure plots the counterfactual results. Panel A plots GDP in three scenarios divided by GDP without policy. Blue line is when subsidizing only adoption with 30.89%, green line is when subsidizing only innovation with 32.05%, and the red line is following the real policy in figure 8. Panel B plots welfare increase compared with the case without policy. Welfare is in consumption equivalent unit.

only innovation, it does not have higher growth rate at the beginning, compared with the adoption subsidy case. But, it has higher growth rate at the late stage of development. This is because subsidizing innovation at the early years can be distortive, allocating resources into innovation instead of adoption although adoption has larger positive externality. Lastly, the baseline case has similar GDP as the adoption subsidy case, and also has higher growth rate at the late stage of development.

The right panel of figure 13 shows the welfare implication of the policies. We calculate the welfare in 100 years<sup>45</sup> since 1970, and compare with the case without policy using the consumption equivalent unit. Subsidizing only adoption is equivalent to 3.74% increase of consumption, subsidizing only innovation is 4.1%, and the baseline case with policy change is 5.25%. This result implies that the state-dependent policy can be the optimal policy.

### 6.3 Optimal Timing to Switch

Motivated by the real world policy in Korea, we study the optimal timing to switch from adoption to innovation subsidy. To be specific, we assume that the government starts with adoption subsidy rate as 30% and it can switch to innovation subsidy as 30% in a single year. In the long-run it keeps innovation subsidy rate as 30%.

<sup>45</sup>The results are different across different time horizon. Figure E.1 shows the welfare increase in 50 years and 500 years.

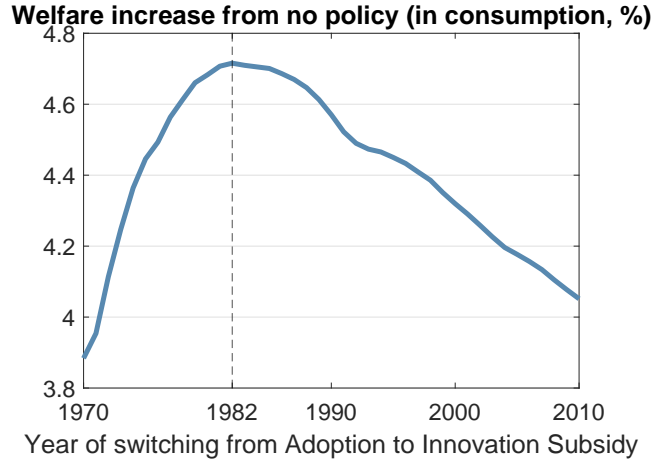


Figure 14: Welfare Increase over Different Year to Switch from Adoption to Innovation

**Notes:** We plot welfare increase compared with the case without policy. Welfare is in consumption equivalent unit. Adoption subsidy is when subsidizing only adoption with 30.89%, innovation subsidy is when subsidizing only innovation with 32.05%, and the baseline is following the real policy in figure 8. In 1982, GDP per capita in Korea was 37% of that of Japan.

Figure 14 shows the welfare increase from the case without any policy in consumption units, over different timing to switch. The result suggests that it was optimal to switch from adoption to innovation subsidy in 1982, when GDP per capital in Korea was 37% of that of Japan. In the early stages of development, productivity gap from the foreign country is large, which generates larger knowledge diffusion from technology adoption than innovation. Therefore, it is better to subsidize adoption instead of innovation. Later, when the gap is closed, the diffusion from innovation is larger than that from adoption. Thus, the government needs to switch to adoption subsidy at a certain point.

## 7 Conclusion

Many developing countries have been trying to improve technology by following technology policies from developed countries. However, the way firms grow in developing countries is different from developed countries, which requires different policies.

In this paper, we study how the firms in developing countries grow over different stages of development. We focus on two ways to improve technology: adoption from foreign country and innovation. Our contribution is to provide a novel micro dataset, find new empirical findings, and build a theoretical framework to study growth from both innovation and adoption. In particular, we capture strategic interactions between adopter and technology seller.

Based on this framework, we quantify the contribution of adoption and innovation, and study the policy implications.

We show that the contribution of technology adoption on growth is 77% in Korea, 1970 but it decreased to 10% in 2020. Korea started with adoption subsidy and then gradually switched to innovation subsidy. This generates 5.25% increase in welfare, which is higher than other alternatives such as subsidizing only adoption (3.74%) or subsidizing only innovation (4.1%). Furthermore, we study the optimal timing of the switch from adoption to innovation subsidy. Our result suggests that the country needs to switch from adoption to innovation subsidy when it reaches 37% of frontier country's GDP.

We believe that our framework can be used to study broader questions. Cross-country comparison would be a very interesting future research. How was adoption subsidy in Korea different from other developing countries? Are there any fundamental factors that increase the effectiveness of technology adoption? These questions are important to making general policy advice that can be helpful to many developing countries.

## References

- Daron Acemoglu and Ufuk Akcigit. Intellectual property rights policy, competition and innovation. *Journal of the European Economic Association*, 10(1):1–42, 2012.
- Daron Acemoglu, Philippe Aghion, and Fabrizio Zilibotti. Distance to frontier, selection, and economic growth. *Journal of the European Economic association*, 4(1):37–74, 2006.
- Daron Acemoglu, Ufuk Akcigit, Harun Alp, Nicholas Bloom, and William Kerr. Innovation, reallocation, and growth. *American Economic Review*, 108(11):3450–91, 2018.
- Philippe Aghion and Peter Howitt. A model of growth through creative destruction. *Econometrica*, 60(2):323–351, 1992. ISSN 00129682, 14680262. URL <http://www.jstor.org/stable/2951599>.
- Philippe Aghion, Christopher Harris, Peter Howitt, and John Vickers. Competition, imitation and growth with step-by-step innovation. *The Review of Economic Studies*, 68(3):467–492, 2001.
- Philippe Aghion, Antonin Bergeaud, Timothee Gigout, Matthieu Lequien, and Marc Melitz. Exporting ideas: Knowledge flows from expanding trade in goods. *manuscript, Harvard University*, 2019.
- Philippe Aghion, Sergei Guriev, and Kangchul Jo. Chaebols and firm dynamics in korea. *Economic Policy*, 36(108):593–626, 2021.
- Ufuk Akcigit and Sina T Ates. What happened to us business dynamism? Technical report, National Bureau of Economic Research, 2019.
- Ufuk Akcigit, Sina T Ates, and Giammario Impullitti. Innovation and trade policy in a globalized world. Technical report, National Bureau of Economic Research, 2018.
- Ufuk Akcigit, Sina T Ates, Josh Lerner, Richard R Townsend, and Yulia Zhestkova. Fencing off silicon valley: Cross-border venture capital and technology spillovers. Technical report, National Bureau of Economic Research, 2020.
- Ufuk Akcigit, Douglas Hanley, and Stefanie Stantcheva. Optimal taxation and r&d policies. *Econometrica*, 90(2):645–684, 2022.
- Fernando E Alvarez, Francisco J Buera, Robert E Lucas, et al. Idea flows, economic growth, and trade. Technical report, National Bureau of Economic Research, 2017.

- James E Anderson and Eric Van Wincoop. Trade costs. *Journal of Economic literature*, 42(3):691–751, 2004.
- Andrew Atkeson and Ariel Burstein. Pricing-to-market, trade costs, and international relative prices. *American Economic Review*, 98(5):1998–2031, 2008.
- Andrew Atkeson and Ariel Burstein. Aggregate implications of innovation policy. *Journal of Political Economy*, 127(6):2625–2683, 2019.
- David Atkin, Amit K Khandelwal, and Adam Osman. Exporting and firm performance: Evidence from a randomized experiment. *The Quarterly Journal of Economics*, 132(2):551–615, 2017.
- Robert J Barro and Xavier Sala-i Martin. Technological Diffusion, Convergence, and Growth. *Journal of Economic Growth*, 2(1):1–26, March 1997.
- Jan Bena, Miguel A Ferreira, Pedro Matos, and Pedro Pires. Are foreign investors locusts? the long-term effects of foreign institutional ownership. *Journal of Financial Economics*, 126(1):122–146, 2017.
- Jess Benhabib, Jesse Perla, and Christopher Tonetti. Reconciling Models of Diffusion and Innovation: A Theory of the Productivity Distribution and Technology Frontier. *Econometrica*, 89(5):2261–2301, September 2021. doi: 10.3982/ECTA15020. URL <https://ideas.repec.org/a/wly/emetrp/v89y2021i5p2261-2301.html>.
- Nicholas Bloom, John Van Reenen, and Heidi Williams. A toolkit of policies to promote innovation. *Journal of economic perspectives*, 33(3):163–84, 2019.
- Nick Bloom, Rachel Griffith, and John Van Reenen. Do r&d tax credits work? evidence from a panel of countries 1979–1997. *Journal of Public Economics*, 85(1):1–31, 2002.
- Jutta Bolt and Jan Luiten Van Zanden. Maddison style estimates of the evolution of the world economy. a new 2020 update. *Maddison-Project Working Paper WP-15*, University of Groningen, Groningen, The Netherlands, 2020.
- Raffaello Bronzini and Eleonora Iachini. Are incentives for r&d effective? evidence from a regression discontinuity approach. *American Economic Journal: Economic Policy*, 6(4):100–134, 2014.
- Francisco J Buera and Ezra Oberfield. The global diffusion of ideas. *Econometrica*, 88(1):83–114, 2020.



- Jie Cai and Nan Li. Growth through inter-sectoral knowledge linkages. *The Review of Economic Studies*, 86(5):1827–1866, 2019.
- Myung Soo Cha, Nak Nyeon Kim, Ki-Joo Park, and Yitaek Park. Historical statistics of korea. *Studies in Economic History, New York:[42] Springer Publishing*, 2020.
- Zhao Chen, Zhikuo Liu, Juan Carlos Suárez Serrato, and Daniel Yi Xu. Notching r&d investment with corporate income tax cuts in china. *American Economic Review*, 111(7): 2065–2100, 2021.
- Dae-Seung Choe and Sang-Yeop Lee. The effect of tax credit on corporate r&d investment. In *Proceedings of the Korea Technology Innovation Society Conference*, pages 85–98. Korea Technology Innovation Society, 2012.
- Jaedo Choi and Andrei A Levchenko. The long-term effects of industrial policy. Technical report, National Bureau of Economic Research, 2021.
- Jaedo Choi and Younghun Shim. Technology adoption and late industrialization. *Working Paper*, 2022.
- David T Coe and Elhanan Helpman. International r&d spillovers. *European economic review*, 39(5):859–887, 1995.
- David T Coe, Elhanan Helpman, and Alexander W Hoffmaister. North-south r & d spillovers. *The economic journal*, 107(440):134–149, 1997.
- Diego Comin and Bart Hobijn. An exploration of technology diffusion. *American economic review*, 100(5):2031–59, 2010.
- Michelle Connolly and Kei-Mu Yi. How much of south korea’s growth miracle can be explained by trade policy? *American Economic Journal: Macroeconomics*, 7(4):188–221, 2015.
- Gustavo de Souza. The labor market consequences of appropriate technology. Technical report, 2021.
- Antoine Dechezleprêtre, Elias Einiö, Ralf Martin, Kieu-Trang Nguyen, and John Van Reenen. Do tax incentives for research increase firm innovation? an rd design for r&d. Technical report, National Bureau of Economic Research, 2016.
- Jonathan Eaton and Samuel Kortum. International technology diffusion: Theory and measurement. *International Economic Review*, 40(3):537–570, 1999.

- Jonathan Eaton and Samuel Kortum. Trade in capital goods. *European Economic Review*, 45(7):1195–1235, 2001.
- Alexander Gerschenkron. Economic backwardness in historical perspective (1962). *The Political Economy Reader: Markets as Institutions*, pages 211–228, 1962.
- Michela Giorcelli and Bo Li. Technology transfer and early industrial development: Evidence from the sino-soviet alliance. *Working Paper*, 2021.
- Gene M Grossman and Elhanan Helpman. Quality ladders in the theory of growth. *The review of economic studies*, 58(1):43–61, 1991a.
- Gene M Grossman and Elhanan Helpman. Trade, knowledge spillovers, and growth. *European economic review*, 35(2-3):517–526, 1991b.
- Hugo Hopenhayn and Liyan Shi. Knowledge creation and diffusion with limited appropriation. Technical report, working paper, 2020.
- Sabrina T Howell. Financing innovation: Evidence from r&d grants. *American economic review*, 107(4):1136–64, 2017.
- Chang-Tai Hsieh, Peter J Klenow, and Ishan B Nath. A global view of creative destruction. Technical report, National Bureau of Economic Research, 2019.
- Anders Humlum. Robot adoption and labor market dynamics. *Princeton University*, 2019.
- Adam B Jaffe, Manuel Trajtenberg, and Rebecca Henderson. Geographic localization of knowledge spillovers as evidenced by patent citations. *the Quarterly journal of Economics*, 108(3):577–598, 1993.
- Xavier Jaravel, Neviana Petkova, and Alex Bell. Team-specific capital and innovation. *American Economic Review*, 108(4-5):1034–73, 2018.
- Charles I Jones. R & d-based models of economic growth. *Journal of political Economy*, 103(4):759–784, 1995.
- Charles I Jones and John C Williams. Too much of a good thing? the economics of investment in r&d. *Journal of economic growth*, 5(1):65–85, 2000.
- Réka Juhász, Mara P Squicciarini, and Nico Voigtländer. Technology adoption and productivity growth: Evidence from industrialization in france. Technical report, National Bureau of Economic Research, 2020.

- Minho Kim, Munseob Lee, and Yongseok Shin. The plant-level view of an industrial policy: The Korean heavy industry drive of 1973. Technical report, National Bureau of Economic Research, 2021.
- Tor Jakob Klette and Samuel Kortum. Innovating firms and aggregate innovation. *Journal of political economy*, 112(5):986–1018, 2004.
- Michael König, Zheng Michael Song, Kjetil Storesletten, and Fabrizio Zilibotti. From imitation to innovation: Where is all that Chinese R&D going? Technical report, National Bureau of Economic Research, 2020.
- Korea Industrial Technology Association. *Records of Technology Acquisition Contracts: 1962-1995*. Seoul: Korea Industrial Technology Association, [in Korean], 1995.
- Nathan Lane. Manufacturing revolutions: Industrial policy and industrialization in South Korea. *Available at SSRN 3890311*, 2022.
- Jihong Lee, Hyunkyeong Lim, Sangdong Kim, Keunsang Song, and Jae Yu Jung. Korea patent data project (kopdp): Contents and methods. In *The Korean Economic Forum*, pages 12–4, 2020.
- Nelson Lind and Natalia Ramondo. Global innovation and knowledge diffusion. Technical report, National Bureau of Economic Research, 2022.
- Ernest Liu and Song Ma. Innovation networks and R&D allocation. 2022.
- Ernest Liu, Atif Mian, and Amir Sufi. Low interest rates, market power, and productivity growth. *Econometrica*, 90(1):193–221, 2022.
- Ministry of Science and Technology. *Report on science, technology, and research and development activities*. Government Report, [in Korean], 1990.
- Jane Olmstead-Rumsey. Market concentration and the productivity slowdown. *Working Paper*, 2022.
- Stephen L Parente and Edward C Prescott. Barriers to technology adoption and development. *Journal of political Economy*, 102(2):298–321, 1994.
- Jesse Perla and Christopher Tonetti. Equilibrium imitation and growth. *Journal of Political Economy*, 122(1):52–76, 2014.

- Marta Prato. The global race for talent: Brain drain, knowledge transfer and growth. *Working Paper*, 2022.
- Swapnika Rachapalli. Learning between buyers and sellers along the global value chain. Technical report, Working Paper, 2021.
- Dani Rodrik. Getting interventions right: how south korea and taiwan grew rich. *Economic policy*, 10(20):53–107, 1995.
- Paul M Romer. Endogenous technological change. *Journal of political Economy*, 98(5, Part 2):S71–S102, 1990.
- Thomas Sampson. Technology gaps, trade and income. *Working Paper*, 2019.
- Ana Maria Santacreu. Innovation, diffusion, and trade: Theory and measurement. *Journal of Monetary Economics*, 75:1–20, 2015.
- Ana Maria Santacreu. Dynamic gains from trade agreements with intellectual property provisions. *Working Paper*, 2022.
- Eric Verhoogen. Firm-level upgrading in developing countries. *Working Paper*, 2021.
- Fabrizio Zilibotti. Growing and slowing down like china. *Journal of the European Economic Association*, 15(5):943–988, 2017.

# A Appendix: Model

## A.1 Value Function

Value function of home follower is as below.

$$\begin{aligned}
& r_{Ht}V_{Ht}(\mathbf{m}) - \dot{V}_{Ht}(\mathbf{m}) \\
&= \max_{x_{H2mt}, a_{H2mt}} \underbrace{\Pi_{Ht}(\mathbf{m})}_{\text{profit}} - \underbrace{(1 - s_{Hrt}) \alpha_{Hr} \frac{(x_{H2mt})^\gamma}{\gamma} w_{Ht}}_{\text{innovation cost}} - \underbrace{(1 - s_{Hat}) \alpha_{Ha} \frac{(a_{H2mt})^\gamma}{\gamma} w_{Ht}}_{\text{Adoption cost}} \\
&+ x_{H2mt} \sum_n \tilde{f}_{m_F}(n) \underbrace{[V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m})]}_{\text{Gain from innovation}} \\
&+ a_{H2mt} \sum_n \tilde{g}_{m_F}(n) \left[ \underbrace{[V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m})]}_{\text{Gain from adoption}} - \underbrace{(1 - s_{Hat}) \mathcal{F}_{H1mt}}_{\text{adoption fee}} \right] \\
&+ x_{H1mt} \sum_n f_{m_F - m_D}(n) \underbrace{[V_{Ht}(m_F, m_D - n) - V_{Ht}(\mathbf{m})]}_{\text{loss from follower innovation}} \\
&+ a_{H1mt} \sum_n g_{m_F - m_D}(n) \underbrace{[V_{Ht}(m_F, m_D - n) - V_{Ht}(\mathbf{m})]}_{\text{loss from follower adoption}} \\
&+ (x_{F\mathbf{m}t} + \tilde{x}_{F\mathbf{m}t}) \sum_n f_{-m_F + m_D}(n) \underbrace{[V_{Ht}(m_F - n, m_D) - V_{Ht}(\mathbf{m})]}_{\text{loss from foreign firm innovation}} \\
&+ a_{F\mathbf{m}t} \sum_n g_{-m_F + m_D}(n) \left[ \underbrace{[V_{Ht}(m_F - n, m_D) - V_{Ht}(\mathbf{m})]}_{\text{loss from foreign leader adoption}} + \underbrace{\mathcal{F}_{F\mathbf{m}t}}_{\text{adoption fee}} \right] \\
&+ \underbrace{\phi(V_{Ht}(\mathbf{0}) - V_{Ht}(\mathbf{m}))}_{\text{Exogenous spillover}}
\end{aligned} \tag{42}$$

Value function of foreign firm is as below.

$$\begin{aligned}
& r_{Ht}V_{Ht}(\mathbf{m}) - \dot{V}_{Ht}(\mathbf{m}) \\
&= \max_{x_{F\mathbf{m}t}, a_{F\mathbf{m}t}} \underbrace{\Pi_{Ft}(\mathbf{m})}_{\text{profit}} - \underbrace{(1 - s_{Frt}) \alpha_{Fr} \frac{(x_{F\mathbf{m}t})^\gamma}{\gamma} w_{Ft}}_{\text{innovation cost}} - \underbrace{(1 - s_{Fat}) \alpha_{Fa} \frac{(a_{F\mathbf{m}t})^\gamma}{\gamma} w_{Ft}}_{\text{Adoption cost}} \\
&+ x_{F\mathbf{m}t} \sum_n f_{m_F}(n) \underbrace{[V_{Ft}(m_F + n, m_D) - V_{Ft}(\mathbf{m})]}_{\text{Gain from innovation}} \\
&+ a_{F\mathbf{m}t} \sum_n g_{m_F}(n) \left[ \underbrace{[V_{Ft}(m_F + n, m_D) - V_{Ft}(\mathbf{m})]}_{\text{Gain from adoption}} - \underbrace{(1 - s_{Fat}) \mathcal{F}_{F\mathbf{m}t}}_{\text{adoption fee}} \right] \\
&+ x_{H1\mathbf{m}t} \sum_n f_{-m_F}(n) \underbrace{[V_{Ft}(m_F - n, m_D) - V_{Ft}(\mathbf{m})]}_{\text{loss from home leader innovation}} \\
&+ a_{H1\mathbf{m}t} \sum_n g_{-m_F}(n) \underbrace{[V_{Ft}(m_F - n, m_D) - V_{Ft}(\mathbf{m})]}_{\text{loss from home leader adoption}} + \mathcal{F}_{H1\mathbf{m}t} \\
&+ x_{H2\mathbf{m}t} \sum_n \tilde{f}_{-m_F-m_D}(n) \underbrace{[V_{Ft}(\min\{m_F, m_F + m_D - n\}, \max\{m_D - n, n - m_D\}) - V_{Ft}(\mathbf{m})]}_{\text{loss from home follower innovation}} \\
&+ a_{H2\mathbf{m}t} \sum_n \tilde{g}_{-m_F-m_D}(n) \underbrace{[V_{Ft}(\min\{m_F, m_F + m_D - n\}, \max\{m_D - n, n - m_D\}) - V_{Ft}(\mathbf{m})]}_{\text{loss from home follower adoption}} + \mathcal{F}_{F2\mathbf{m}t} \\
&- \underbrace{\tilde{x}_{F\mathbf{m}t} V_{Ft}(m_F, m_D)}_{\text{Replaced by Entrant}} + \underbrace{\phi(V_{Ht}(\mathbf{0}) - V_{Ht}(\mathbf{m}))}_{\text{Exogenous spillover}}
\end{aligned} \tag{43}$$

Value function of potential entrant in country  $F$  is defined as below.

$$\begin{aligned}
& r_{Ft} \tilde{V}_{Ft}(\mathbf{m}) - \dot{\tilde{V}}_{Ft}(\mathbf{m}) = \max_{\tilde{x}_{F\mathbf{m}t}} - (1 - s_{Frt}) \underbrace{\tilde{\alpha}_{Fr} \frac{(\tilde{x}_{F\mathbf{m}t})^\gamma}{\gamma} w_{Ft}}_{\text{innovation cost}} \\
&+ \tilde{x}_{F\mathbf{m}t} \sum_n g_{m_F}(n) V_{Ft}(m_F + n, m_D)
\end{aligned} \tag{44}$$

## A.2 Adoption Fee

Adoption fee when the home follower adopts from foreign firm is as below when the gap from foreign firm is  $m_F$ , and the gap from domestic competitor is  $m_D$ .

$$\begin{aligned}
\mathcal{F}_{H2\mathbf{m}} &= \operatorname{argmax}_{\mathcal{F}_{H2\mathbf{m}}} \left( \sum_n \tilde{g}_{m_F}(n) V_H(m_F + n, m_D + n) - \mathcal{F}_{H2\mathbf{m}} - V_H(\mathbf{m}) \right)^\xi \\
&\cdot \left( \sum_{n=1}^{m_D} \tilde{g}_{m_F}(n) V_F(-m_F, -m_D - n) + \sum_{n=m_D+1}^{\bar{m}-m_F} \tilde{g}_{m_F}(n) V_F(-m_F - (n - m_D), n - m_D) \right. \\
&\quad \left. + \mathcal{F}_{H1\mathbf{m}} - V_F(-m_F + m_D, -m_D) \right)^{1-\xi} \\
\mathcal{F}_{H2\mathbf{m}} &= (1 - \xi) \left( \sum_n g_{m_F}(n) V_H(m_F + n, m_D + n) - V_H(\mathbf{m}) \right) \\
&\quad - \xi \left( \sum_n g_{m_F}(n) V_F(-m_F + m_D - n, -m_D - n) - V_F(-m_F + m_D, -m_D) \right)
\end{aligned} \tag{45}$$

Adoption fee when the foreign adopts technology from home leader is as below when the gap from domestic firm is  $m_F$ , and the gap of home leader from home follower is  $m_D$ .

$$\begin{aligned}
\mathcal{F}_{F\mathbf{m}} &= \operatorname{argmax}_{\mathcal{F}_{F\mathbf{m}}} \left( \sum_n g_{m_F}(n) V_F(m_F + n, m_D) - \mathcal{F}_{F\mathbf{m}} - V_H(\mathbf{m}) \right)^\xi \\
&\cdot \left( \sum_n g_{m_F}(n) V_H(-m_F - n, m_D) + \mathcal{F}_{F\mathbf{m}} - V_H(-m_F, m_D) \right)^{1-\xi} \\
\mathcal{F}_{F\mathbf{m}} &= (1 - \xi) \left( \sum_n g_{m_F}(n) V_H(m_F + n, m_D) - V_H(\mathbf{m}) \right) \\
&\quad - \xi \left( \sum_n g_{m_F}(n) V_F(-m_F - n, m_D) - V_F(-m_F, m_D) \right)
\end{aligned} \tag{46}$$

## A.3 Optimal Policy Function

The optimal innovation rate and adoption rate of home follower is as below.

$$\begin{aligned}
x_{H2\mathbf{m}t} &= \left\{ \frac{1}{(1 - s_{Hrt})\alpha_{Hr}w_{Ht}} \sum_n \tilde{f}_{m_F}(n) [V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m})] \right\}^{\frac{1}{\gamma-1}} \\
a_{H2\mathbf{m}t} &= \left\{ \frac{1}{(1 - s_{Hat})\alpha_{Ha}w_{Ht}} \sum_n \tilde{g}_{m_F}(n) [V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m}) - (1 - s_{Hat})\mathcal{F}_{H2\mathbf{m}t}] \right\}^{\frac{1}{\gamma-1}}
\end{aligned} \tag{47}$$

Likewise, the optimal innovation and adoption rate of foreign incumbent with gap  $\mathbf{m}$  is as follows.

$$\begin{aligned}
x_{F1\mathbf{m}t} &= \left\{ \frac{1}{(1 - s_{Frt})\alpha_{Fr}w_{Ft}} \sum_n f_{m_F}(n) [V_{Ft}(m_F + n, m_D) - V_{Ft}(\mathbf{m})] \right\}^{\frac{1}{\gamma-1}} \\
a_{F1\mathbf{m}t} &= \left\{ \frac{1}{(1 - s_{Fat})\alpha_{Fa}w_{Ft}} \sum_n g_{m_F}(n) [V_{Ft}(m_F + n, m_D) - V_{Ht}(\mathbf{m}) - (1 - s_{Fat})\mathcal{F}_{F\mathbf{m}t}] \right\}^{\frac{1}{\gamma-1}}
\end{aligned} \tag{48}$$

Lastly, the optimal innovation rate of foreign entrant is as below.

$$x_{F2\mathbf{m}t} = \left\{ \frac{1}{(1 - s_{Frt})\alpha_{Fr}w_{Ft}} \sum_n f_{m_F}(n) V_{Ft}(m_F + n, m_D) \right\}^{\frac{1}{\gamma-1}} \tag{49}$$

## B Appendix: Data

### B.1 Technology Adoption data

Table B.1: Industry Composition of Technology Adoption

Sector	Frequency	Percent
machinery	2,261	26.55
electronics	2,111	24.79
chemical manufacturing	1,369	16.08
chemical fiber	423	4.97
metal	422	4.96
food	265	3.11
non-metallic products	230	2.70
shipbuilding	226	2.65
pharmaceutical	211	2.48
contruction	155	1.82
telecommunications	132	1.55
electrics	92	1.08
textile	66	0.78
paper	35	0.41
agriculture	31	0.36
etc.	487	5.72
Total	8,516	100.00



Figure B.1: Example of Adoption Contract

# TECHNICAL COLLABORATION AGREEMENT

BY AND BETWEEN

NIPPON ELECTROIC CO., LTD.

AND

SAMSUNG ELECTRON DEVICES CO., LTD.

## Section 4 Supply of Written Technical Information

- (a) During the term of this Agreement NEC will upon reasonable request furnish SED with one transparent copy of each drawing, specification and other technical document as well as programs and related documentation within the scope specified in Section 1 (d) hereof. The time, manner and other details of furnishing such written NEC Technical Information shall be separately determined by the parties upon mutual consultation.

Figure B.2: Example of Adoption Contract

**Section 7 Compensation**

- (a) In consideration of the technical assistance, rights and licenses to be rendered or granted by NEC to SED hereunder, SED shall pay to NEC royalties computed at the rate of three percent (3%) of the Net Sales during the term of this Agreement.
- (b) "Net Sales" means the aggregate of all Net Selling Prices with respect to each annual accounting period ending December 31 of each year.

Table B.2: Country Composition of Technology Adoption

Country	Frequency	Percent
JPN	4,225	50.00
USA	2,224	26.32
DEU	470	5.56
FRA	339	4.01
GBR	310	3.67
ITA	148	1.75
CHE	133	1.57
NLD	114	1.35
CAN	78	0.92
SWE	58	0.69
BEL	55	0.65
NOR	47	0.56
DEN	44	0.52
AUS	38	0.45
AUT	26	0.31
FIN	23	0.27
RUS	21	0.25
HKG	19	0.22
SGP	11	0.13
etc.	67	0.79
Total	8,450	100

一信石材工藝 (株)				一信石材工藝 (株)			
(Il Shin Stoneworks Co., Ltd.)				(Il Shin Stoneworks Co., Ltd.)			
〔設立年月日〕 1971.2.26 〔事業者登録番號〕 101-81-08982				〔startyear〕 1971.2.26 〔Business ID〕 101-81-08982			
〔營業項目〕 大理石工藝品加工業				〔sector〕 marble processing			
〔任 員〕 (代)劉孝永				〔CEO〕 (代)劉孝永			
〔本 社〕 〒110  서울鍾路區貫鐵洞45-1 (75) 8335-7				〔address〕 〒110  서울鍾路區貫鐵洞45-1 (75) 8335-7			
〔工 場〕 〒520 全北全州市八福洞1街270-4 (4) 1731-3				〔address2〕 〒520 全北全州市八福洞1街270-4 (4) 1731-3			
〔Cable〕 "ILSTONE" Seoul 〔從 業 員〕 217名				〔Cable〕 "ILSTONE" Seoul 〔Employees〕 217名			
〔主 製 品〕 大理石花瓶, 彫刻品, 花崗岩原石				〔products〕 marble vase, sculpture, granite stone			
〔主製品の年産能力〕 代理石花瓶 15,000個, 花崗岩 10,000才				〔production cap〕 marble vase 15,000 granite 10,000才			
〔購入原材料年間消費量〕 代理石原石 10,000個(300m <sup>3</sup> )				〔material used〕 raw marble 10,000個(300m <sup>3</sup> )			
〔貿易業許可番號〕 750374				〔trade ID〕 750374			
〔輸 出〕 代理石花瓶, 代理石彫刻花瓶, 花崗岩原石, 純粹彫刻品				〔export〕 marble vase, sculpture, granite stone			
〔輸 入〕 代理石原石, 主要 石加工機械				〔import〕 raw marble, processing machinery			
〔去 來 銀 行〕 第一銀行 鍾路支店				〔bank〕 第一銀行 鍾路支店			
〔經 營 實 績〕 (決算期 12月末 現在) (單位: 千圀)				〔 (決算期 12月末 現在) (單位: 千圀)〕			
資産・資本	1977年	1978年	1979年	year	1977年	1978年	1979年
總 資 産	410,737	681,743	735,121	total asset	410,737	681,743	735,121
流動資産	142,313	326,754	373,651	current assets	142,313	326,754	373,651
固定資産	225,344	278,096	344,960	fixed asset	225,344	278,096	344,960
移延資産	43,078	76,293	16,504	deferred asset	43,078	76,293	16,504
流動負債	123,721	270,994	195,225	current debt	123,721	270,994	195,225
固定負債	59,133	116,268	161,935	fixed debt	59,133	116,268	161,935
資 本 金	160,000	200,000	200,000	capital	160,000	200,000	200,000
剩 餘 金	67,882	94,480	177,961	surplus	67,882	94,480	177,961
賣出損益							
賣 出 額	456,036	680,464	—	sale	456,036	680,464	—
純 利 益	48,361	58,598	128,480	profit	48,361	58,598	128,480

Figure B.3: Snapshot of Annual Reports of Korean Companies

**Notes:** Both graph is in the balanced growth path of the model. We fix the gap between two domestic firms as zero.

## B.2 Firm-level Balance Sheet data

For the period between 1970 and 1982, we digitize Annual Reports of Korean Companies. The reports are published by the Korea Productivity Center. Figure B.3 shows the example of a firm data in the reports.

### Coverage

It covers firms that have more than 50 employees. We compare the value added from the reports and the aggregate data from Bank of Korea.<sup>46</sup> The firms in the data covers around 70% of gross output in manufacturing. For the period from 1983, we use KIS-VALUE dataset. It covers publicly traded firms and firms with assets more than 3 billion Korean Won since 1981. Coverage rate of KIS will be added.

### Variables

<sup>46</sup>The data can be downloaded from Economic Statistics of the Bank of Korea, [https://ecos.bok.or.kr/EIndex\\_en.jsp](https://ecos.bok.or.kr/EIndex_en.jsp).

Annual Reports of Korean Companies has information including sales, total assets, fixed assets, employment, profit, export, start year. Employment data starts from 1972. Export variable is only available to small subset of firms. KIS-VALUE data includes all the variables from Annual Reports and also has R&D, cost of goods sales, wage bills. We convert all nominal values into 2015 US dollars. We validate two data by comparing overlapping period, 1981-1982. The variables are mostly same in the two dataset.

### **B.3 Matching foreign firm with USPTO data**

We use company name to match firms in the adoption data with the USPTO data. First, we run fuzzy matching by using Python function “fuzzymatcher”. We remove words such as “co”, “ltd”, “inc” before running the code. We impose minimum similarity score as 0.35. For the remaining one, we manually match firms with USPTO ID from patentsview data. Patentsview data sometimes assign multiple assignee ID to one firm. We use global corporate patent dataset ([Bena et al., 2017](#)) which provides matching between global Compustat ID (gvkey) and patent ID. If two assignees have the same gvkey, we merge them and consider as one firm.

Among 9,051 adoption contracts, 7,877 contracts have foreign firm’s name, and 4,657 number of observations are matched with USPTO ID of foreign firms. We have 2,073 unique USPTO ID attached to foreign firms.

## C Empirical Analysis: Robustness Checks and Additional Graphs

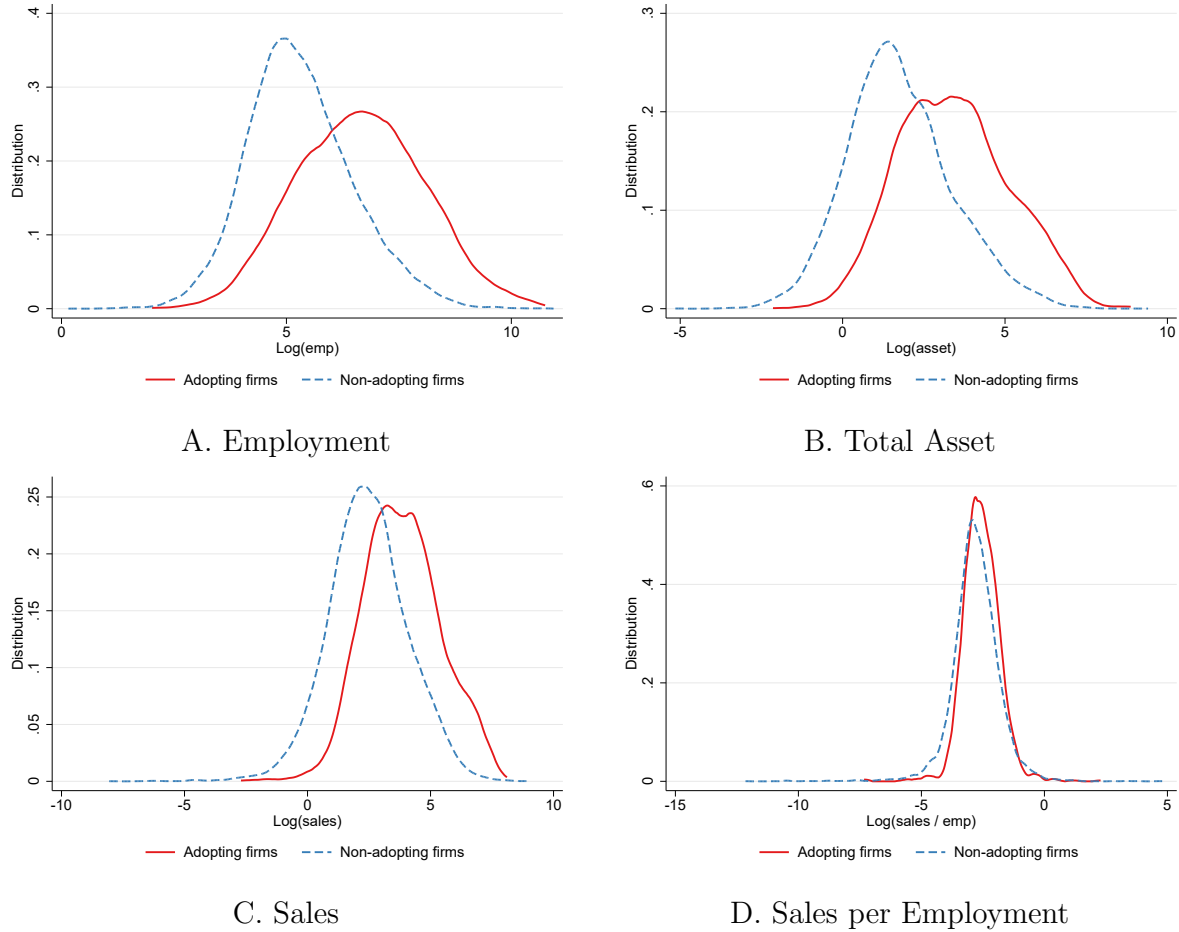


Figure C.1: Distribution of Adopting and Non-adopting Firms

**Notes:** We plot the distribution of  $\log(\text{employment})$  and  $\log(\text{total asset})$ ,  $\log(\text{sales})$ ,  $\log(\text{sales per employment})$  by using kernel density estimation. We control sector-year fixed effects.

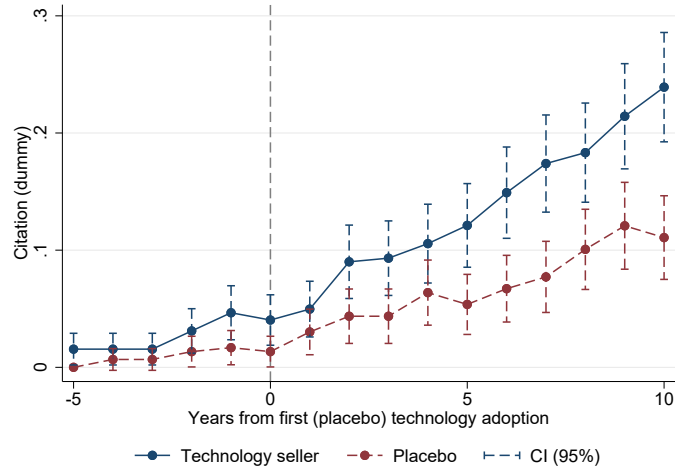


Figure C.2: Raw average of patent citations between two groups

**Notes:** The figure plots the average number of the citations from Korean never-adopters to the foreign firms in two groups (seller and placebo). Vertical line is 95% confidence interval.

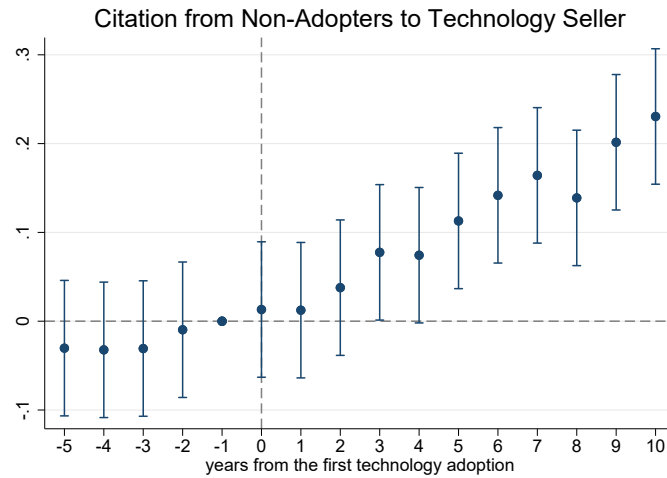


Figure C.3: Event study result of patent citations: intensive margin

**Notes:** The figure displays the difference between the foreign firm that sold technology to Korean firm and the foreign firm that did not in terms of the inverse hyperbolic transformation of the number of citations received from the Korean never-adopters.

Table C.1: Event study result of citations from the first technology adoption

	Citation (dummy)	Citation (IHS)
5 years before event	-0.0148 (0.0130)	-0.0304 (0.0172)
4 years before event	-0.0213 (0.0130)	-0.0323 (0.0166)
3 years before event	-0.0213 (0.0139)	-0.0308 (0.0172)
2 years before event	-0.0124 (0.0143)	-0.00963 (0.0201)
1 year before event	0 (.)	0 (.)
event year	-0.00275 (0.0147)	0.0132 (0.0188)
1 years after event	-0.00995 (0.0160)	0.0124 (0.0213)
2 years after event	0.0173 (0.0173)	0.0378 (0.0238)
3 years after event	0.0205 (0.0186)	0.0775** (0.0287)
4 years after event	0.0133 (0.0206)	0.0743* (0.0339)
5 years after event	0.0388 (0.0204)	0.114** (0.0379)
6 years after event	0.0537* (0.0229)	0.143*** (0.0397)
7 years after event	0.0681** (0.0247)	0.166*** (0.0445)
8 years after event	0.0545* (0.0258)	0.140** (0.0475)
9 years after event	0.0644* (0.0280)	0.204*** (0.0538)
10 years after event	0.100*** (0.0291)	0.233*** (0.0558)
N	9,920	9,920
AR2	.4035	.5376
firm fixed	yes	yes
year fixed	yes	yes

Standard errors in parentheses

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

## D Details on Solving the model

### D.1 Balanced Growth Path

On the balanced growth path, wage of each country, consumption grows at the same rate  $g_t$ , while the distribution of productivity gap  $\mu_{\mathbf{m}t}$ , innovation rate  $x_{\mathbf{c}mt}$ , adoption rate  $a_{\mathbf{c}mt}$ , and the relative price  $P_{Ft}$ <sup>47</sup> stay the same. Therefore, it is useful to divide equation (30) with  $P_{Ht}C_{Ht}$  and define  $v_{Ht} = \frac{V_{Ht}}{P_{Ht}}$  as normalized value function,  $\omega_{Ht} = \frac{w_{Ht}}{C_{Ht}}$ , as normalized wage, and  $\tilde{p}_{H\mathbf{m}t} = \frac{p_{H\mathbf{m}t}}{C_{Ht}}$ . Also, define consumption share in each country as  $\psi_{Ht} = \frac{C_{Ht}}{C_{Ht} + P_{Ft}C_{Ft}}$  and represent profit function as below.

$$\begin{aligned}\Pi_{Ht}(\mathbf{m}) &= \pi_{Ht}(\mathbf{m}) \cdot C_{Ht} + \pi_{Ht}^*(\mathbf{m}) \cdot P_{Ft}C_{Ft} \\ \frac{\Pi_{Ht}(\mathbf{m})}{C_{Ht}} &= \pi_{Ht}(\mathbf{m}) + \pi_{Ht}^*(\mathbf{m}) \cdot \frac{1 - \psi_{Ht}}{\psi_{Ht}}\end{aligned}\tag{50}$$

where  $\pi_{Ht}(\mathbf{m})$ , and  $\pi_{Ht}^*(\mathbf{m})$  are the profit divided by total consumption in each market. Then, we can normalize value function as below.

$$\begin{aligned}& (r_{Ht} - g_t)v_{Ht}(\mathbf{m}) \\ &= \max_{x_{H1\mathbf{m}t}, a_{H1\mathbf{m}t}} \pi_{Ht}(\mathbf{m}) + \pi_{Ht}^*(\mathbf{m}) \cdot \frac{1 - \psi_{Ht}}{\psi_{Ht}} - (1 - s_{Hrt})\alpha_{Hr} \frac{(x_{H1\mathbf{m}t})^\gamma}{\gamma} w_{Ht} - (1 - s_{Hat})\alpha_{Ha} \frac{(a_{H1\mathbf{m}t})^\gamma}{\gamma} w_{Ht} \\ &+ x_{H1\mathbf{m}t} \sum_n f_{m_F}(n) [V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m})] \\ &+ a_{H1\mathbf{m}t} \sum_n g_{m_F}(n) [(V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m}) - (1 - s_{Hat})\mathcal{F}_{H1\mathbf{m}t})] \\ &+ x_{H2\mathbf{m}t} \sum_n \tilde{f}_{m_F - m_D}(n) [V_{Ht}(m_F, m_D - n) - V_{Ht}(\mathbf{m})] \\ &+ a_{H2\mathbf{m}t} \sum_n \tilde{g}_{m_F - m_D}(n) [V_{Ht}(m_F, m_D - n) - V_{Ht}(\mathbf{m})] \\ &+ (x_{F\mathbf{m}t} + \tilde{x}_{F\mathbf{m}t}) \sum_n f_{-m_F}(n) [V_{Ht}(m_F - n, m_D) - V_{Ht}(\mathbf{m})] \\ &+ a_{F\mathbf{m}t} \sum_n g_{-m_F}(n) [V_{Ht}(m_F - n, m_D) - V_{Ht}(\mathbf{m}) + \mathcal{F}_{F\mathbf{m}t} \frac{1 - \psi_{Ht}}{\psi_{Ht}}] \\ &+ \phi(V_{Ht}(\mathbf{0}) - V_{Ht}(\mathbf{m}))\end{aligned}\tag{51}$$

Note that from the household Euler equation (23), we know  $r_{Ht} - g_t = \rho$  in any  $t$ . We solve the balanced growth path in two layers. First, we make a guess of  $\{\omega_H, \omega_F, \psi_H\}$ . Then, we

---

<sup>47</sup>Note that we normalize price index of home country  $P_{Ht} = 1$ .



make a guess of value function for each  $\mathbf{m}$ , and iterate until it converges using the equation (51). After the normalized value functions converges, we check the labor market clearing condition from equation (21) for each country, and check the trade balance condition from equation (22). We update these three variables until labor market clears in each country and trade is balanced.

## D.2 Transition Dynamics

We solve the transition of the model following the below steps.

1. We discretize the continuous time model where each period is divided as  $\Delta t = 2^{-5}$ .
2. Solve balanced growth path. Assume that the economy converges to the balanced growth path until period  $T$
3. We make the first guess of  $\mathbb{X}_t^0 = \{\omega_{Ht}, \omega_{Ft}, \psi_{Ht}\}_{t=0}^{t=T}$
4. Given the guess, we solve value function, innovation, and adoption rate backward from the period  $T$  to period 0.
5. Given the innovation and adoption decisions, we solve the distribution of productivity gap  $\{\mu_{H\mathbf{m}t}\}_{t=0}^{t=T}$  forward from period 0 to period  $T$ .  $\mu_{H\mathbf{m}0}$  is given as the initial condition. We also solve implied  $\tilde{\mathbb{X}}_t^1 = \{\omega_{Ht}, \omega_{Ft}, \psi_{Ht}\}_{t=0}^{t=T}$  using  $\{\mu_{H\mathbf{m}t}\}_{t=0}^{t=T}$ .
6. Get the distance  $\|\mathbb{X}_t^0 - \mathbb{X}_t^1\|$  between the guess and implied value.<sup>48</sup>
7. Update the guess as below until  $\|\mathbb{X}_t^0 - \mathbb{X}_t^1\| < \epsilon$

$$\mathbb{X}_t^{i+1} = (1 - \Delta)\mathbb{X}_t^i + \Delta\tilde{\mathbb{X}}_t^{i+1} \quad (52)$$

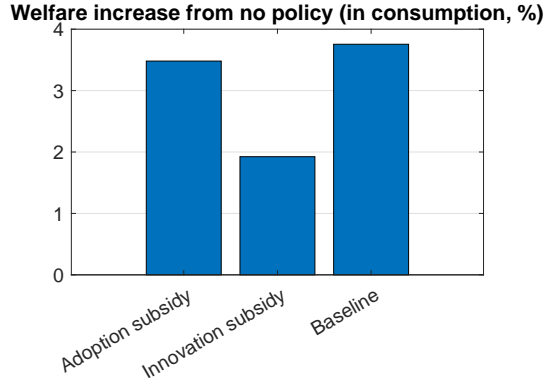
where  $0 < \Delta < 1$  is dampening parameter

## E Additional Figures in Quantitative Exercise

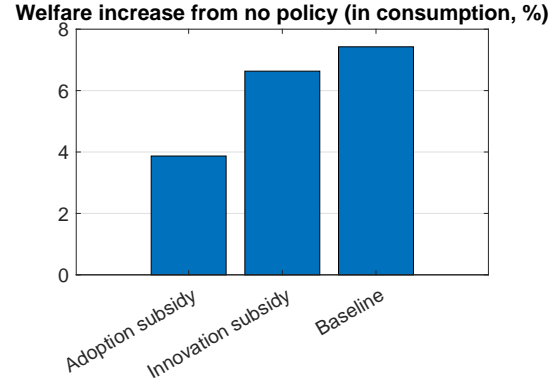
To decompose the contribution of adoption and innovation subsidy, we compare the baseline with counterfactuals where we shut down either adoption or innovation subsidies or both of them.

---

<sup>48</sup>We use Euclidean norm.



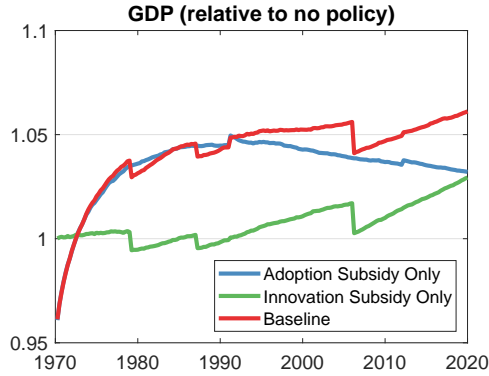
A. Welfare in 50 years



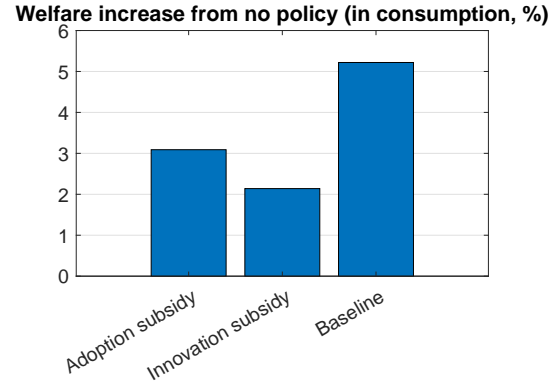
B. Welfare in 500 years

Figure E.1: Welfare Increase in Different Time Horizon

**Notes:** We plot welfare increase compared with the case without policy. Welfare is in consumption equivalent unit. Adoption subsidy is when subsidizing only adoption with 30.89%, innovation subsidy is when subsidizing only innovation with 32.05%, and the baseline is following the real policy in figure 8.



A. Relative GDP



B. Welfare increase (%)

Figure E.2: Results of the Counterfactual Analysis

**Notes:** This figure plots the counterfactual results. Panel A plots GDP in three scenarios divided by GDP without policy. Blue line is when we shut down innovation subsidy, green line is when we shut down adoption subsidy, and the red line is following the real policy in figure 8. Panel B plots welfare increase compared with the case without policy. Welfare is in consumption equivalent unit.