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

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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 3.65% higher welfare than the case without any policy, which is higher than time-invariant policies.

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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.

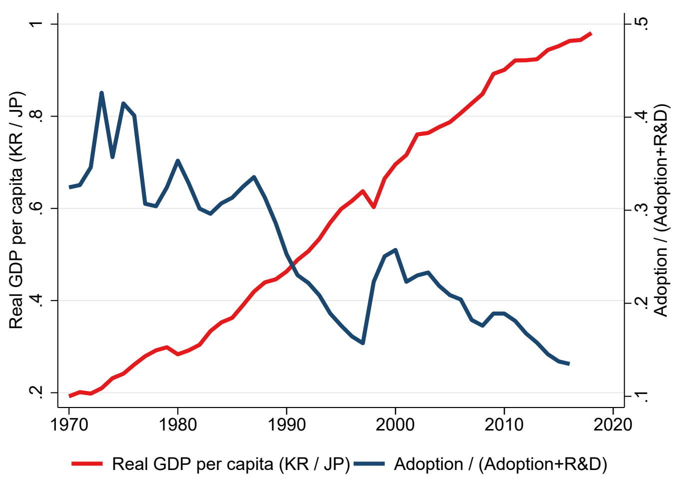


Figure 1: Relative GDP per capita and Expenditure Share of Adoption over time

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.[1] 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

[1] 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. The 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 δ 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 3.65% higher than the case without a policy in the consumption unit. Welfare increase from this policy is higher than subsidizing only adoption (3.01%) or subsidizing only innovation (2.38%).

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 1986 when GDP per capita in Korea was 48% 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 their strategic interactions. 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 use comprehensive adoption and innovation data, provide 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 the byproduct of trade.[2] Coe and Helpman (1995), Coe et al. (1997), Eaton and Kortum (2001) view knowledge is embedded 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 foreign buyers.[3] 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 and Ramondo (2022) develop models with trade, innovation, and adoption in multi-

[2] Prato (2022) studies knowledge diffusion from migration.

[3] For empirical evidence, refer to Atkin et al. (2017), Aghion et al. (2019)

country settings. They infer adoption using international patent, trade, or country-level R&D investment. While these papers use indirect adoption measures, we use 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 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 the labor market in Brazil, where the government decreased adoption subsidies but increased R&D subsidies. For quantitative papers, Jones and Williams (2000) show that positive externalities from R&D (non-appropriability of knowledge and intertemporal spillover) dominate 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.[4] Liu and Ma (2022) study the optimal R&D resource allocation in a multi-sector model with an 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).[5] While most papers in the literature focus on specific technologies or industries, we provide evidence from comprehensive data that captures all 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 (Aghion et al., 2001; Acemoglu and Akcigit, 2012; Akcigit and Ates, 2019; Olmstead-Rumsey,

[4] Bloom et al. (2019) summarize both empirical and theoretical papers on innovation policies.

[5] Refer to (Verhoogen, 2021) for thorough literature review.

2022; Liu et al., 2022).[6] 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 model's key feature is that 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 foreign firms. This adoption decision is endogenous, where the adopter needs to pay the 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. The 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.[7]

[6] See Ates (2021) for a thorough literature review.

[7] 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 seller's loss.

Second, we model knowledge diffusion from innovation and adoption in a flexible way so that the size of diffusion can be estimated from microdata. 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 the entrant), and the follower receives knowledge diffusion with probability δ. Specifically, the home follower can start from the home leader's productivity level with probability δ 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 a variety of goods $j \in [0,1]$ which are consumed by the household. Also, the goods are tradable across countries with an iceberg cost of $D \geq 1$. Firms need to ship D units 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 the leader and the one with lower productivity the follower. The follower becomes the 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.[8]

Household

A representative household consumes various goods, supplies labor, pays lump-sum tax, and owns domestic firms in each country. Household in period t has the following utility function.

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

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

[8] 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.

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

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. The asset market is cleared in every period by the following equation.[9]

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

The right-hand side is the sum of the value of all domestic firms.[10]

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

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

y_{H1jt}, y_{H2jt} are the output in product line j, consumed by the home household and produced by the leader and the follower. The 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 that are exported. C_{Ft} is defined in a symmetric way as below.[11]

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

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 σ. Then, they are aggregated by Cobb-Douglas across product lines. Accordingly, the price index of final consumption P_{ct} is below.

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

Where ψ_H and ψ_F are the demand shifter for goods produced in H and F, p_{cit} is the price of firm i in the domestic market, and p^*_{cit} is the price when exporting to the foreign market.

Market Structure

We assume that three firms in each market (home and foreign) participate in the Bertrand

[9] We do not allow international capital flows.

[10] In the case of country F, V_{F1jt} is the value of the incumbent, and V_{F2jt} is that of the potential entrant.

[11] From now on, we do not specify variables for the foreign country as long as it is symmetric.

competition, where they set the price given other firms' pricing decisions. As in Atkeson and Burstein (2008), we assume no interaction between home and foreign markets[12] and do not allow dynamic collusion. Firms recognize that their pricing decision changes the demand for their goods.

Production

The production function of a variety is linear in labor, as below.

$$\mathcal{Y}_{cijt} = q_{cijt} l_{cijt} \tag{7}$$

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 innovation and adoption. The output can be consumed by both home and foreign households as below.

$$\mathcal{Y}_{cijt} = y_{cijt} + D \cdot y^*_{cijt} \tag{8}$$

Due to the iceberg cost, it needs to produce D units of goods to export one unit of intermediate goods.

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 λ^h through innovation or adoption. λ is a fixed step size in the economy. Therefore, we can express the productivity as λ^n in which n denotes the cumulative number of steps that the firms improved. Then, the productivity gap m_F between the home leader and foreign firm in variety j can be written as below.

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

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

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

$m_F > 0$ implies the firm has higher productivity than the foreign firm. $m_D < 0$ implies the 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 the firms' pricing, market share, and profit. The productivity gap also determines dynamic decisions such as innovation and adoption rates, which will be explained in more detail later.

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

Innovation

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

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

We assume $\gamma > 1$, so the innovation cost function is convex. α_{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.

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

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.[13] 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[14] as below.

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

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 makes an adoption contract. To simplify the model, we assume it adopts technology from the foreign firm, not the home leader.[15,16] The adopter pays a one-time adoption fee to the foreign firm, which improves productivity. The 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

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

[14] This labor can be interpreted as the researcher who conducts investigate the foreign technology, learn, and implement, which is different from the adoption fee to the seller.

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

[16] Firm in country F adopts only from home leader, not the follower.

on probability a, the firm improves its productivity as follows.

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

$\mathbb{G}_{\mathbf{m}}(n)$ 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 catch up with the foreign firm from only one adoption, which is a 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).[17] Our assumption is consistent with the empirical facts that the adopter does not import the latest technology. Instead, it imports older and inferior technology.[18] Moreover, if the adoption brings full catching-up, the adoption fee would always be higher when the initial relative productivity of the 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 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 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 the 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. We impose the maximum technology gap as $\bar{m}$ to make the computation feasible. Therefore, the number of potential step sizes from adoption and innovation differs across 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.

[17] 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.

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

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 $-\bar{m}$.

$$f(n) = c_0 n^{-\eta}, \qquad n \in \{1, \cdots, \bar{n}\} \tag{15}$$

c_0 is decided such that $\sum_{n=1}^{n=\bar{n}} f(n) = 1$. 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.

$$\begin{aligned} f_m(n) &= \begin{cases} f(1) + \mathcal{A}(m) & \text{for} \quad n = 1 \\ f(n) & \text{for} \quad n \in \{2, \cdots, \bar{n}\} \end{cases} \\ \mathcal{A}(m) &= \sum_{s=1}^{m-1} f(s) \end{aligned} \tag{16}$$

$\eta > 0$ ensures that the expected step size decreases with m, and smaller η 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 η.[19] Thanks to the additive feature of the distribution, we only need to pin down one parameter, η. We use the same functional form for both $g_m(n)$ (adoption) and $f_m(n)$ (innovation), but use different slope parameter, η_a for adoption and η_r for innovation.

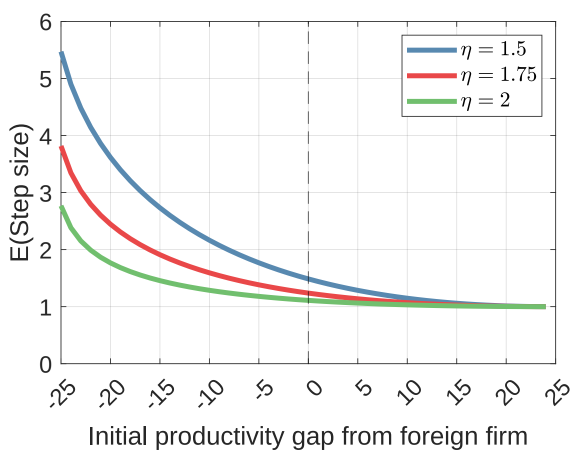


Figure 2: Expected productivity gain from adoption and innovation

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 η in the model.

[19]When $\eta \to \infty$, the model becomes a step-by-step model with only one step improvement.

Potential Entrant

In country F, there is a potential entrant $F2$ who can innovate and replace the incumbent.[20] The innovation cost of the entrant is the same as that of the incumbent as below.

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

With probability x_{F2}, they improve on top of the incumbent's productivity as below, and the incumbent exit the market.[21]

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

Knowledge Diffusion

The follower has the same structure of innovation and adoption, except that it receives knowledge diffusion from the leader stochastically. Specifically, with a fixed probability δ, 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.

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

The first term is when there is no diffusion, and the second is step size distribution with knowledge diffusion. If $\delta = 1$, it becomes equivalent to 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.

Knowledge diffusion generates a 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 the 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 productivity more and creates a 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 the externality decreases as the country catches up with the foreign country.

Lastly, we allow that there is an exogenous productivity spillover. With probability ϕ,

[20] For simplicity, we do not allow it to adopt the technology.

[21] Note that in a foreign country, the potential entrant can always build on the incumbent's technology. It simplifies the computation by reducing the number of state variables.

the technology is shared by all three firms, and they have the same productivity.[22]

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. The government holds a balanced budget in every period as below.

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

Labor Market Clearing

In each country labor market clears by the following equation.

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

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

Trade balance

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

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

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, and consumption grow at the same rate. Also, the distribution of productivity gap, interest rates, and the relative price is constant over time.

Household

[22] The example of exogenous spillover is the leakage of technology or the expiration of a patent.

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

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

Production and Profits

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

$$\sum_{i=1}^{2} p_{Hij} y_{Hij} + p^*_{Fj} y^*_{Fj} = P_H C_H \tag{24}$$

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 the home market is as below.

$$s_{Hij} = \frac{\psi_H p_{Hij}^{1-\sigma}}{\sum_{i=1}^{2} \psi_H p_{Hij}^{1-\sigma} + \psi_F p_{Fj}^{*1-\sigma}}, \qquad s^*_{Fj} = \frac{\psi_F p_{Fj}^{*1-\sigma}}{\sum_{i=1}^{2} \psi_H p_{Hij}^{1-\sigma} + \psi_F p_{Fj}^{*1-\sigma}} \tag{25}$$

And the demand y_{cij}, y^*_{cij} is as follows.

$$y_{Hij} = \frac{p_{Hij}^{-\sigma}}{\sum_{i=1}^{2} p_{Hij}^{1-\sigma} + p_{Fj}^{*1-\sigma}}, \qquad y^*_{Fij} = \frac{p_{Fj}^{*-\sigma}}{\sum_{i=1}^{2} p_{Hij}^{1-\sigma} + p_{Fj}^{*1-\sigma}} \tag{26}$$

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

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

The profit functions from country c are the following.

$$\pi_{Hij} = \frac{s_{Hij}(1 - \frac{\sigma-1}{\sigma})}{1 - \frac{\sigma-1}{\sigma} s_{Hij}}, \qquad \pi^*_{Fj} = \frac{s^*_{Fj}(1 - \frac{\sigma-1}{\sigma})}{1 - \frac{\sigma-1}{\sigma} s^*_{Fj}} \tag{28}$$

The equilibrium in the foreign market is defined symmetrically. The firm makes a profit from two sources: the domestic market and the foreign market. Finally, the total profit of the firm in country c, position i, and product line j is the following.

$$\Pi_{cij} = \pi_{cij} P_c Y_c + \pi^*_{cij} P_{-c} Y_{-c} \tag{29}$$

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, the 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 the value function as a function of the productivity gap vector $\mathbf{m} := \{m_F, m_D\}$. For 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 the gap from the home leader, and m_D is the gap between the home leader and follower. For example, if the productivity of the home leader is λ^3, that of the home follower is λ^2, and that of the foreign firm is λ^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 a state variable.

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

$$
\begin{aligned}
& r_{Ht}V_{Ht}(\mathbf{m}) - \dot{V}_{Ht}(\mathbf{m}) \\
&= \max_{x_{H1\mathbf{m}t}, a_{H1\mathbf{m}t}} \underbrace{\Pi_{Ht}(\mathbf{m})}_{\text{profit}} - (1 - s_{Hrt}) \underbrace{\alpha_{Hr}\frac{(x_{H1\mathbf{m}t})^{\gamma}}{\gamma} w_{Ht}}_{\text{innovation cost}} - \underbrace{(1 - s_{Hat})\alpha_{Ha}\frac{(a_{H1\mathbf{m}t})^{\gamma}}{\gamma} w_{Ht}}_{\text{Adoption cost}} \\
&+ x_{H1\mathbf{m}t} \sum_n f_{m_F}(n) \underbrace{[V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m})]}_{\text{Gain from innovation}} \\
&+ a_{H1\mathbf{m}t} \sum_n g_{m_F}(n)[(\underbrace{V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m})}_{\text{Gain from adoption}} - \underbrace{(1 - s_{Hat})\mathcal{F}_{H1\mathbf{m}t}}_{\text{adoption fee}})] \\
&+ x_{H2\mathbf{m}t} \sum_n \tilde{f}_{m_F - m_D}(n) \underbrace{[V_{Ht}(m_F, m_D - n) - V_{Ht}(\mathbf{m})]}_{\text{loss from follower innovation}} \\
&+ a_{H2\mathbf{m}t} \sum_n \tilde{g}_{m_F - m_D}(n) \underbrace{[V_{Ht}(m_F, m_D - n) - V_{Ht}(\mathbf{m})]}_{\text{loss from follower adoption}} \\
&+ (x_{F\mathbf{m}t} + \tilde{x}_{F\mathbf{m}t}) \sum_n f_{-m_F}(n) \underbrace{[V_{Ht}(m_F - n, m_D) - V_{Ht}(\mathbf{m})]}_{\text{loss from foreign firm innovation}} \\
&+ a_{F\mathbf{m}t} \sum_n g_{-m_F}(n) \underbrace{[V_{Ht}(m_F - n, m_D) - V_{Ht}(\mathbf{m})}_{\text{loss from foreign leader adoption}} + \underbrace{\mathcal{F}_{F\mathbf{m}t}}_{\text{adoption fee}}\ ] \\
&+ \underbrace{\phi(V_{Ht}(\mathbf{0}) - V_{Ht}(\mathbf{m}))}_{\text{Exogenous spillover}}]
\end{aligned}
\tag{30}
$$

The first line of the 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 value change from the home follower's innovation and adoption. The following two lines denote the foreign firms' (incumbent and entrant) innovation and adoption. Note that the adoption can only happen for 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 the foreign firm is always zero. The last line has the exogenous spillover, which is governed by the parameter ϕ. Value function of home follower, foreign firm, foreign entrant are defined symmetrically, in equation (42), (43), (44) in Appendix A.1.

Adoption Fee

The adoption fee is a one-time payment that summarizes all the adopter's future profit gain and the seller's loss. The bargaining is only between the adopter and the seller, and we assume they cannot make the contract contingent on future behavior. For example, we do not allow the foreign firm to prohibit the adopter's exporting to the foreign country.[23] Also, we do not allow the foreign firm to promise not to sell the technology to another domestic firm. This assumption can be micro-founded if we assume that the foreign firm cannot commit its future behavior. Lastly, we do not allow one foreign firm to bargain with two domestic firms simultaneously. 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.

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

$0 \leq \xi \leq 1$ 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.

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

Adoption fee of home follower and foreign firm are defined in a similar way in equation (45), (46) in Appendix A.2. The adoption fee is higher if the leader loses more or the follower gains more from the adoption. It depends on 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 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 the profit function over the technology gap from the foreign

[23] This is 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 the 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.

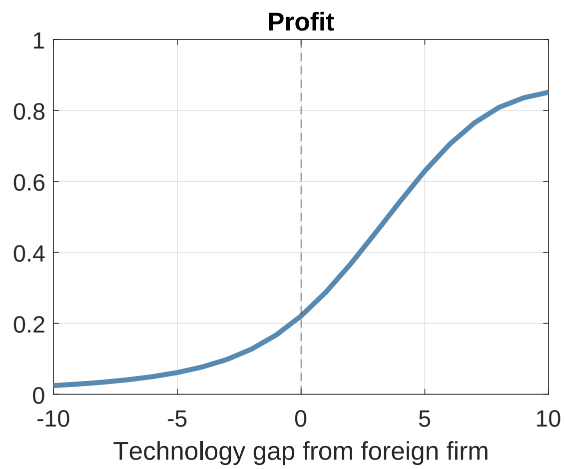


Figure 3: Profit function over technology gap

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 room for technology trade. First, when the wage in the follower's country is lower, the foreign firm's technology can be used more efficiently in the home country and makes a positive total surplus. Second, when the trade cost is high, the two markets are more segregated, and it is more effective to produce in the home country and sell to the household in the home country. Thus, selling technology can increase the total revenue, which increases the entire surplus from the adoption contract. It creates an interaction between trade policy and adoption. Since the adoption fee decreases and the adoption rate rises with the import tariff, the government may want to increase the import tariff when it wants to increase the adoption rate. Lastly, when the foreign firm sells technology, the 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 from selling to another country, which we will discuss in more detail in Section 6.

Optimal Innovation and Adoption rate

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

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

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

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

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 the 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 $\mathbf{m}$.

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

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.

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

The first two lines are the added mass from the home leader's innovation and adoption. The third and fourth lines are from the home follower's innovation and adoption, where the follower did not leapfrog the leader. The fifth and sixth lines are also from home followers, but they leapfrog the leader in this case. The next two lines are from foreign incumbents and entrants with the same structure as domestic firms. The next line indicates the added mass from the exogenous spillover, which is added to $\mathbf{m} = (m_F, m_D) = (0, 0)$. The 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_{cmt} be 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 $\{r_{ct}, w_{ct}, p_{cijt}, p^*_{cijt}, y_{cijt}, y^*_{cijt}, l_{cijt}, x_{cijt}, a_{cijt}, \mu_{\mathbf{m}t}, Q_{\mathbf{m}t}, C_{ct}, A_{ct}, T_{ct}\}^{t\in[0,\infty), j\in[0,1], c\in\{H,F\}}_{i\in\{1,2\}, m\in\{-\bar{m},\cdots,\bar{m}\}}$

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 make the competitive equilibrium not efficient. First, all firms have positive markup that makes firms produce less than socially optimal. Second, innovation and adoption have 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 the 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 more severe than the innovation. Lastly, innovation and adoption have a business stealing effect. The innovation and adoption incentive includes improving productivity and stealing the market share of other firms. However, social planner only cares about aggregate productivity and output. If the step size from innovation or adoption is small, firms might improve technology only marginally while spending substantial resources on innovation or adoption. It 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).[24] These have the universe of technology import

[24] We extend the data used in Choi and Shim (2022) which is until 1982 to 1993 and add adoption fee information. We also obtained some contracts in 1994-1995 but did not capture the entire technology import 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.[25] As a result, we collected 8,512 contracts from 2,902 unique firms.[26] 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, etc. We consider the first two as know-how transfers and the third and fourth as licensing. Know-how transfer includes sharing blueprints, design specifications, 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 a fixed fee and royalty rate. Table 1 shows the example of collected data. In terms of the country's origin, Japan accounts for 50%, the US accounts for 26.3%, and Germany, France, and the UK account for 13.1% in sum. Table B.2 shows the distribution of countries in adoption contracts. Regarding the adoption fee, 61.38% of contracts have royalty payments, 76.56% have fixed fees, and 37.97% have both. The average royalty rate is 3.26%, the average fixed fee is 7.84 million dollars which account for 9.31% of yearly sale on average, and the length of the contract is 5.13 year. Figure 4 shows both the number and the average price of adoption contracts increased over time.

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

[26] 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.

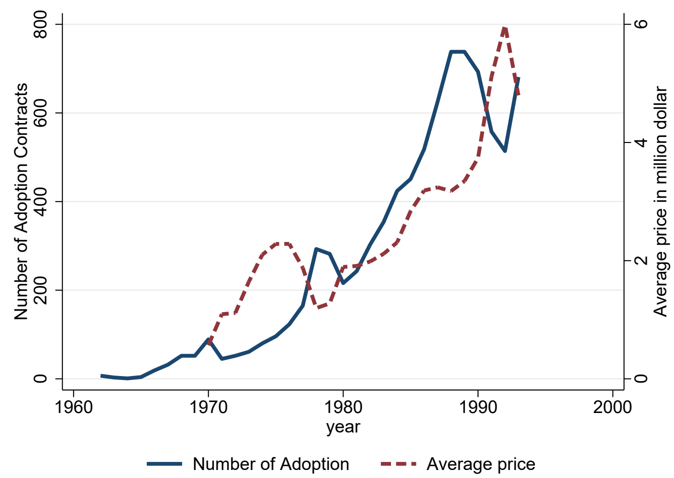


Figure 4: The number of adoption contracts and Average price over time

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 data sources to construct firm-level balance sheet data for Korean firms. First, we digitize firm-level data from the Annual Reports of Korean Companies by the Korea Productivity Center. It is firm survey data that covers more than 50 employees.[27] 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).[28] By using business ID and firm name, we merge these two data.[29] Then, we merge this balance sheet data with the technology adoption data by using firm names. On average, 6.26% of firms adopt technology 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 started in 1950, with Compustat global, which started in 1988. For variables, we use firm sales, employment, and sector. Then we merge it with technology adoption data using the firm name and country.

[27]It accounts for 70% of the value-added share in manufacturing.

[28]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.

[29]We also use the history of firm names in case the firm had changed its name mainly from 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 in 1945 and captures a universe patent registered in Korea by domestic and foreign firms. We merge this data with firm-level data 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 started in 1975 and covered 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. The 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 the 1990s. When we study the citation pattern of Korean firms, we use USPTO instead of Korean Patent data since USPTO has citations for all periods. We use a crosswalk between the 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 employee are in million dollar.

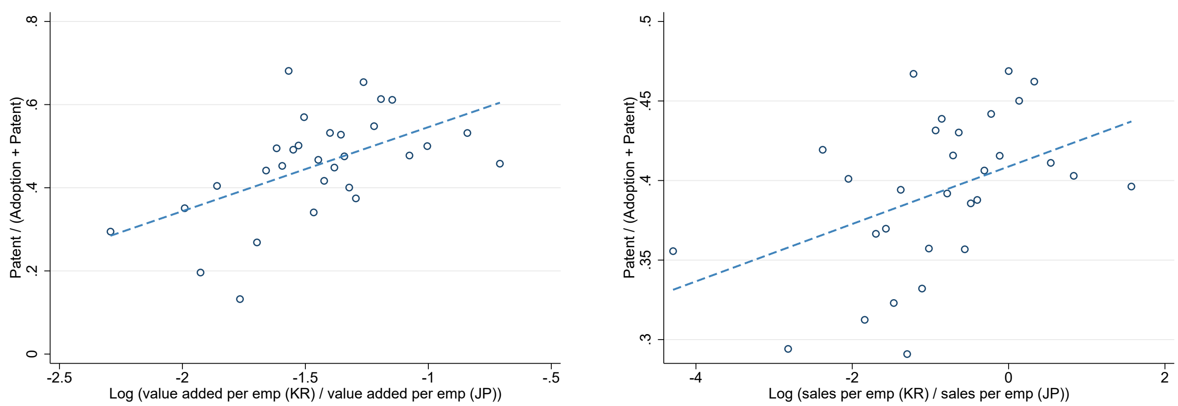
Table 2 shows the summary statistics between adopting and non-adopting firms in 1971-1993. We define adopting firms when they have at least one adoption contract in a given year. 6.21% of total firms adopt the technology. They have bigger size in terms of employment and total assets. Also, they, on average,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

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. It is consistent with our assumption that we 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 Innovation and Adoption over Productivity Gap



A. Sector level B. Firm level

Figure 5: Patent / (patent + adoption) over Productivity Gap

Notes: We plot the number of patents divided by the sum of the number of patents and the number of adoption contracts over the productivity gap. Panel A is at the sector-year level, and the productivity gap is the log value added per employment of Korea divided by that of Japan in each sector and year. We control year-fixed effects. Sector-level data is from STAN OECD data. Panel B is at the firm-year level, and the productivity gap is log sales per employee of a Korean firm divided by that of the foreign firm that sells technology. If the firm does not have an adoption contract, we use the maximum sales per employee of foreign firms in the sector. We control sector and year-fixed effects.

Figure 5 plots the innovation share over the productivity gap, both at the sector and firm levels. We measure innovation as the number of patents and adoption as the number of adoption contracts. Innovation share is the number of patents divided by the sum of the number of patents and adoption contracts at the sector or firm level. At the sector level, we use the log ratio of value added per employee in Korea and Japan. At the firm level, we use the log ratio of sales per employee of adopting firms and the technology seller. If the firm does not adopt, we use the maximum sales per employee of the foreign firm in sector and year.

We can find a positive association between the innovation share and the gap at the sector and firm levels. It implies when Korean firms are close to foreign firms in terms of productivity, they are more likely to innovate instead of adopting foreign technology. This result shows that the firms rely more on innovation at the cross-section, which complements the time-series evidence in the figure 1 in which Korea has been increasing innovation expenditure share as it catches up with foreign countries.

4.2 Productivity Gap and Adoption Fee

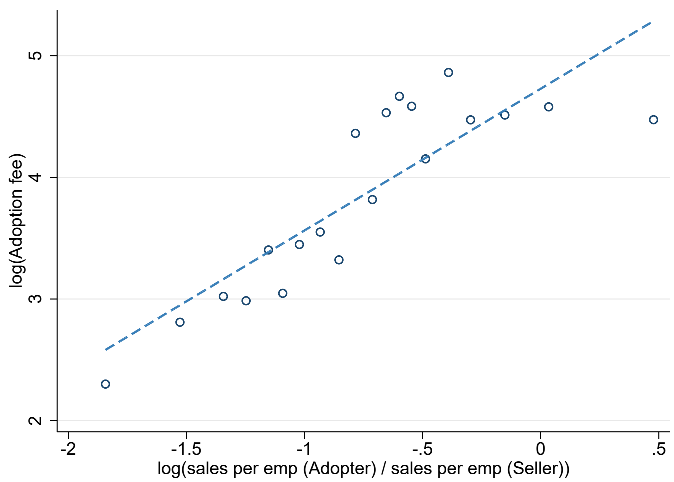


Figure 6: Price of adoption contract and the productivity gap between Korean firm (buyer) and foreign firm (seller)

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

One potential reason for the transition from adoption to innovation is the adoption fee getting higher as firms close the gap from the foreign firm. We study the relationship between the productivity gap and the price of the adoption contract. Figure 6 plots the relative productivity of Korean firms and the adoption fee. The adoption fee is estimated by the sum of the fixed fee and royalty rate times the total sale.[30] The relative productivity

[30]Royalty payment is usually a share of revenue using the adopted technology. Since we do not have disaggregated sales data, we use the firm-level total sales as the revenue. Also, the contract often specifies that it is a 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.

is measured by logged sales per employee of the Korean firm (buyer) divided by that of the foreign firm (technology seller) at the time of the adoption contract. We use global Compustat data to get sales per employee of the foreign firm.[31]

The positive correlation suggests when the Korean firm is closer to the foreign firm, the seller is compensated more by the 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 to the productivity gap when the gap is close to zero. And the adoption fee reacts more to the technology gap when the competition between two firms is stronger. We also run the regression with only fixed fees and royalty rates as robustness checks. Table 3 shows that both fixed fees and royalty rates have a positive correlation with the productivity gap.

We use detailed information from patent data to see whether the degree of competition matters for the correlation. If two firms are in the same technology field (IPC 3 digit level) in patent data, we consider the two firms are in the intense competition since they compete in the same product market. To be specific, we list the ten most frequent patent classes. Then, we make a dummy variable whether more than half of the 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 stronger when the two firms are in the same technology field. Table 3 shows that the interaction term between the 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 the competition effect is important in deciding on adoption fees.

4.3 Productivity Growth over the Initial Productivity Gap

Another reason for the transition from adoption to innovation is the productivity growth from adoption becomes smaller as firms close the gap from the foreign firm. 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.

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

[31] For samples that do not have information on foreign firms, we use maximum sales per employee within sector-year.

Table 3: Regression of adoption price with technology gap

	Fixed fee	Royalty	Total Fee	Total Fee
Gap	0.117**	0.124***	0.627***	0.561***
	(0.0503)	(0.0465)	(0.0545)	(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: The fixed fee and Total fee are logged. The total fee is the sum of the fixed fee and royalty rate times sales times contract years. The gap is the log ratio of sales per employee 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.

$\log(\frac{\text{Sales/emp}_{i,t+5}}{\text{Sales/emp}_{i,t}})$ is the growth rate of labor productivity after innovation or adoption. gap_{it} is log(Sales per emp of Korean firm/Sales per emp of Foreign firm) in the year of the adoption or innovation, which is same as in the figure 5. In the case of innovation, we use the maximum sales per employee of the foreign firm in sector and year. $X_{i,t}$ includes control variables such as capital intensity growth which is defined as the growth rate of fixed assets per employment 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 4 shows the result of the regression. The first column runs the regression with productivity growth after adoption, the second column with the one after innovation, and the third column pulls both innovation and adoption with an interaction term. The coefficient is negative for both adoption and innovation, which implies the advantage of backwardness (Gerschenkron, 1962). It rationalizes the negative correlation between the expected gain and the relative productivity in the model.

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

Table 4: Sales per Employee Growth over the Initial Productivity Gap

	Adoption	Innovation	Both
Productivity gap (t)	-0.120***	-0.0457***	-0.0562***
	(0.0208)	(0.0144)	(0.0133)
gap x adoption			**-0.0576*****
			(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). The productivity gap is the log ratio of sales per employee 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(sales / emp) of foreign technology sellers in the same sector. The first column includes only adopting firms. The second column uses only innovating firms that applied for at least one patent in a year. We exclude firms that have both adoption and innovation. The third column includes all the firms. In all regression, we control the growth rate of fixed asset / employment for 5 years. Standard errors are clustered at the Korean firm level.

regression.

4.4 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 matched two foreign firms, one of which sold technology (treated) while the other did not (control). We use minimum distance matching[32] in terms of logged patent stock while exactly matching on the country, year, and

[32] We use kmatch function in STATA.

the main patent field (IPC 3 digit).[33] Table 5 shows the descriptive statistics of two groups and p-values. The event year is when the firm sells technology to a 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 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	4.46	0.22
	(2.24)	(2.33)	
log (cumulative citations)	1.77	1.80	0.39
	(0.49)	(0.46)	
N	374	374	

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

$$Y_{it} = \sum_{k=-5}^{10} \beta_{\mathrm{k}}^{\mathrm{Seller}} \mathbf{1}_{\left\{L_{it}^{\mathrm{Seller}}=k\right\}} + \sum_{k=-5}^{10} \beta_k^{All} \mathbf{1}_{\left\{L_{it}^{\mathrm{All}}=k\right\}} + \alpha_i + \gamma_t + \epsilon_{it} \tag{39}$$

Y_{it} is a 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}^{All} is the number of years from the first (placebo) adoption and L_{it}^{Seller} is the same variable but applies only to the technology seller (treated). α_i is the foreign firm fixed effects, γ_t is year fixed effects, and ϵ_{it} is the error term. Therefore, β_k^{All} captures common trend around the event year, and $\beta_k^{\mathrm{Seller}}$ captures the difference between treated and control firms. We cluster standard error at the technology field level (3-digit IPC) and year.

Figure 7 plots β_k^{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 the two groups. This result would identify the model's knowledge diffusion parameter δ. Details of model counterpart is in Section 5.1.2.

[33] We use the most frequent three digit IPC class in each foreign firm.

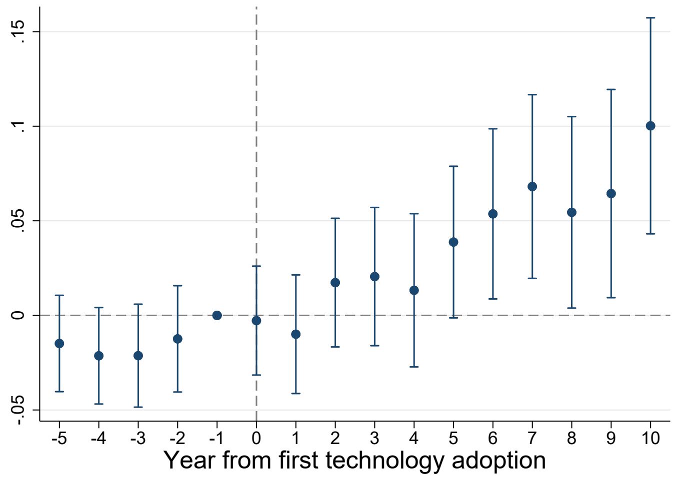


Figure 7: Event study result of patent citations

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

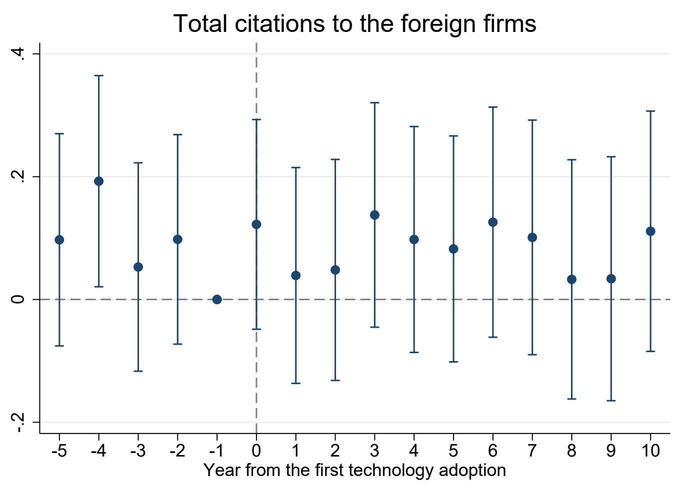


Figure 8: Event study result of patent citations (placebo)

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

A potential identification threat is an unobserved shock to the foreign firm that increases adoption probability and the number of citations received. For example, Sony's technology turned out to be superior, Korean firms became more likely to adopt from Sony, and also citations to Sony increased after the adoption year. As a placebo test, we ran the same regression with the number of citations received from all the other countries except Korea. Figure 8 shows 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 margins.

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

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

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

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 β^{seller} in equation 40, which is the difference in the 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 before and post five 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 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 the foreign firm, follows $N(d, 1)$, and m_D, the gap from the home follower, follows a 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 parameters to minimize the distance between the moments from the model and data from 1970 to 1990.

5.1.1 External Calibration

We use discount rate $\rho = 0.02$, a common value in the literature. R&D and adoption cost curvature parameter γ 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 the foreign firm and is set to be 25 for a computational reason.[34] $\bar{m}_D$ is set to be 5.

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

[34] We increase $\bar{m}$ until the point in which it does not affect key results.

[35] 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.

[36] We collected the adoption tax credit law over time from https://glaw.scourt.go.kr

Likewise, the government also subsidized innovation by giving R&D tax credits. It started in 1981 with a tax credit rate of 10%. In 1990, it increased the tax credit rate to 15%, and in 2009, it 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).[37]

We include s_{Hat}, s_{Hrt} into the model while assuming the perfect foresight of the agents. In other words, firms know the plan of policy change in advance. For country F, $s_{Fat} = 0, s_{Frt} = 0$.[38]

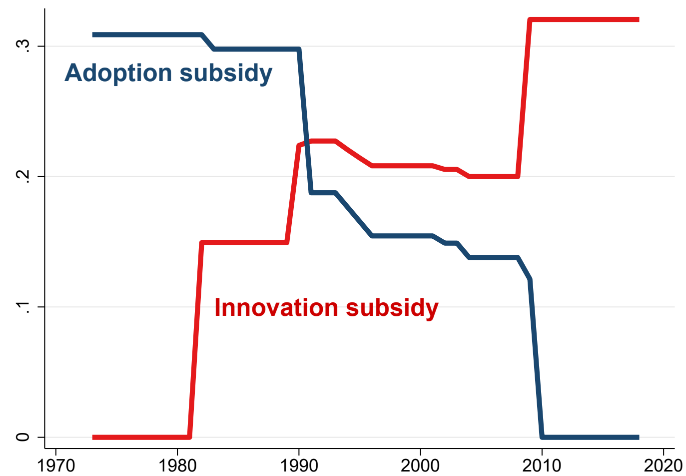


Figure 9: Innovation and adoption subsidy rate in Korea

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. Specifically, we start the economy in 1970 with the initial technology distribution in which firms in the home country have lower productivity and solve the transition until it converges to a balanced growth path. We compare the moments in the first 20 years between the model and the data. 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 the two countries, we adjust the cost parameter of innovation and adoption to get the average

[37] We use the tax credit rate for 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 an innovation subsidy rate.

[38] Since we calibrate α_{Fa}, α_{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.

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 Θ to minimize the distance between empirical moments M_i^D and moments from model $M_i(\Theta)$ as follows.

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

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

Adoption fee / yearly sale

The adoption fee over the yearly sale from the adoption contract is 22.4% on average.[39] Likewise, we calculate the adoption fee over annualized sales in the model and compare two moments. The critical parameter is ξ which governs the bargaining power of the adopter.

β^a, β^r (productivity growth with the initial productivity gap from adoption and innovation) In table 4, we regress the sales per employee growth from adoption and innovation over the initial productivity gap. The coefficient for adoption is -0.12 and for innovation is -0.046. These coefficients inform 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. We calculate the sales per employee growth from adoption and innovation for each simulated firm. Then, we regress it with the initial sales per employee gap from the foreign firm. Then, we compare the regression coefficient in the model and the data in table 4. The key parameters are η_x, η_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 7, we develop a simple model of patent citation. In the model, the home follower can receive knowledge diffusion from adopted technology. We assume they need to cite the foreign firm's patent when they innovate by building on the diffused knowledge. Then the increased citation from a domestic follower (non-adopters) to the foreign firm is $x \cdot \delta$, where x is the innovation rate, and δ is the probability of getting knowledge diffusion. Therefore, we match $x \cdot \delta = 0.0284$. The key parameter is δ.

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 λ, which is the unit productivity growth from innovation and adoption.

[39] If the firm pays the fee over multiple years, we sum all the payments.

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%.[40] These inform the scale parameter of innovation cost, α_r, and the scale parameter of adoption cost α_a. From equation (33), we can calculate the innovation expenditure function, which decreases with α_r. Likewise, α_a decreases adoption rate and adoption expenditure which is adoption rate times adoption fee.

GDP gap in 1970 and 2020 The initial log ratio of GDP per capita[41] between Korea and Japan was 1.64 in 1970. It 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 became 0.019 in 2020. It informs ϕ, which is the exogenous spillover parameter. When we have higher ϕ, convergence is faster, and the GDP gap after 50 years is smaller.

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

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. λ is 1.049, which means one step improvement increases 4.9% of labor productivity. $\eta_x > \eta_a$ implies the slope of the step size distribution of adoption is larger than that of the innovation. This is because, from the regression (38), sales per employee is more sensitive to the initial productivity gap for adoption than innovation. On the other hand, $\alpha_a > \alpha_r$ 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 lower than the innovation in the model. ξ, the bargaining power parameter is 0.367, which implies that the adopter takes roughly one-third of the total surplus from the adoption. δ, the probability of getting knowledge diffusion is 0.256, which is much lower than one. d, the initial productivity gap is -24.01, meaning the productivity of foreign firms is 2.6 times larger than that of Korean firms. α_F is 5.891, which implies F

[40] 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), and value-added in manufacturing is from the Input-Output table provided by the Bank of Korea.

[41] GDP per capita is price level adjusted measure.

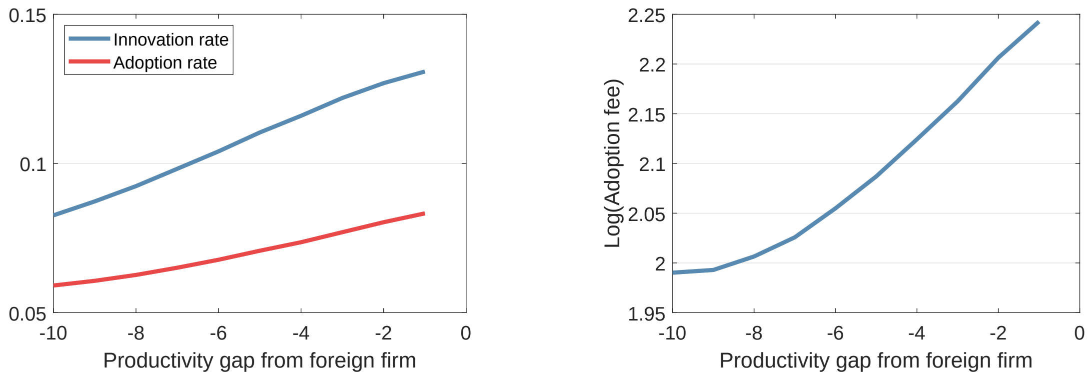
Table 7: Estimation result

Parameter	Description	Value	Source
Externally Calibrated			
ρ	Time preference	0.02	Long-run interest rate
σ	Elasticity of Substitution	8	Anderson and Van Wincoop (2004)
ψ_H	Demand Shifter of Home good	0.25	Equal share
ψ_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)
γ	Innovation / adoption cost curvature	2	Acemoglu et al. (2018)
Internally Calibrated			
λ	Unit step size	1.049	
η_a	Slope of step size from adoption	1.133	
η_r	Slope of step size from innovation	1.752	
α_a	Adoption cost	3.371	
α_r	Innovation cost	2.642	Jointly Estimated through SMM
ξ	Bargaining power of adopter	0.367	
δ	knowledge diffusion	0.256	
d	Initial productivity gap	-24.010	
α_F	Relative cost in F	5.891	
ϕ	Exogenous spillover	0.029	

Table 8: Moments

Moment	Model	Data
Adoption fee / annual sale	0.229	0.224
β^a : productivity growth with gap (adoption)	-0.119	-0.120
β^i : productivity growth with gap (innovation)	-0.045	-0.046
Δ 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

has a higher cost for innovation and adoption. It is because the entrant in F always has a higher incentive to innovate. ϕ is 0.029, so the firms are getting exogenous spillover with 2.9% every period.



A. Adoption, Innovation rate

B. Adoption fee

Figure 10: 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.

5.3 Quantitative Result

First, we document how the firm behaves according to the productivity gap. The left panel of figure 10 plots the adoption and innovation rate over the productivity gap.[42] 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 10 shows that the adoption fee increases as the relative productivity of the firm become higher. This is because both the gain for the adopter and the loss for the leader increase with the productivity gap.

Second, we document how the economy converges to the balanced growth path from the initial productivity distribution. Figure 11 plots the relative GDP per capita and adoption expenditure share, which is the same as the figure 1 in the Introduction. While Korea converges with Japan, the expenditure share of adoption also decreases in the model. This is because 1) the adoption fee increases as Korea catches up, 2) productivity growth from adoption become smaller compared with innovation[43] 3) the government gradually decreases the adoption subsidy rate and increases the innovation subsidy rate, as we can see in the figure 9.

While the policy partially generates the decreasing trend of adoption expenditure share,

[42]We take the average of the first 20 years on the transition.

[43]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.

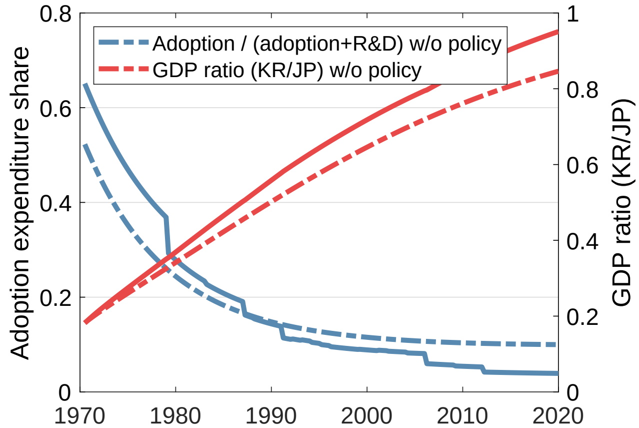


Figure 11: Relative GDP and adoption expenditure share with and without policy

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.

the model still produces a strong trend of decreasing adoption expenditure share without the policy change. Dashed lines in figure 11 show the transition without policy. We can see that the adoption expenditure share decreases over time even without the policy change, but it is flatter than the baseline case. Also, the convergence is slower than the baseline case.

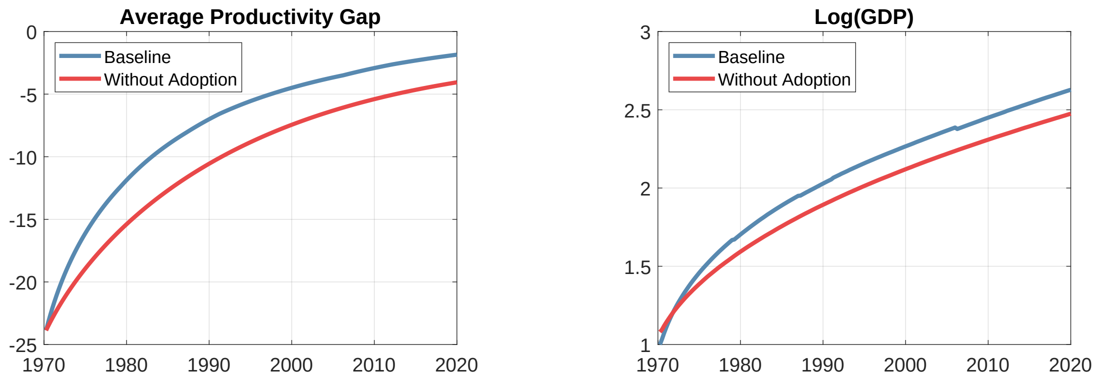
5.4 Untargeted moments

Untargeted Moments - innovation / adoption rate, adoption fee over gap will be added here

5.5 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 infinity. Second, we calculate the contribution of adoption and innovation to GDP growth in each period.

The left panel of figure 12 shows the average productivity gap over time in the baseline case and the case where we shut down the adoption. It shows that convergence is much slower without adoption. This is because adoption provides a better way to reduce the gap from the foreign firm, especially in the early period of development. The right panel of figure 12 compares log(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,



A. Average Productivity Gap B. Log(GDP)

Figure 12: Counterfactual without Adoption

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

the growth rate is much higher with adoption in the early period. GDP in 2020 is 17.45% higher in the baseline case. Welfare in 100 years is 13.81% higher in the baseline case, which is equivalent to having 14.22% higher consumption in every period.

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

Figure 13 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 innovation. Again, the policy change has contributed to this decreasing trend, but the model still has decreasing pattern even without any policy.

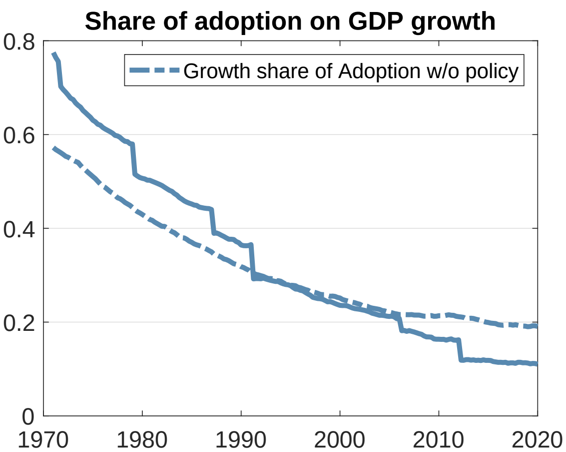


Figure 13: Contribution on GDP growth of adoption and innovation

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.

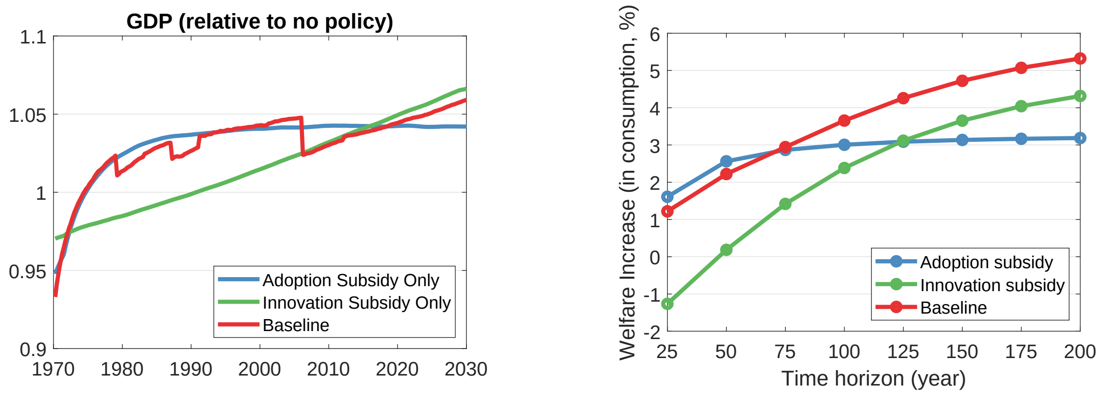
6 Policy Analysis

In this section, we first discuss the policy implication of the model. Then, we evaluate the technology policy implemented in Korea since 1970, which started as an adoption subsidy and switched to an innovation subsidy. Next, we study the optimal timing of the 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, the 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 in them. On the other hand, innovation and adoption have negative externalities by stealing the other firm's profit. 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 a larger positive externality 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



A. Relative GDP B. Welfare increase (%)

Figure 14: Results of the Counterfactual Analysis

Notes: This figure plots the counterfactual results. Panel A plots GDP in three scenarios divided by GDP without policy. The blue line is when subsidizing only adoption with 30.89%, the green line is when subsidizing only innovation with 32.05%, and the red line follows the actual policy in figure 9. Panel B plots welfare increase compared with the case without policy in different time horizons. Welfare is in consumption equivalent unit.

larger when the firm is far from the foreign firm and becomes smaller 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 the year from the data as in figure 9. We compare the baseline with three alternative scenarios. First, there is no subsidy at all. Second, the government subsidizes only adoption with 30.89%, the initial value in the baseline. Lastly, the government subsidizes only innovation with 32.05%, the final value in the baseline.[44]

The left panel of figure 14 shows the relative GDP compared with the case without any policy over time. When we subsidize adoption only, it brings a higher growth rate at

[44]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.1.

the early stage. It gets higher GDP compared to the case without policy. However, the relative GDP does not grow exponentially, implying that subsidizing only adoption does not generate a significantly higher long-run growth rate. On the other hand, when we subsidize only innovation, it does not have a higher growth rate at the beginning compared with the adoption subsidy case. But, it has a higher growth rate at the late stage of development. This is because subsidizing innovation in the early years can be distortive, allocating resources into innovation instead of adoption, although adoption has a larger positive externality. Lastly, the baseline case has a GDP similar to the adoption subsidy case and has a higher growth rate at the late stage of development.

The right panel of figure 14 shows the welfare implication of the policies over the different time horizons. Specifically, we calculate the discounted sum of utility of different time horizons. Then, we calculate the percentage increase from the benchmark without any policy in terms of consumption units. For example, a 3% increase means the welfare is equivalent to the case when we uniformly increase consumption by 3%. When the time horizon is short such as 25 or 50 years, subsidizing only adoption generates larger welfare than other alternatives. However, when we expand the time horizon, the welfare from subsidizing innovation becomes larger than subsidizing adoption only. In 100 year horizon, subsidizing only adoption is equivalent to a 3.01% increase in consumption, subsidizing only innovation is 2.38%, and the baseline case with policy change is 3.65%. This result implies that the state-dependent policy performs better than the time-invariant policies.

6.3 Optimal Timing to Switch

Motivated by the actual 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 an adoption subsidy rate of 30%, and it can switch to an innovation subsidy of 30% in a single year. In the long-run, it keeps the innovation subsidy rate at 30%.

Figure 15 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 1986 when GDP per capita in Korea was 48% of that of Japan. In the early stages of development, the 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.

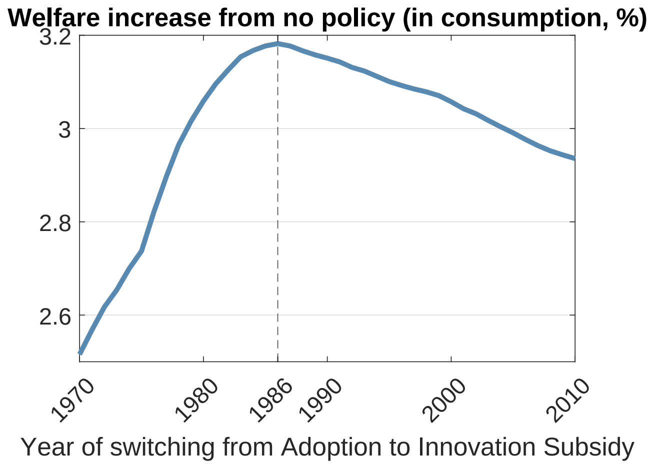


Figure 15: Welfare Increase over Different Year to Switch from Adoption to Innovation

Notes: We plot welfare increase compared with the case without policy over different timings of switching. Welfare increase is in consumption equivalent unit. We start with adoption subsidy 30% and innovation subsidy 0% and switch to adoption subsidy 0% and innovation subsidy 30% in a certain year. In 1986, GDP per capita in Korea was 48% of that of Japan.

6.4 Optimal Policy

Optimal policy analysis will be added here

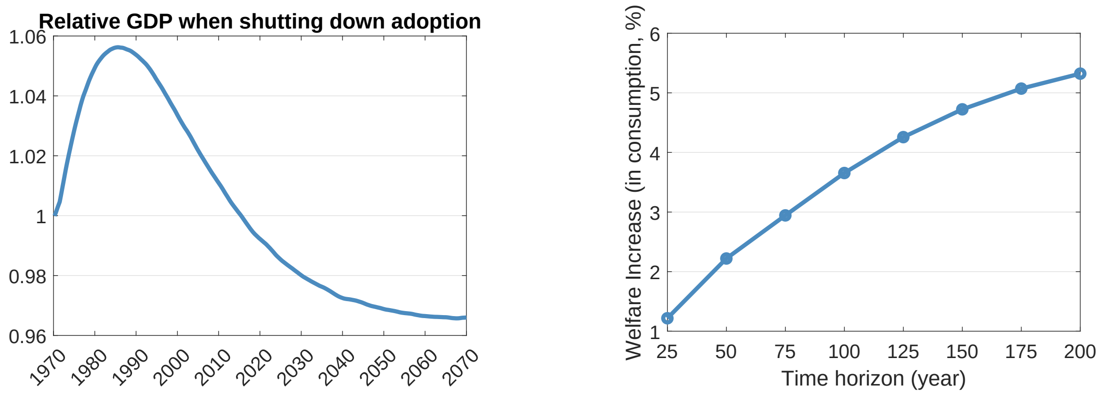
6.5 Japan's Policy to Prevent Exporting Technology

This subsection asks what happens when the Japanese government prevents firms from exporting technology. Japanese incumbents always earn benefits from selling technology; if not, they will not sell technology. However, firms might sell more technology than the socially optimal level of Japan because they do not internalize the future loss for the potential entrant. The potential entrant will get a smaller profit when the previous incumbent sells technology, and the Korean firm has relatively higher productivity. Therefore, there can be an incentive for the Japanese government to prevent exporting technology.[45]

As an example, we study the counterfactual where Japanese firms cannot export technology to Korean firms and compare the GDP of Japan with the benchmark case with adoption. Both cases do not have any policies.

The left panel of figure 16 shows that in the short-run, Japan has higher GDP when shutting down the adoption channel compared with the benchmark case with adoption. But

[45]This is in line with the current policies of the U.S. in which they try to prevent technology leakage to China.



A. Relative GDP

B. Welfare increase (%)

Figure 16: Results of the Counterfactual when Japan Shuts Down Adoption

Notes: This figure plots the counterfactual results when the Japanese government prevents firms from exporting technology and compares it with the benchmark case with adoption. Panel A plots the GDP of Japan when the government shuts down exporting adoption and divides it by the GDP of Japan in the case of adoption. Both cases have no policy. Panel B plots welfare increase compared with the case without a policy in different time horizons. Welfare is in consumption equivalent unit.

in the long run, it has lower GDP because the long-run growth rate is lower without adoption. The right panel of figure 16 shows that Japan has higher welfare if it closes technology export. In 100 year horizon, it has 3.65% higher welfare when it shuts down exporting technology compared with the benchmark case.

7 Conclusion

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

In this paper, we study how firms in developing countries grow over different stages of development. We focus on two ways to improve technology: adoption from foreign countries and innovation. Our contribution is providing a novel micro dataset, finding new empirical findings, and building a theoretical framework to study growth from innovation and adoption. In particular, we capture strategic interactions between adopters and technology sellers. 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 to growth was 77% in Korea in 1970, but it decreased to 10% in 2020. Korea started with an adoption subsidy and then gradually switched to an innovation subsidy. The state-dependent policy generates a 3.65% increase in welfare, which is higher than other alternatives, such as subsidizing only adoption (3.01%) or subsidizing only innovation (2.38%). 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 48% of the 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 for making general policy advice that can be helpful to many developing countries.

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A Appendix: Model

A.1 Value Function

Value function of home follower is as below.

$$
\begin{aligned}
&r_{Ht}V_{Ht}(\mathbf{m}) - \dot{V}_{Ht}(\mathbf{m}) \\
&= \max_{x_{H2\mathbf{m}t}, a_{H2\mathbf{m}t}} \underbrace{\Pi_{Ht}(\mathbf{m})}_{\text{profit}} - (1 - s_{Hrt}) \underbrace{\alpha_{Hr}\frac{(x_{H2\mathbf{m}t})^{\gamma}}{\gamma} w_{Ht}}_{\text{innovation cost}} - \underbrace{(1 - s_{Hat})\alpha_{Ha}\frac{(a_{H2\mathbf{m}t})^{\gamma}}{\gamma} w_{Ht}}_{\text{Adoption cost}} \\
&+ x_{H2\mathbf{m}t} \sum_{n} \tilde{f}_{m_F}(n) \underbrace{\left[V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m})\right]}_{\text{Gain from innovation}} \\
&+ a_{H2\mathbf{m}t} \sum_{n} \tilde{g}_{m_F}(n) [(\underbrace{V_{Ht}(m_F + n, m_D + n) - V_{Ht}(\mathbf{m})}_{\text{Gain from adoption}} - \underbrace{(1 - s_{Hat})\mathcal{F}_{H1\mathbf{m}t}}_{\text{adoption fee}})] \\
&+ x_{H1\mathbf{m}t} \sum_{n} f_{m_F - m_D}(n) \underbrace{\left[V_{Ht}(m_F, m_D - n) - V_{Ht}(\mathbf{m})\right]}_{\text{loss from follower innovation}} \\
&+ a_{H1\mathbf{m}t} \sum_{n} g_{m_F - m_D}(n) \underbrace{\left[V_{Ht}(m_F, m_D - n) - V_{Ht}(\mathbf{m})\right]}_{\text{loss from follower adoption}} \\
&+ (x_{F\mathbf{m}t} + \tilde{x}_{F\mathbf{m}t}) \sum_{n} f_{-m_F + m_D}(n) \underbrace{\left[V_{Ht}(m_F - n, m_D) - V_{Ht}(\mathbf{m})\right]}_{\text{loss from foreign firm innovation}} \\
&+ a_{F\mathbf{m}t} \sum_{n} g_{-m_F + m_D}(n) \underbrace{[V_{Ht}(m_F - n, m_D) - V_{Ht}(\mathbf{m})}_{\text{loss from foreign leader adoption}} + \underbrace{\mathcal{F}_{F\mathbf{m}t}}_{\text{adoption fee}}] \\
&+ \underbrace{\phi(V_{Ht}(\mathbf{0}) - V_{Ht}(\mathbf{m}))}_{\text{Exogenous spillover}}]
\end{aligned}
\tag{42}
$$

Value function of foreign firm is as below.

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

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

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

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.

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

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.

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

A.3 Optimal Policy Function

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

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

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

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

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

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

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 reasoable 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

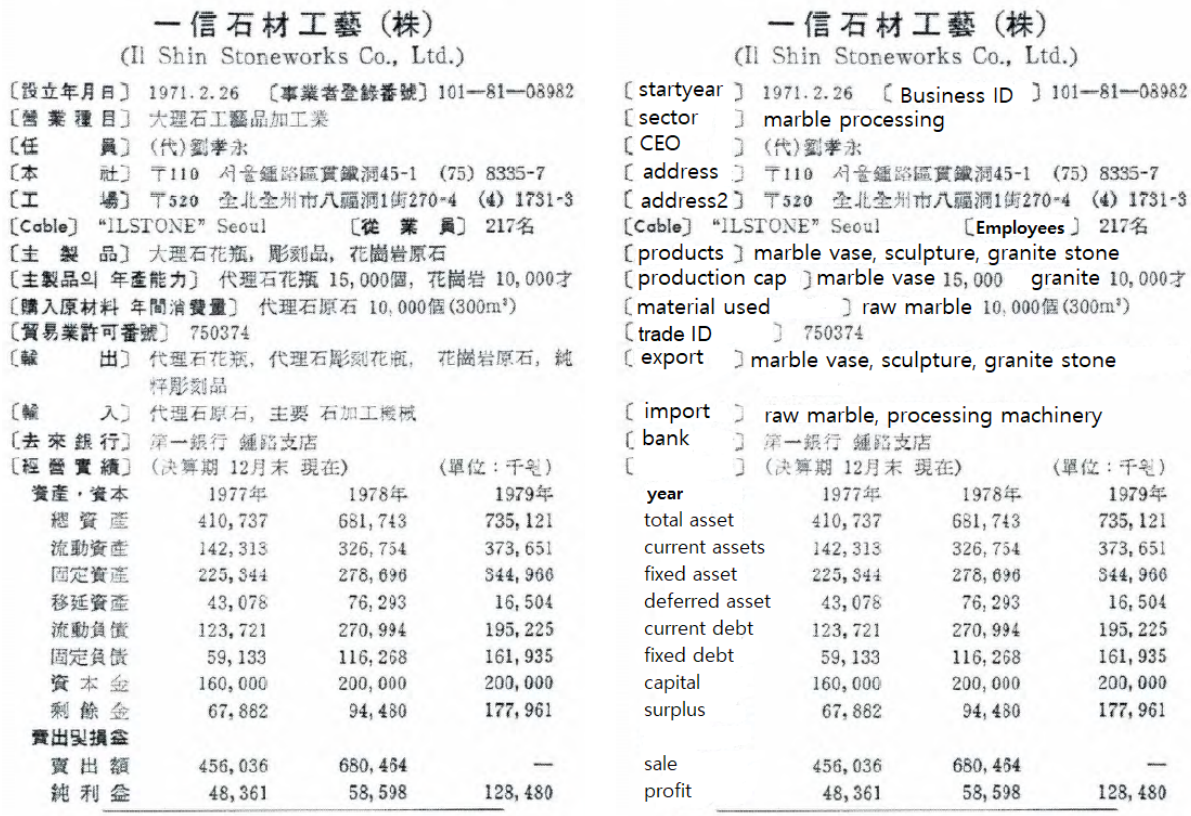
Section 7 Compensation

(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）
(Il Shin Stoneworks Co., Ltd.)

〔設立年月日〕 1971.2.26 〔事業者登錄番號〕 101—81—08982
〔營業種目〕 大理石工藝品加工業
〔任　　員〕 (代)劉孝永
〔本　　社〕 〒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
〔Cable〕 "ILSTONE" Seoul 〔從業員〕 217名
〔主製品〕 大理石花瓶，彫刻品，花崗岩原石
〔主製品의 年產能力〕 代理石花瓶 15,000個，花崗岩 10,000才
〔購入原材料 年間消費量〕 代理石原石 10,000個(300m³)
〔貿易業許可番號〕 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
〔輸　　入〕 代理石原石，主要 石加工機械
〔去來銀行〕 第一銀行 鍾路支店
〔經營實績〕 (決算期 12月末 現在) (單位：千원)

資產・資本	1977年	1978年	1979年
總資產	410,737	681,743	735,121
流動資產	142,313	326,754	373,651
固定資產	225,344	278,696	344,966
移延資產	43,078	76,293	16,504
流動負債	123,721	270,994	195,225
固定負債	59,133	116,268	161,935
資本金	160,000	200,000	200,000
剩餘金	67,882	94,480	177,961
賣出與損益			
賣出額	456,036	680,464	—
純利益	48,361	58,598	128,480

一信石材工藝（株）
(Il Shin Stoneworks Co., Ltd.)

〔startyear〕 1971.2.26 〔Business ID〕 101—81—08982
〔sector〕 marble processing
〔CEO〕 (代)劉孝永
〔address〕 〒110 서울鍾路區貫鐵洞45-1 (75) 8335-7
〔address2〕 〒520 全北全州市八福洞1街270-4 (4) 1731-3
〔Cable〕 "ILSTONE" Seoul 〔Employees〕 217名
〔products〕 marble vase, sculpture, granite stone
〔production cap〕 marble vase 15,000 granite 10,000才
〔material used〕 raw marble 10,000個(300m³)
〔trade ID〕 750374
〔export〕 marble vase, sculpture, granite stone
〔import〕 raw marble, processing machinery
〔bank〕 第一銀行 鍾路支店
〔 〕 (決算期 12月末 現在) (單位：千원)

year	1977年	1978年	1979年
total asset	410,737	681,743	735,121
current assets	142,313	326,754	373,651
fixed asset	225,344	278,696	344,966
deferred asset	43,078	76,293	16,504
current debt	123,721	270,994	195,225
fixed debt	59,133	116,268	161,935
capital	160,000	200,000	200,000
surplus	67,882	94,480	177,961
sale	456,036	680,464	—
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.[46] 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

[46]The data can be downloaded from Economic Statistics of the Bank of Korea, https://ecos.bok.or.kr/EIndex_en.jsp.

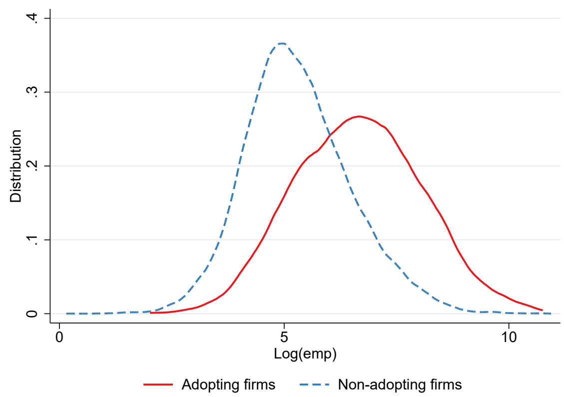
Annual Reports of Korean Companies has information including sales, total assets, fixed assets, employment, profit, export, start year. Employment data starts from 1972. Export variable is only available to small subset of firms. KIS-VALUE data includes all the variables from Annual Reports and also 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

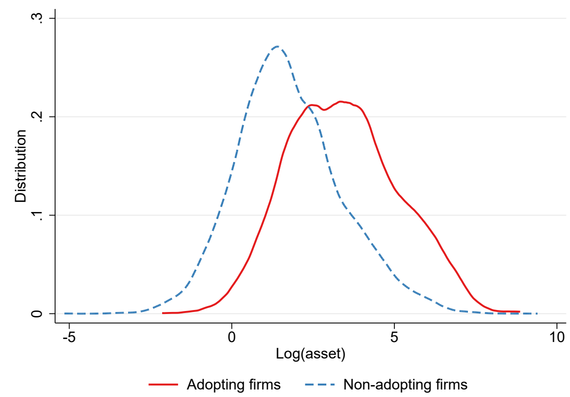
We use company name to match firms in the adoption data with the USPTO data. First, we run fuzzy matching by using Python function "fuzzymatcher". We remove words such as "co", "ltd", "inc" before running the code. We impose minimum similarity score as 0.35. For the remaining one, we manually match firms 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.

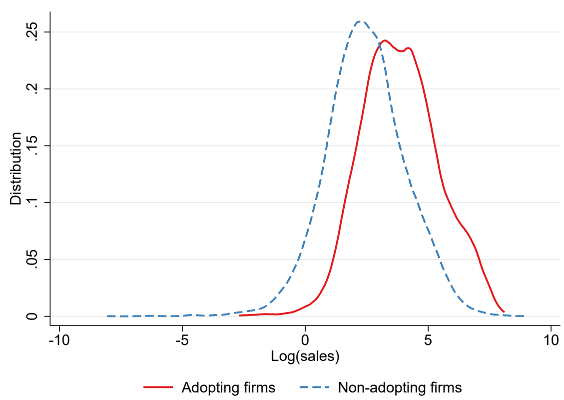
C Empirical Analysis: Robustness Checks and Additional Graphs



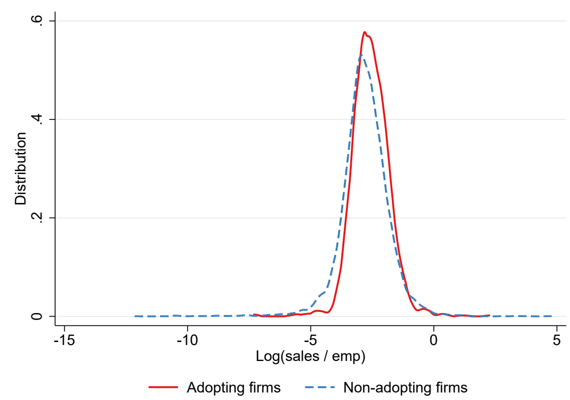
A. Employment



B. Total Asset



C. Sales



D. Sales per Employee

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

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

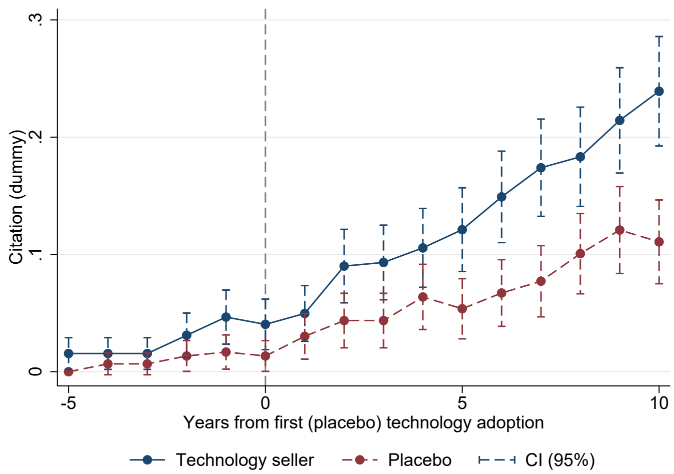


Figure C.2: Raw average of patent citations between two groups

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.

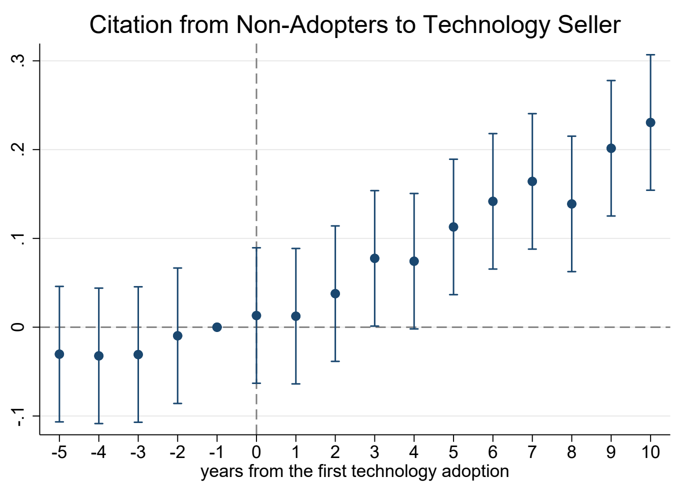


Figure C.3: Event study result of patent citations: intensive margin

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	-0.0304
	(0.0130)	(0.0172)
4 years before event	-0.0213	-0.0323
	(0.0130)	(0.0166)
3 years before event	-0.0213	-0.0308
	(0.0139)	(0.0172)
2 years before event	-0.0124	-0.00963
	(0.0143)	(0.0201)
1 year before event	0	0
	(.)	(.)
event year	-0.00275	0.0132
	(0.0147)	(0.0188)
1 years after event	-0.00995	0.0124
	(0.0160)	(0.0213)
2 years after event	0.0173	0.0378
	(0.0173)	(0.0238)
3 years after event	0.0205	0.0775^{**}
	(0.0186)	(0.0287)
4 years after event	0.0133	0.0743^{*}
	(0.0206)	(0.0339)
5 years after event	0.0388	0.114^{**}
	(0.0204)	(0.0379)
6 years after event	0.0537^{*}	0.143^{***}
	(0.0229)	(0.0397)
7 years after event	0.0681^{**}	0.166^{***}
	(0.0247)	(0.0445)
8 years after event	0.0545^{*}	0.140^{**}
	(0.0258)	(0.0475)
9 years after event	0.0644^{*}	0.204^{***}
	(0.0280)	(0.0538)
10 years after event	0.100^{***}	0.233^{***}
	(0.0291)	(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 $x_{c\mathbf{m}t}$, adoption rate $a_{c\mathbf{m}t}$, and the relative price P_{Ft}[47] 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

[47] 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.[48]

7. Update the guess as below until $\|\mathbb{X}_t^0 - \mathbb{X}_t^1\| < \epsilon$

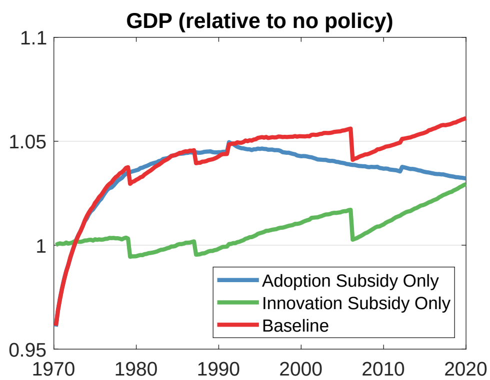
$$\mathbb{X}_t^{i+1} = (1 - \Delta)\mathbb{X}_t^i + \Delta\tilde{\mathbb{X}}_t^{i+1} \tag{52}$$

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

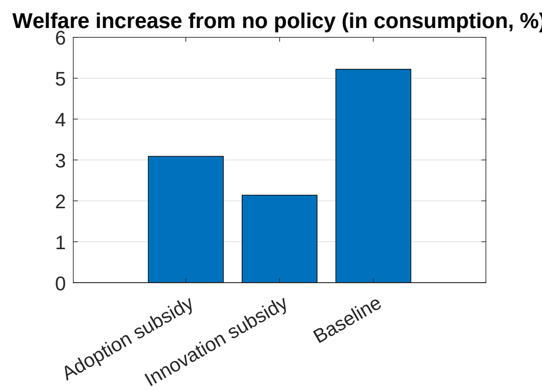
E Additional Figures in Quantitative Exercise

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.

[48] We use Euclidean norm.



A. Relative GDP



B. Welfare increase (%)

Figure E.1: 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 9. Panel B plots welfare increase compared with the case without policy. Welfare is in consumption equivalent unit.