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

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Abstract

Should governments in developing countries support technology adoption or promote innovation? To answer this question, we digitize the universe of technology transfer contracts between Korean and foreign firms with the price of technologies. We find that when the productivity gap between domestic and foreign firms is smaller, (i) the adoption fee is higher, (ii) the productivity growth from adoption is smaller, (iii) firms are more likely to invest in innovation than adoption. Motivated by these findings, we build a two-country growth model with endogenous adoption and innovation decisions. Foreign firms can sell technologies for an endogenous fee, internalizing the future loss of profit due to stronger competition with domestic firms. The productivity gains from adoption and innovation depend on the productivity gap with foreign firms, which makes the effects of adoption and innovation subsidies also vary with the gap. We estimate the model and quantitatively investigate the effect of several policies along the transitional dynamics. We evaluate Korea's technology policies since 1973, which started with an adoption subsidy and shifted its weight to an innovation subsidy as the productivity of Korean firms converged with that of international competitors. Our result suggests that the state-dependent policy increased consumption-equivalent welfare by 4.84%, which is higher than subsidizing only innovation or adoption. Furthermore, it was optimal to switch from an adoption subsidy to an innovation subsidy in 1985 when Korea's GDP reached 54% of Japan's.

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1 Introduction

The Samsung Group, which was founded in South Korea in 1938 as a small company that produced noodles, entered the electronics industry in 1969. Back then, it did not have the technology necessary to produce electronic products. To tackle this problem, Samsung aggressively adopted technologies by signing technology transfer contracts with Japanese companies.[1] Using these adopted technologies, it started to produce electronic products and expand its market share. As Samsung developed into a strong competitor, Japanese firms became more reluctant to share their technologies and charged higher adoption fees. At that point, Samsung switched its strategy from adopting foreign technologies to inventing its own technologies. This transition from adoption to innovation is a sharp feature in the data. As the GDP per capita of Korea converged with that of Japan, the aggregate adoption expenditure share has decreased from 62% in 1970 to 13% in 2020 (Figure B.1).[2]

This observation leads to the following questions. What are the contributions of technology adoption and innovation to technological growth over different stages of development? Furthermore, technological growth involves spillovers across firms, and development strategies usually include policies to incentivize them. What relative weight should be given to adoption versus innovation, and how should it change over stages of development? Korea is an interesting example to study as it started technology policy by subsidizing adoption in 1973 and gradually switched to subsidizing innovation.[3] What would have happened if the Korean government had skipped the adoption subsidy and enacted the innovation subsidy, as in developed countries? Or, what if it never transitioned to innovation subsidy and subsidized only adoption? Exploring these questions will shed light on the optimal state-dependent policy in developing countries.[4]

This paper studies the role of technology adoption and innovation in development and yields empirical, theoretical, and quantitative contributions. Empirically, we digitize a new dataset of firm-to-firm adoption contracts and their prices. We document new empirical facts about the roles of adoption and innovation in contributing to a country's development path and how this relates to the productivity gap between domestic and foreign firms. Theoretically, we build a new model with endogenous adoption and innovation decisions in which the adoption price internalizes buyer and seller incentives. Quantitatively, we solve the transition of the model in which

[1] Samsung adopted technologies mostly from Japanese companies such as Sanyo, Sony, and NEC.

[2] Adoption expenditure share is the adoption expenditure divided by the sum of adoption and R&D expenditure. Adoption expenditure is the gross payment to foreign firms for sharing industrial processes, designs, and licensing for patents and trademarks.

[3] To be specific, Korean government started to subsidize adoption at 30% in 1973, decreased to 15% in 1993, and 0% in 2010. It started to subsidize R&D at 15% in 1982, increased to 23% in 1991, and to 32% in 2009. Figure 6 shows the full picture. The adoption subsidy exempted corporate tax from the expenditure to import technology from foreign firms. The innovation subsidy exempted corporate tax for the R&D expenditure.

[4] The government in Brazil was also trying to switch from adoption to innovation subsidy. In 2001, it taxed technology adoption from foreign firms and subsidize innovation (De Souza, 2021). Likewise, China supported technology adoption mainly through FDI in the early years. In 2016, president Xi presented innovation-driven development as the 13th five-year plan, which he specified increasing R&D and patent intensity as an important goal.

Korean firms catch up with foreign firms and estimate the model using simulated method of moments. We then evaluate the actual policy in Korea over a 50-year horizon, which sheds light on the optimal state-dependent policy.

We overcome the challenge of finding systematic data on firm-level technology adoption by digitizing data on contract-level technology imports in Korea from 1962 to 1993. These data capture all technology transfer contracts between Korean and foreign firms, with detailed information such as adoption fees.[5] Furthermore, we exploit the firm-to-firm structure of the data by merging it with firm-level balance sheet and patent data for both Korean and foreign firms.[6] This firm-to-firm structure allows us to study how the cost and gain from adoption change with the productivity gap between firms.

We document four new empirical findings. First, firms are more likely to innovate than adopt when the productivity gap between domestic and foreign firms is small. Second, the adoption fee is higher when the productivity gap is small. This shows that foreign firms internalize the adopter's relative position to determine the adoption fee. Third, when the productivity gap is large, the productivity gain from adoption is relatively larger than that from innovation. Lastly, when Korean firms adopt a foreign technology, non-adopting firms are more likely to cite patents of the foreign firm that sold the technology. This implies that the adopted technology is diffused to other non-adopting firms, which motivates the government to subsidize adoption.

To quantify the empirical findings and study the policy counterfactuals, we build a two-country growth model in which firms can increase productivity by adopting foreign technology or by innovating. We build upon the step-by-step innovation model and extend it by adding another firm in a foreign country to capture the strategic interactions between domestic and foreign firms.[7] A new element is that domestic firms can adopt technology from foreign firms. Foreign firms lose future profit when they sell technology to other firms due to the stronger competition with domestic firms. The adoption fee is determined by Nash bargaining between two firms, internalizing all future profit changes due to the adoption. The endogenous adoption price depends on the technology gap between domestic and foreign firms and is quantified with the adoption price data.

In the model, innovation is inventing a new technology and adoption is learning an existing technology of foreign firms. Adoption differs from innovation in several ways. First, adoption cannot yield a higher productivity than the foreign firm from which firms are adopting technology. Second, the adopting firm must pay an adoption fee to the foreign firm. Lastly, productivity gains

[5] More than 50% of contracts are between Korean and Japanese firms. 95% of the adoption contracts involve know-how transfer in which Korean firms receive blueprints and detailed information of technologies. In many cases, Korean engineers could visit foreign firms and learn the know-how by interacting with foreign engineers.

[6] Firm-level balance sheet data contains basic information such as sales, employment, total assets, fixed assets, and industry at the firm-year level.

[7] While Akcigit and Ates (2019) have two domestic firms in each sector and study the competition between domestic firms, Akcigit et al. (2021) have one domestic and one foreign firm and study the competition between domestic and foreign firms. Our model has two domestic firms and one foreign firm and studies domestic competition and foreign competition. Also, we add technology adoption which is new to this literature.

from adoption and innovation differ, and the difference depends on the initial productivity gap with the foreign firm. This difference is governed by two key parameters, which are estimated from the data. Our empirical analysis suggests that adoption brings a larger productivity gain when domestic firms are far from foreign firms, and vice versa.[8]

Adoption and innovation generate knowledge diffusion across domestic firms. With a positive probability, a home follower can learn the home leader's technology and improve on it when innovating or adopting.[9] This intertemporal spillover can make the social return larger than the private return, which motivates the government to subsidize adoption and innovation. Foreign firms also internalize knowledge diffusion and raise the adoption fee, which makes the discrepancy between the social and private return of adoption larger. The size of the intertemporal spillover depends on the probability of knowledge diffusion and the productivity gain from adoption and innovation. Since the productivity gain depends on the current productivity gap with the foreign firm, the spillover from adoption and innovation and the optimal subsidy rate change over different stages of development.

In the quantitative section, we solve the transition of the model from the initial state—in which Korean firms have lower productivity than foreign firms—to the balanced growth path in which both countries have similar productivity.[10] We simulate moments from the model along the transition and estimate parameters to match moments between the model and data. The estimated model replicates the catching-up period of Korea and matches untargeted moments such as decreasing adoption expenditure share over time and increasing adoption fee as a function of the relative productivity.

Using the estimated model, we first decompose growth between adoption and innovation. We find that adoption accounted for 76% of TFP growth in 1973, but declined to 15% by 2022. Relative productivity gain from adoption decreases, and firms switch from adoption to innovation over time. Next, we evaluate Korea's technology policies since 1973, when the Korean government began subsidizing adoption through a tax credit. The government gradually decreased the adoption subsidy rate. It launched R&D subsidy in 1982 and steadily increased the subsidy rate over time. We compare it with three counterfactuals. First, we shut down both subsidies. Second, we subsidize only adoption at the initial rate (31%). Second, we subsidize only innovation at the final rate (32%). The actual policy increases consumption-equivalent welfare by 4.84% compared with the case without subsidies. The welfare increase from this policy is higher than subsidizing only adoption (3.69%) or only innovation (3.28%). This result suggests that state-dependent policy can generate higher welfare than time-invariant policies with similar subsidy rates.

Motivated by these results, we quantitatively study the optimal subsidies. First, we study the

[8]This result is in line with common assumptions in the literature, such as Acemoglu et al. (2006); Benhabib et al. (2021); König et al. (2020).

[9]Without knowledge diffusion, it must start from its own productivity level. If we assume the probability is one, our model nests the common assumption in the quality ladder literature whereby the potential entrant (follower) can always build on the incumbent's technology.

[10]The initial state is not a steady state but a point along the transition of the model.

optimal timing of switching from an adoption subsidy to an innovation subsidy while keeping the subsidy rate at 32%.[11] We find that welfare would have been the largest when the government switched to an innovation subsidy in 1992, which is very close to the year when the Korean government decreased the adoption subsidy rate and increased the innovation subsidy rate. Furthermore, we allow the government to choose the optimal rate of adoption and innovation subsidy and the timing of the switch. The optimal policy starts an adoption subsidy at 52% and switches to an innovation subsidy at 53% in 1985 when Korea's GDP was 54% of Japan's. This subsidy increases consumption-equivalent welfare by 6.46%, which is higher than the actual policy.

1.1 Related Literature

First, this paper is related to the endogenous growth literature. While many papers have developed adoption-led growth models (e.g., Parente and Prescott, 1994; Comin and Hobijn, 2010; Perla and Tonetti, 2014), or models with both adoption and innovation (Grossman and Helpman, 1991a; Barro and Sala-i Martin, 1997; Acemoglu et al., 2006; Santacreu, 2015; Benhabib et al., 2021; König et al., 2020), most papers do not have systematic and direct measure on adoption and its fees, which makes it hard to conduct quantitative analysis. This paper is one of the first papers in the literature to use comprehensive adoption and innovation data and provide new empirical facts and policy counterfactuals. Furthermore, while most papers abstract away from the foreign firm's incentive to sell technology, we model adoption that requires mutual agreement between two firms and endogenize adoption prices that incorporate both firms' incentive.[12] We capture the strategic interactions between firms by building on the step-by-step innovation literature (Aghion et al., 2001; Acemoglu and Akcigit, 2012; Akcigit et al., 2020, 2021; Akcigit and Ates, 2019; Olmstead-Rumsey, 2022; Liu et al., 2022; Sui, 2022).[13] Most step-by-step innovation models assume exogenous knowledge diffusion in which the follower can exogenously catch up with the leader. We open this black box by studying the technology adoption, which can explain a significant portion of this knowledge diffusion.

Second, this paper contributes to the literature on international knowledge diffusion. Several papers develop models in which knowledge diffusion is the byproduct of trade. Coe and Helpman (1995), Coe et al. (1997), and Eaton and Kortum (2001) view knowledge is embedded in goods and diffused through international trade. Grossman and Helpman (1991b), Alvarez et al. (2017), Buera and Oberfield (2020), Hsieh et al. (2019), and Rachapalli (2021) assume technology transfer is facilitated by goods trade in which firms interact with foreign firms. In contrast to these papers, we focus on technology adoption, which is a deliberate attempt to acquire technology from foreign firms and not a byproduct of other activities. Other papers also explicitly model technology

[11] To be specific, the government started the adoption subsidy at 32% and can choose one year to shut down the adoption subsidy and start the innovation subsidy at 32%. 32% is the maximum subsidy rate in the actual policy.

[12] Our notion of adoption differs from imitation in Acemoglu et al. (2006), Perla and Tonetti (2014), and König et al. (2020) since the firm must get approval and pay to the foreign firm to adopt the technology in our model.

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

adoption (Eaton and Kortum, 1999; Santacreu, 2015; Sampson, 2019; Lind and Ramondo, 2022). While these papers use indirect adoption measures such as patents, trade, and R&D stock, we use a direct measure from technology imports data. Santacreu (2022) is an exception; she uses country-level license payment data to study the effect of trade and intellectual property policies. Instead of aggregated country-level data, our paper uses firm-to-firm adoption data, which allows us to study strategic interactions between firms.

Third, this paper contributes to the literature that studies technology policies. Bloom et al. (2002), Bronzini and Iachini (2014), Dechezleprêtre et al. (2016), Howell (2017), and Chen et al. (2021) study the effect of R&D subsidy on innovation and its spillover. De Souza (2021) studies the effects of technology substitution policy on the labor market in Brazil, where the government decreased adoption subsidies but increased R&D subsidies. Jones and Williams (2000), Acemoglu et al. (2018), Atkeson and Burstein (2019), Akcigit et al. (2021), Akcigit et al. (2022), and Liu and Ma (2022) study the optimal R&D policy based on innovation-led growth models.[14] While most papers focus on innovation policy in developed countries, we study adoption and innovation policy in developing countries. Furthermore, we study the appropriate policies over different stages of development, focusing on the transitional dynamics of the model.

Lastly, this paper is related to the literature that studies a period of rapid growth in Korea. Lane (2022), Choi and Levchenko (2021), and Kim et al. (2021) study industrial policy in the 1970s, Connolly and Yi (2015) study trade policy reforms, and Aghion et al. (2021) study the pro-competitive reforms after the financial crisis in 1997. The most closely related paper is our other paper Choi and Shim (2022), in which we study the role of technology adoption in industrialization, focusing on sector-specific and temporary subsidies in the 1970s. Choi and Shim (2022) study earlier period when Korean firms were far from the frontier. In this paper, we focus on the period in which the country transitioned from adoption to innovation and the strategic interactions between Korean and foreign firms became important.[15] Furthermore, this paper studies the growth of Korea and its implemented policies over a long horizon in which it developed from a low-income and non-innovative country to a high-income and innovative country.

The remainder of the paper is organized as follows. Section 2 introduces technology imports, firm-level balance sheet, and patent data. Section 3 presents empirical facts. Section 4 describes the two-country growth model with endogenous innovation and adoption decisions. Section 5 explains the estimation procedure and shows that the estimated model can match untargeted moments well. Section 6 presents policy counterfactuals, and Section 7 concludes.

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

[15] In Choi and Shim (2022), we abstract away from the reaction or incentive of the foreign firm because Korean firms were far from the frontier and not important to the foreign firms' profit. On the other hand, this paper abstracts away from sectoral differences and spatial aspects.

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
Hyundai Automobile	Kyukoto Engineering (Japan)	3	79.6.14	Concrete mixer	Know-how Transfer	Royalty 5%

2 Data

2.1 Technology Adoption Data

We construct a firm-to-firm technology import dataset. To be specific, we collect and digitize contracts from the National Archives of Korea and supplement them with data from Korea Industrial Technology Association (1995).[16] The data includes the universe of technology import for the period 1962-1993 since Korean firms were required to submit adoption contracts to the government when they import technology from a foreign country.[17] As a result, we collected 8,404 contracts from 2,865 unique Korean firms.[18] Figure A.1 and A.2 in Appendix A.1 show an example of contract, where we can see the contents and payment for the contract.

We collect the name of the Korean firm (buyer) and foreign firm (seller), the date and length of the contract, a description of the technology, the contents of the contract, and the adoption fee, which consists of a fixed fee and royalty rate. Table 1 shows examples of collected data. For instance, Samsung adopted technology to produce color TV from Nippon Electronic in 1978. The length of contract was 10 years in which Samsung could get know-how transfer and licensing of patents and it paid 800,000 dollars as a fixed fee. 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. Appendix A.1 presents summary statistics of the data such as country distribution, contents of contracts, and average adoption fee.

[16] Compared with data that we used in Choi and Shim (2022), we add adoption fee information, foreign firm information, and include the period from 1983 to 1993.

[17] Korean firms were strictly required to report all transactions involving foreign currencies under the Foreign Capital Inducement Act. To be specific, they reported details of technology imports to the Economic Planning Board.

[18] 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.

2.2 Patent Data

Korean patent office data. To measure the innovation of Korean firms, we use patent data from Korean Intellectual Property Office.[19] The data starts in 1945 and includes the universe of 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. 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 the United States Patent Office data (USPTO, hereafter) since it has citations for all periods.[20] Also, we use USPTO to measure the innovation of foreign firms. The detailed procedure to match foreign firms names with USPTO data is in Appendix A.3.

2.3 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. This is firm survey data that covers firms with more than 50 employees.[21] 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 (2.65 million dollars in 2015).[22] By using the business ID and firm name, we merge these two data.[23] Then, we merge the balance sheet data with the technology adoption data by using firm names.

Foreign firms. We use Compustat data for the foreign firms where we can observe 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. We merge this data with technology adoption data using the firm name and country.

Table A.3 in Appendix A.4 shows the summarity statistics of adopting and non-adopting firms using the merged data.

[19] We download the data from Korean Intellectual Property Rights Information Service, following the procedure in Lee et al. (2020).

[20] We use a crosswalk between the Korean patent office firm ID and USPTO ID made by Lee et al. (2020).

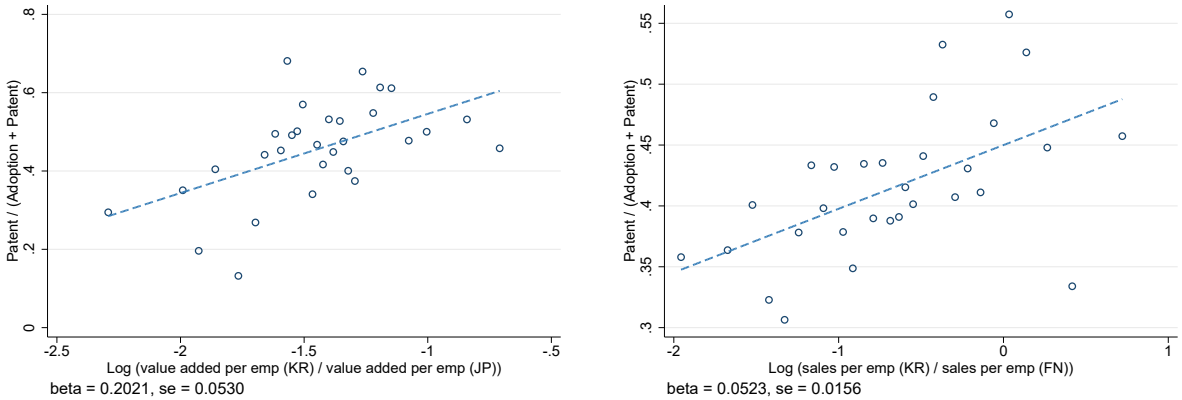
[21] It accounts for 70% of the value-added share in manufacturing.

[22] KIS-VALUE data is collected by a private company, which covers firms that are subject to external edit. The 1981 Act on External Audit of Joint-Stock Corporations requires that all publicly traded firms and other firms larger than the asset threshold have to report their balance sheet information.

[23] We also use the history of firm names in case the firm had changed its name mainly from www.saramin.co.kr

3 Stylized Facts

3.1 Innovation and Adoption over Productivity Gap



A. Sector level

B. Firm level

Figure 1: Patent / (patent + adoption) over Productivity Gap

Notes: This figure plots 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 1 plots the innovation share over the productivity gap with foreign firms, 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. For the productivity gap, we calculate the value added per employees in Korea divided by that in Japan and use it as the productivity gap. For firm-level analysis, we use the sales per employee of adopting firms divided by the technology seller. If the firm does not adopt, we use the maximum sales per employee of the foreign firm in sector and year. Table B.1 in Appendix B shows the regression result.

We find a positive and statistically significant correlation between the innovation share and the gap at the sector and firm levels. It implies that when Korean firms are close to foreign firms in terms of productivity, they are more likely to innovate instead of adopt.

3.2 Adoption Fee over Productivity Gap

One potential reason for the firm's transition from adoption to innovation is the adoption fee getting higher as the firm closes the productivity gap with foreign firms. We study the relationship

Table 2: Adoption Fee and Relative Productivity

	Fixed fee	Royalty	Total fee	Total fee
Relative productivity	0.117**	0.124***	0.627***	0.561***
	(0.0503)	(0.0465)	(0.0545)	(0.0598)
Relative productivity 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: This table shows the result of equation (1) in which we regress the adoption fee with the relative productivity. The fixed fee and total fee are logged. Royalty is the royalty rate (in percentage). The total fee is the sum of the fixed fee and royalty rate times sales times contract years. Relative productivity 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.

between the productivity gap and the price of the adoption contract by running the following regression:

$$\mathcal{F}_{ijt} = \beta \log \left(\frac{q_{it}}{q_{jt}} \right) + \alpha_{s(i)} + \delta_t + \epsilon_{ijt} \,, \tag{1}$$

where $\mathcal{F}_{ijt}$ is the adoption fee that Korean firm i pays to foreign firm j at year t. q_{it} is labor productivity measured by sales per employee of firm i. We use global Compustat data to get sales per employee of the foreign firm.[24] $\alpha_{s(i)}$ is sector fixed effects, and δ_t is year fixed effects.

Table 2 shows a positive and statistically significant correlation between the adoption fee and relative productivity. The adoption fee consists of a fixed fee and the royalty payment, which is the royalty rate times firm sales. In the first column, we regress log fixed fee on the relative productivity. We find that a 1% increase in relative productivity is associated with a 0.117% increase in the fixed fee. In the second column, we regress the royalty rate (in percentage) with the relative productivity. A 1% increase in relative productivity is associated with a 0.124 percent point increase in the royalty rate. In the third column, we regress log total adoption fee, which is the sum of fixed fee and royalty rate times firm sales times contract years.[25] A 1% increase in the relative productivity is associated with a 0.561% increase in the total adoption fee. The positive correlation

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

[25]The royalty payment is usually a share of the revenue made by using the adopted technology. Since we do not have disaggregated sales data, we use the firm-level total sales as the revenue.

suggests that when the Korean firm is closer to the foreign firm, the seller is compensated more with the adoption fee.

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 intense competition since they compete in the same product market. To be specific, we list the ten most frequent patent classes of each firm. Then, we make a dummy variable is equal to one if 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. The last column in Table 2 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 for the adoption price. This suggests that the competition effect is relevant to determine adoption fees.

3.3 Productivity Gain from Adoption and Innovation over Technology Gap

Another potential reason for the transition from adoption to innovation is that the productivity gain from adoption becomes smaller as firms close the technology gap with the foreign firm. To study the productivity gain from adoption and innovation over the technology gap, we run a regression as below:

$$\log\left(\frac{q_{i,t+5}}{q_{i,t}}\right) = \beta \cdot \log\left(\frac{q_{i,t}}{q_{j,t}}\right) + \Gamma \cdot X_{it} + \alpha_{s(i)} + \delta_t + \epsilon_{it}\,, \tag{2}$$

where $\log(\frac{q_{i,t+5}}{q_{i,t}})$ is the growth rate of labor productivity after 5 years from either innovation or adoption of firm i. $\log\left(\frac{q_{i,t}}{q_{j,t}}\right)$ is the relative productivity in the year of the adoption or innovation, which is the same measure used in the Table 2. Since innovating firm does not have corresponding foreign firm j, we pick the foreign technology seller with the maximum sales per employee 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 over 5 years. Lastly, we control for sector and year-fixed effects. We exclude firms that both innovate and adopt in the same year.

Figure 2 shows the result in a binscatter plot. The productivity growth from adoption is larger when the productivity gap is larger, and vice versa. While the initial productivity gap has a negative correlation with productivity growth both for adopting and innovating firms, the absolute value of the coefficient is larger for adoption than innovation. This implies that the productivity gap matters more for adoption than innovation.[26] Table B.2 in Appendix B shows the result of the

[26]There is a potential endogeneity problem if the firms with lower productivity are selected into adoption. In the quantitative section, we tackle this problem by using indirect inference. We simulate the same regression while consid-

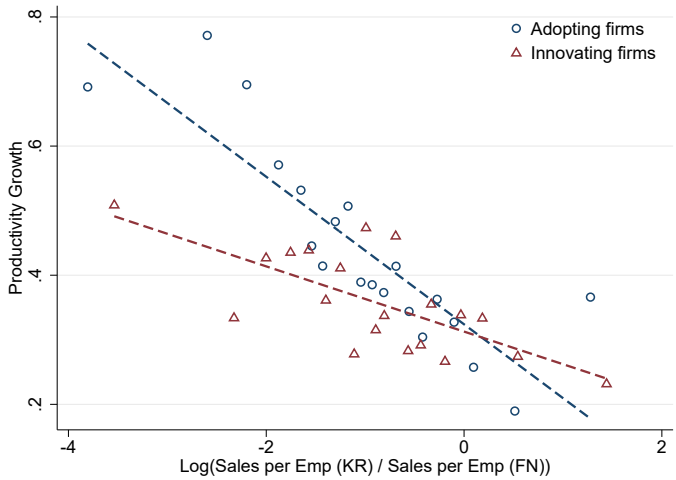


Figure 2: Productivity Growth from Adoption and Innovation over Initial Productivity Gap

Notes: This figure plots $\Delta \log(\text{sales / emp})_{i,t+5}$ in the Y-axis and $\log$(sales per emp of Korean firm / sales per emp of Korean firm)$_{i,t}$ in the X-axis. It is a binscatter plot where each dot has multiple firm-year observations. Blue circles are innovating firms that have at least one patent, and red triangles are adopting firms that have at least one adoption contract. We exclude firms that have both innovation and adoption in a given year. We control growth rate of fixed asset / employment for 5 years and include sector and year-fixed effects. 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.

regression in which we include an interaction term between the productivity gap and adoption. The interaction term is significantly negative, which suggests the difference in the coefficients between adoption and innovation is statistically significant.

3.4 Knowledge Diffusion from Adoption

We now study the knowledge diffusion from the adopted technology to other firms that did not directly adopt the technology. We use patent citations 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 citations to the foreign technology seller compared with the other one.

To mimic the ideal experiment, we use a matching-based event study.[27] We match two foreign firms, one of which sold technology (treated) while the other did not (control). We use minimum distance matching in terms of the log patent stock while exactly matching on the country, year,

ering the selection in the model and match the coefficients with the data.

[27] Our specification is similar to Jaravel et al. (2018) and Prato (2022).

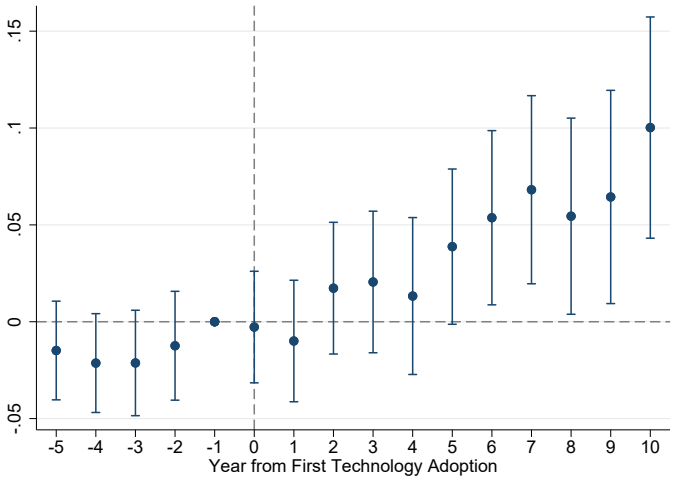


Figure 3: Event Study Result of Patent Citations

Notes: The figure plots β_k^{Seller} in equation (3), 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 receiving citations 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.

and the main patent field (IPC 3 digit).[28] Table B.3 in Appendix B shows no statistically significant difference between the two groups regarding cumulative patents and citations. 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. We exclude the citations from adopters. Specifically, we estimate the below equation.

$$Y_{it} = \sum_{k=-5}^{10} \beta_{\text{k}}^{\text{Seller}} \mathbf{1}_{\{L_{it}^{\text{Seller}}=k\}} + \sum_{k=-5}^{10} \beta_k^{All} \mathbf{1}_{\{L_{it}^{\text{All}}=k\}} + \alpha_i + \gamma_t + \epsilon_{it}\,, \tag{3}$$

where Y_{it} is a citation dummy variable equal to one if a Korean firm that never adopted cites 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 are the foreign firm fixed effects, γ_t are year fixed effects, and ϵ_{it} is the error term. Therefore, β_k^{All} captures common trend around the event year, and β_k^{Seller} captures the difference between treated and control firms. We cluster standard error at the technology field level (3-digit IPC) and year.

Figure 3 plots β_k^{Seller}. There is an increase in the number of patent citations to the technology seller compared to control firms. It suggests that Korean firms build on the adopted technology of other Korean firms, which implies a positive externality of adoption. We do not find a clear pre-

[28] For the patent field, we use the most frequent three-digit IPC class in each foreign firm.

trend before the first technology adoption, supporting the difference is not driven by the different trends between the two groups.[29]

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 run the same regression with the number of citations received from all the other countries except Korea. Figure B.3 in Appendix B shows no clear difference between treated and control groups in terms of total citations, which bolsters the credibility of the event study result.

4 Model

4.1 Setup

We develop a dynamic general equilibrium model in which firms in two countries can increase productivity by innovating and adopting technologies. Firms are forward looking. Time is continuous. There are two countries home and foreign, and a continuum of a variety of goods $j \in [0, 1]$. The goods are tradable across countries with an iceberg cost of $D \geq 1$.[30] In country H, there are two firms, h and $\tilde{h}$ in each product line j. We call a firm a leader if it has the highest productivity. The other firm is the follower. Both can innovate and adopt to increase productivity. In country F, there is a representative firm f in each product line j. It can also innovate and adopt technology from firms in country H. Instead of the follower, there is a potential entrant $\tilde{f}$ which can enter and replace the incumbent by innovating.[31]

4.2 Household

A representative household in each country consumes goods, supplies labor, pays lump-sum taxes, and owns domestic firms. Households in period t have the following utility function:

$$U_{ct} = \int_t^\infty \exp(-\rho(s-t)) \ln C_{cs} ds \,, \tag{4}$$

where C_{cs} is the final consumption at s, and $\rho > 0$ is the discount factor. Households maximize utility subject to the budget constraint:

[29] We present additional results in Appendix B. Figure B.5 plots the difference of the inverse hyperbolic transformation of the number of citations to study the intensive margin as well. Table B.4 shows the entire coefficients with standard errors for both extensive and intensive margins. Table B.5 shows the result from difference-in-difference specification which summarizes the results.

[30] Firms need to ship D units of goods for one unit of the good to export to another country.

[31] This assumption can reduce the number of state variables since we do not need to keep track of the gap between two foreign firms.

$$r_{ct}A_{ct} + L_c w_{ct} = P_{ct}C_{ct} + T_{ct} + \dot{A}_{ct}\,, \tag{5}$$

where r_{ct} is interest rate, L_c is the labor endowment, w_{ct} is wage, P_{ct} is the price index of final consumption, T_{ct} is the lump-sum tax that finances innovation and adoption subsidies, and A_{ct} is the household's assets.

Final consumption C_{Ht} is given by

$$C_{Ht} = \exp(\int_0^1 \ln((\psi_H^{\frac{1}{\sigma}} y_{hjt}^{\frac{\sigma-1}{\sigma}} + \psi_H^{\frac{1}{\sigma}} y_{\tilde{h}jt}^{\frac{\sigma-1}{\sigma}} + \psi_F^{\frac{1}{\sigma}} y_{fjt}^{*\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}})dj)\,, \tag{6}$$

where $y_{hjt}, y_{\tilde{h}jt}$ are the output in product line j, consumed by the home household and produced by h and $\tilde{h}$, respectively.[32] y^*_{fjt} is the output of the foreign firm and exported to country H. The superscript asterisk denotes the goods that are exported. ψ_H and ψ_F are demand shifters for goods produced in the country H and F.[33] We assume $1 < \sigma < \infty$, meaning the goods within a product line are imperfect substitutes to each other with elasticity of substitution σ. The price index of final consumption P_{ct} is given by

$$P_{Ht} = \exp(\int_0^1 \ln((\psi_H^{\frac{1}{\sigma}} p_{ht}^{1-\sigma} + \psi_H^{\frac{1}{\sigma}} p_{\tilde{h}t}^{1-\sigma} + \psi_F^{\frac{1}{\sigma}} p_{ft}^{*1-\sigma})dj)\,, \tag{7}$$

where p_{it} is the price of firm i in the domestic market, and p^*_{it} is the price in the foreign market.

A representative household maximizes utility from the equation (4) given the budget constraint from the equation (5). This generates the following Euler equation:

$$\frac{\dot{C}_{ct}}{C_{ct}} = \rho - (r_{ct} - \frac{\dot{P}_{ct}}{P_{ct}}). \tag{8}$$

4.3 Firms

Production. The production function of a variety is

$$\mathcal{Y}_{ijt} = q_{ijt} l_{ijt}\,, \tag{9}$$

where q_{ijt} is the firm's productivity and l_{ijt} is labor used by firm i in product line j at time t. q_{ijt} evolves by innovation and adoption. Output can be consumed by the home household or exported to another country. Hence,

$$\mathcal{Y}_{ijt} = y_{ijt} + D \cdot y^*_{ijt}. \tag{10}$$

[32] C_{Ft} is defined symmetrically. We define equations for the foreign country in Appendix C.1.

[33] Since we have two firms in H and one firm in F, we use the demand shifters to make the two countries symmetric.

Market structure. We assume that the three firms in each market (home and foreign) engage in Bertrand 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 and do not allow dynamic collusion.[34] Firms recognize that their pricing decision changes demand for their goods.

Productivity gap. From now on, we omit the time argument when it does not cause confusion. Firms can increase productivity by λ^n through innovation or adoption. n is the number of steps of improvement, and λ is a unit step size in the economy. Therefore, we can express the productivity as λ^N, where N denotes the cumulative number of steps that the firms have taken. Then, the productivity gap m_{Fi} between firm i and the foreign firm in variety j, measured in steps can be written as

$$\frac{q_{ij}}{q_{fj}} = \frac{\lambda^{N_{ij}}}{\lambda^{N_{fj}}} = \lambda^{\boldsymbol{m_{Fi}}}, \quad m_{Fi} \in \mathbb{Z}, \quad i \in \{h, \tilde{h}\}. \tag{11}$$

Likewise, we can express the gap with the domestic competitor, m_{Di} as follows:

$$\frac{q_{ij}}{q_{-ij}} = \frac{\lambda^{N_{ij}}}{\lambda^{N_{-ij}}} = \lambda^{\boldsymbol{m_{Di}}}, \quad m_{Di} \in \mathbb{Z}, \quad i \in \{h, \tilde{h}\}, \tag{12}$$

where $m_{Fi} > 0$ implies the firm i has higher productivity than the foreign firm. $m_{Di} > 0$ implies the firm i has higher productivity than the domestic competitor. The state variable is a vector $\mathbf{m}_i = \{m_{Fi}, m_{Di}\} \in \mathbb{Z}^2$. Given the aggregate variables such as the wage and the consumption share, $\mathbf{m}_i$ determines the firm i's 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.

Innovation. Firm chooses an innovation rate at a cost in labor is given by

$$C_{cr}(x) = \alpha_{cr}\frac{x^\gamma}{\gamma}. \tag{13}$$

We assume $\gamma > 1$, so the innovation cost function is convex. α_{cr} governs the scale of the innovation cost in country c. Since the firm needs to hire labor, the cost is proportional to the wage w_c. Innovation rate x implies that, with probability x, the firm improves its productivity by

$$q_{ij}(t + \Delta) = \lambda^n q_{ij}(t), \quad n \sim \mathbb{F}(n; m_{Fi}). \tag{14}$$

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

where n is a stochastic variable that determines the number of steps of improvement, and $\mathbb{F}(n; m_{Fi})$ is the step size distribution which is fixed across time and country. It depends on m_F, which is the productivity gap with the foreign firm.[35] To be specific, we assume the expected step size from innovation is weakly decreasing with m_{Fi}. This is motivated by the empirical finding in Section 3.3.[36] The specific functional form is from Akcigit et al. (2021) and decribed in Appendix C.6.

Conditional on a successful innovation by firm i with step size n, the state variable of firm i changes to $(m_{Fi} + n, m_{Di} + n)$. Similarly, when the domestic competitor innovates with step size n, it changes to $(m_{Fi}, m_{Di} - n)$. If the foreign firm innovates with step size n, it changes to $(m_{Fi} - n, m_{Di})$.

Adoption. Firms choose an adoption rate a at a cost of labor, given by

$$C_{ca}(a) = \alpha_{ca} \frac{a^\gamma}{\gamma}. \tag{15}$$

Again, we assume that the firm hires labor to adopt, so the cost is proportional to the wage w_c. This labor cost can be interpreted as the researcher who investigates the foreign technology, learn, and implement, which is different from the adoption fee to the seller. α_{ca} governs the scale of the adoption cost in country 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.[37,38] The adopter pays a one-time adoption fee to the foreign firm. The adoption fee is determined through Nash bargaining between the adopter and the foreign firm, which will be explained in detail in Section 4.4. Then, the firm improves its productivity by

$$q_{ij}(t + \Delta) = \lambda^n q_{ij}(t), \quad n \sim \mathbb{G}(n; m_{Fi}), \tag{16}$$

where $\mathbb{G}(n; m_{Fi})$ is the step size distribution, which depends on the current gap from the foreign firm m_{Fi}. The expected step size from adoption decreases with m_{Fi}, which is motivated by the empirical finding in Section 3.3.[39] The functional form is same as $\mathbb{F}(n; m_{Fi})$, but the slope of the expected step size over m_{Fi} can be different.

Note that the adopter does not necessarily catch up with the foreign firm from only one adop-

[35] In the case of the firm in country F, only the gap from the domestic leader matters.

[36] This captures the advantage of backwardness in Gerschenkron (1962). When firms have lower productivity than foreign firms, they can observe what technologies are successful or not, which makes them easier to innovate.

[37] This assumption is motivated by the estimated size of adoption expense between domestic firms is only 6.3% of the total adoption expense (Lee, 2022). In the model equilibrium, even if we allow adoption between the domestic firms, firms do not adopt from a domestic competitor under our estimated parameters. This is because two domestic firms have no wage difference and trade cost, and with enough level of elasticity of substitution, the total surplus from the adoption contract is negative, which makes no room for them to trade technology.

[38] Firms in country F adopt only from the home leader, not the follower.

[39] This implies that the domestic firm can learn and improve productivity a lot from adoption when the foreign firm has better technologies.

tion.[40] Let $g(n; m_{Fi})$ be the probability of improving n steps when the gap from foreign firm is m_F. If $g(1; m_{Fi}) = 1$, it nests the case of König et al. (2020) in which adoption (imitation) brings only one step regardless of the current gap. If we assume $g(m_{Fi}; m_{Fi}) = 1$, it nests the case of Perla and Tonetti (2014) and Benhabib et al. (2021). $g(m_{Fi}; m_{Fi}) = 1$ implies that the adoption fee would always be higher when the initial productivity gap is smaller, which is not the case in the data. Hence, our more flexible specification can explain the empirical patterns better.

In the model, 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, $g(0; m_{Fi}) = 1$ for $m_{Fi} \geq 0$. Second, the firm cannot leapfrog the foreign firm through adoption, i.e., $g(n; m_{Fi}) = 0$ for $n > -m_{Fi}$. Third, the expected step size from adoption and innovation decreases with m_{Fi}, but the slopes are different. Our empirical finding implies the slope is larger for adoption, which suggests the productivity gain from adoption is larger than that from innovation when m_{Fi} is small, and vice versa. Lastly, the adopter needs to pay the adoption fee $\mathcal{F}_{i,\mathbf{m}}$ to the foreign firm.

Potential entrant. In country F, there is a potential entrant $\tilde{f}$ which can innovate and replace the incumbent.[41] The innovation cost of the entrant is the same as that of the incumbent in equation (13). With probability x, they improve on top of the incumbent's productivity as[42]

$$q_{fj}(t + \Delta) = \lambda^n q_{fj}(t), \quad n \sim \mathbb{F}(n; m_{Ff}). \tag{17}$$

Knowledge diffusion. Motivated by Section 3.4, we assume that the domestic follower can receive knowledge diffusion from the domestic leader. Specifically, with a probability δ, the domestic follower can build on the domestic leader's technology when innovating or adopting. Hence, the step size distribution for domestic follower depends not only on the productivity gap with foreign firms but also on the gap with the domestic leader. The step size distribution of the follower with $m_{Di} < 0$ is

$$\begin{aligned} \tilde{f}(n; m_{Fi}, m_{Di}) &= (1-\delta) f(n; m_{Fi}) + \delta f(n + m_{Di}; m_{Fi} - m_{Di}) \\ \tilde{g}(n; m_{Fi}, m_{Di}) &= (1-\delta) g(n; m_{Fi}) + \delta g(n + m_{Di}; m_{Fi} - m_{Di}) \,, \end{aligned} \tag{18}$$

where the first term is the case without knowledge diffusion in which the follower improves productivity from its current position, which happens with probability $(1 - \delta)$. The second is the case with knowledge diffusion in which it improves from the leader's position $m_{Fi} - m_{Di}$, which

[40] This 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).

[41] For simplicity, we do not allow potential entrants to adopt the technology.

[42] When the entrant innovates in country F, the incumbent f exits. 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.

happens with probability δ.[43]

Knowledge diffusion generates an intertemporal spillover from both innovation and adoption. When the leader innovates or adopts, it also increases the future productivity of the follower. However, this knowledge diffusion hurts the leader's profit in the future. Since the leader takes that into account, a higher δ reduces the innovation and adoption rate of the leader.

The level of spillover is proportional to the expected productivity gain times the probability of knowledge diffusion. If the step size is larger, it improves productivity more and creates a larger spillover to the follower. Since the productivity gain from adoption and innovation changes across productivity gaps, the intertemporal spillover from adoption and innovation also change. For instance, if the productivity gain from adoption is larger than innovation, the spillover is larger from adoption than from innovation.

Lastly, we allow for productivity spillovers across countries. With probability ϕ, domestic firms get the access to the technology of foreign firms for free. We include this parameter to capture unobserved international spillovers outside the official adoption contracts, such as technology stealing or reverse engineering. Also, $\phi > 0$ guarantees non-degenerate stationary distribution of technology gap and it is a common feature in step-by-step innovation model (Acemoglu and Akcigit, 2012; Liu and Ma, 2022).

Government policy. We consider subsidies to adoption and innovation. The government in home country subsidizes s_{Hat} fraction of the adoption cost, and subsidizes s_{Hrt} fraction of innovation cost. The cost of both subsidies are financed by the lump-sum tax from the household.

4.4 Equilibrium

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

Production and profits. The productivity gap $\mathbf{m}_i$ determines the production and profit of intermediate goods given the wage, total consumption in two countries, and trade cost. Firms in each product country engage in Bertrand competition. Since utility is Cobb-Douglas over product lines, the household spends the same amount of expenditure $P_c C_c$ on each product line j. This leads to the following equilibrium condition:

$$\sum_{i=h,\tilde{h}} p_{ij} y_{ij} + p^*_{fj} y^*_{fj} = P_H C_H. \tag{19}$$

[43] 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 follower can always build on the incumbent's technology.

By solving the household utility maximization problem given the variety price, s_{ij}, the market share of firm $i \in \{h, \tilde{h}\}$ and s^*_{fj}, the market share of firm f in the home market are

$$s_{ij} = \frac{\psi_H p_{ij}^{1-\sigma}}{\sum_{i=h,\tilde{h}} \psi_H p_{ij}^{1-\sigma} + \psi_F p_{fj}^{*1-\sigma}} \quad s^*_{fj} = \frac{\psi_F p_{fj}^{*1-\sigma}}{\sum_{i=h,\tilde{h}} \psi_H p_{ij}^{1-\sigma} + \psi_F p_{fj}^{*1-\sigma}}. \tag{20}$$

And the demand y_{ij}, y^*_{fj} are:

$$y_{ij} = \frac{p_{ij}^{-\sigma}}{\sum_{i=h,\tilde{h}} p_{ij}^{1-\sigma} + p_{fj}^{*1-\sigma}}, \qquad y^*_{fj} = \frac{p_{fj}^{*-\sigma}}{\sum_{i=h,\tilde{h}} p_{ij}^{1-\sigma} + p_{fj}^{*1-\sigma}}. \tag{21}$$

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

$$p_{ij} = \frac{1 - \frac{\sigma-1}{\sigma} s_{ij}}{\frac{\sigma-1}{\sigma}(1 - s_{ij})} \frac{w_H}{q_{ij}}, \qquad p^*_{fj} = \frac{1 - \frac{\sigma-1}{\sigma} s^*_{fj}}{\frac{\sigma-1}{\sigma}(1 - s^*_{fj})} \frac{D \cdot w_F}{q_{fj}}. \tag{22}$$

The profit functions from country H are.

$$\pi_{ij} = \frac{s_{ij}(1 - \frac{\sigma-1}{\sigma})}{1 - \frac{\sigma-1}{\sigma} s_{ij}}, \qquad \pi^*_{fj} = \frac{s^*_{fj}(1 - \frac{\sigma-1}{\sigma})}{1 - \frac{\sigma-1}{\sigma} s^*_{fj}}. \tag{23}$$

The equilibrium in the foreign market is defined similarly in Appendix C.1. The firm makes profits from two sources: the domestic market and the foreign market. Finally, the total profit of the firm $i \in \{h, \tilde{h}\}$ in sector j is

$$\Pi_{ij} = \pi_{ij} P_H Y_H + \pi^*_{ij} P_F Y_F. \tag{24}$$

If we combine the equation (20) and (22), we can solve the price, market share, and profit as functions of the productivity gap, relative wage, trade costs, and household expenditure. Therefore, given the aggregate variables, the productivity gap $\mathbf{m}_i$ fully determines the static variables of all firms.

Value function. Note that given the aggregate variables, firm profit depends only on the productivity gap, and the innovation and adoption decision change the gap over time. Hence, we can represent the value function as a function of the productivity gap vector $\mathbf{m}_i = \{m_{Fi}, m_{Di}\}$. Without loss of generality, assume that h is the home leader and $\tilde{h}$ is the follower. For $i \in \{h, \tilde{h}\}$, m_{Fi} is the gap from firm f, and m_D is the gap from the domestic competitor. For $i = f$, m_{Fi} is the gap from the home leader h, and m_D is the gap between the home leader and follower. For example, if the productivity of h is λ^3, $\tilde{h}$ is λ^2, and f 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 $\{-2, 1\}$.

The value function of h with gap $\mathbf{m}_h = (m_{Fh}, m_{Dh})$ with $m_{Dh} > 0$ is

$$
\begin{aligned}
& r_{Ht} V_{Ht}(\mathbf{m}_h) - \dot{V}_{Ht}(\mathbf{m}_h) \\
&= \max_{x_{Ht}(\mathbf{m}_h), a_{Ht}(\mathbf{m}_h)} \underbrace{\Pi_{Ht}(\mathbf{m}_h)}_{\text{profit}} - (1 - s_{Hrt}) \underbrace{\alpha_{Hr} \frac{x_{Ht}(\mathbf{m}_h)^\gamma}{\gamma} w_{Ht}}_{\text{innovation cost}} - (1 - s_{Hat}) \underbrace{\alpha_{Ha} \frac{a_{Ht}(\mathbf{m}_h)^\gamma}{\gamma} w_{Ht}}_{\text{adoption cost}} \\
&+ x_{Ht}(\mathbf{m}_h) \sum_n f(n; m_{Fh}) \underbrace{[V_{Ht}(m_{Fh} + n, m_{Dh} + n) - V_{Ht}(\mathbf{m}_h)]}_{\text{gain from innovation}} \\
&+ a_{Ht}(\mathbf{m}_h) \sum_n g(n; m_{Fh}) [(\underbrace{V_{Ht}(m_{Fh} + n, m_{Dh} + n) - V_{Ht}(\mathbf{m}_h)}_{\text{gain from adoption}} - (1 - s_{Hat}) \underbrace{\mathcal{F}_{Ht}(\mathbf{m}_h)}_{\text{adoption fee}})] \\
&+ x_{Ht}(\mathbf{m}_{\tilde{h}}) \sum_n \tilde{f}(n; \mathbf{m}_{\tilde{h}}) \underbrace{[V_{Ht}(m_{Fh}, m_{Dh} - n) - V_{Ht}(\mathbf{m}_h)]}_{\text{loss from follower innovation}} \\
&+ a_{Ht}(\mathbf{m}_{\tilde{h}}) \sum_n \tilde{g}(n; \mathbf{m}_{\tilde{h}}) \underbrace{[V_{Ht}(m_{Fh}, m_{Dh} - n) - V_{Ht}(\mathbf{m}_h)]}_{\text{loss from follower adoption}} \\
&+ (x_{Ft}(\mathbf{m}_f) + \tilde{x}_{Ft}(\mathbf{m}_f)) \sum_n f(n; m_{Ff}) \underbrace{[V_{Ht}(m_{Fh} - n, m_{Dh}) - V_{Ht}(\mathbf{m}_h)]}_{\text{loss from foreign firm innovation}} \\
&+ a_{Ft}(\mathbf{m}_f) \sum_n g(n; m_{Ff}) [\underbrace{V_{Ht}(m_{Fh} - n, m_{Dh}) - V_{Ht}(\mathbf{m}_h)}_{\text{loss from foreign firm adoption}} + \underbrace{\mathcal{F}_{Ft}(\mathbf{m}_f)}_{\text{adoption fee}}] \\
&+ \phi \underbrace{(V_{Ht}(0, m_D) - V_{Ht}(\mathbf{m}_h))}_{\text{exogenous spillover}}].
\end{aligned}
\tag{25}
$$

Firms choose the optimal innovation rate $x_{Ht}(\mathbf{m}_h)$ and the adoption rate $A_{Ht}(\mathbf{m}_h)$ to maximize the discounted sum of profits. The second line of the value function includes the operating profit, which is defined in equation (23) and (24). Then, the firm spends innovation and adoption costs. s_{Hrt} and s_{Hat}, are innovation and adoption subsidy rates, respectively. The next two lines show the gain from innovation and adoption where the step size n follows the distribution $f(n; m_{Fh}), g(n; m_{Fh})$. The adoption fee $\mathcal{F}_{Ht}(\mathbf{m}_h)$ is an endogenous variable which will explained later in equation (29). The next two lines represent the value change from the innovation and adoption of the domestic competitor. $x_{Ht}(\mathbf{m}_{\tilde{h}}), a_{Ht}(\mathbf{m}_{\tilde{h}})$ denote the innovation and adoption rate of the domestic competitor. Since another firm is the follower, it has different step size distribution given by $\tilde{f}(n; \mathbf{m}_{\tilde{h}}), \tilde{g}(n; \mathbf{m}_{\tilde{h}})$. The following two lines denote the foreign firms' (incumbent and entrant) innovation and adoption. The last line has the exogenous spillover, which is governed by the parameter ϕ. The value functions of home follower, foreign firm, and the foreign entrant are defined similarly, in equation (50), (51), and (52) in Appendix C.2.

Optimal innovation and adoption rate. From the value function equation, we can compute the optimal innovation and adoption rate by using first order conditions. The optimal innovation rate

of home leader with gap $\mathbf{m}_h$ is given by

$$x_{Ht}(\mathbf{m}_h) = \{\frac{1}{(1-s_{Hrt})\alpha_{Hr}w_{Ht}}\sum_n f(n;m_{Fh})[V_{Ht}(m_{Fh}+n, m_{Dh}+n) - V_{Ht}(\mathbf{m}_h)]\}^{\frac{1}{\gamma-1}}. \tag{26}$$

Likewise, the optimal adoption rate of home leader with gap $\mathbf{m}$ when $m_D > 0$ is as follows:

$$a_{Ht}(\mathbf{m}_h) = \{\frac{1}{(1-s_{Hat})\alpha_{Ha}w_{Ht}}\sum_n g(n;m_{Fh})[V_{Ht}(m_{Fh}+n, m_{Dh}+n) - V_{Ht}(\mathbf{m}_h) - (1-s_{Hat})\mathcal{F}_{Ht}(\mathbf{m}_h)]\}^{\frac{1}{\gamma-1}}. \tag{27}$$

The optimal innovation and adoption rate of home follower, foreign incumbent, and entrant are in (55), (56), (57) in Appendix C.4.

Adoption fee. The adoption fee is an endogenous object which is jointly determined with the value functions. It is a one-time payment that internalizes all the adopter's future gains and the seller's loss. The bargaining only happens 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.[44] 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. If either of the firms did not agree on the term, the adoption does not happen and both have no change in their values. $\mathcal{F}_{Ht}(\mathbf{m}_h)$, the adoption fee of the home leader is determined by the Nash bargaining, by

$$\begin{aligned}\mathcal{F}_{Ht}(\mathbf{m}_h) = &\underset{\mathcal{F}_{Ht}(\mathbf{m}_h)}{\operatorname{argmax}}(\sum_n g(n;m_{Fh})V_{Ht}(m_{Fh}+n, m_{Dh}+n) - \mathcal{F}_{Ht}(\mathbf{m}_h) - V_{Ht}(\mathbf{m}_h))^{\xi} \\ &\cdot (\sum_n g(n;m_{Fh})V_{Ft}(m_{Ff}-n, m_{Df}+n) + \mathcal{F}_{Ht}(\mathbf{m}_h) - V_{Ft}(\mathbf{m}_f))^{1-\xi},\end{aligned} \tag{28}$$

where $0 \le \xi \le 1$ is the bargaining power of the adopter. $\sum_n g(n;m_{Fh})V_{Ht}(m_{Fh}+n, m_{Dh}+n)$ is the expected value of the adopter after an adoption in which it improves the gap from all firms by n steps. Net value from adoption is the new value minus the price $\mathcal{F}_{H\mathbf{m}t}$ and its outside option is the current value $V_{Ht}(\mathbf{m})$. Likewise, the expected value of the seller after the adoption is $\sum_n g(n;m_{Fh})V_{Ft}(-m_{Ff}-n, m_{Df}+n)$ where it has lower value from the decreased relative productivity, but receives adoption fee $\mathcal{F}_{Ht}(\mathbf{m}_h)$. The outside option is the current value $V_{Ft}(-m_{Ff}, m_{Df})$. When we solve the problem in equation (28), we obtain that

[44] This is very rare in the data where only 1.3% of the contracts restrict the adopter's future exports.

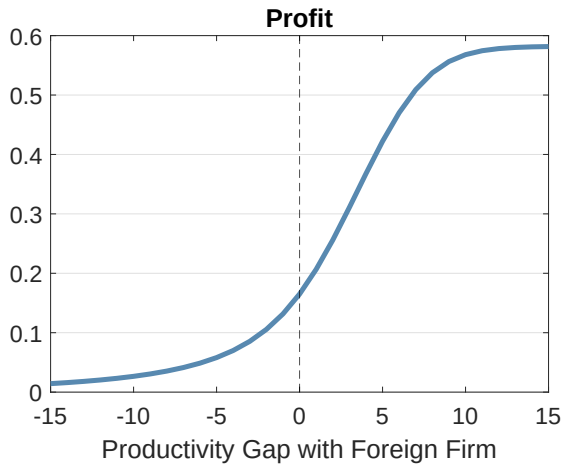


Figure 4: Profit Function over Productivity Gap with Foreign Firms

Notes: This figure plots the profit of the firm in the X-axis and productivity gap with the foreign firm in the Y-axis. We fix the gap between domestic firms as zero. We impose $\sigma = 8, D = 1.2, \lambda = 1.1$

$$\begin{aligned}\mathcal{F}_{H\mathbf{m}t} &= (1-\xi)(\sum_n g(n; m_{Fh}) V_H(m_{Fh}+n, m_{Dh}+n) - V_H(\mathbf{m}_h)) \\ &- \xi(\sum_n g(n; m_{Fh}) V_F(-m_{Ff}-n, m_{Df}+n) - V_F(\mathbf{m}_f)).\end{aligned} \tag{29}$$

The adoption fee of home follower and foreign firm are defined in a similar way in equation (53), (54) in Appendix C.3. The adoption fee is higher if the foreign firm loses more or the domestic firm gains more from the adoption. It depends on two forces: the extent of the advantage of backwardness and the competition effect. From the advantage of backwardness, the productivity gain from adoption is larger when the initial productivity gap is larger. This means the foreign firm gains more, and the domestic firm loses more as well. It makes the price higher when the productivity gap is larger. However, the gain of profit from productivity improvement increases when the initial gap is smaller. Figure 4 shows the example of the profit function over the technology gap from the foreign firm, fixing other gaps. We can see that the slope of the profit function is small when m_{Fi} is small. The slope of the profit function increases as the domestic firm gets closer to the foreign firm. Therefore, the willingness to pay for technology adoption increases with m_{Fi}.

Note that if the total surplus from the contract is negative, then the adoption contract does not happen. Several circumstances increase the total surplus, making room for technology trade. First, when the wage in the home country is lower, the foreign firm's technology can make more output in the home country and generate a positive total surplus. Second, when the trade cost is high, the two markets are more segmented, and it is more profitable 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 surplus from the adoption contract.[45] Third, firms in different countries produce imperfect substitutes. Therefore, when the elasticity of substitution is smaller, producing all varieties with good technology is valuable. Lastly, when the foreign firm sells technology, the potential entrant also loses its future profit, but the foreign firm does not internalize it.[46]

Distribution of productivity gap. The distribution of the productivity gap is the state variable in the economy. Without loss of generality, we assume h is the home leader and use the gap from the home leader's perspective as the aggregate state variable. Let $\mathbf{m} = (m_F, m_D)$. We define $\mathbb{T}_i(\mathbf{m}, n)$ as the probability that firm i improves productivity n steps when the aggregate state variable is $\mathbf{m}$ as follows,

$$\begin{aligned}
\mathbb{T}_h(\mathbf{m}, n) &= f(n; m_F) x_{Ht}(m_F, m_D) + g(n; m_F) a_{Ht}(m_F, m_D) \qquad (30)\\
\mathbb{T}_{\tilde{h}}(\mathbf{m}, n) &= \tilde{f}(n; m_F - m_D, -m_D) x_{Ht}(m_F - m_D, -m_D) + \tilde{g}(n; m_F - m_D, -m_D) a_{Ht}(m_F - m_D, -m_D)\\
\mathbb{T}_f(\mathbf{m}, n) &= f(n; -m_F)(x_{Ft}(-m_F, m_D) + \tilde{x}_{Ft}(-m_F, m_D)) + g(n; -m_F) a_{Ft}(-m_F, m_D).
\end{aligned}$$

Let $\mu_{\mathbf{m}t}$ be the share of product lines with gap $\mathbf{m}$ in time t. For computational reason, let $\bar{m}$ be the maximum productivity gap. The law of motion of $\mu_{\mathbf{m}t}$ is

$$\begin{aligned}
&\dot{\mu}_t(m_F, m_D) = \\
&\sum_{n=1}^{m_F+\bar{m}} \underbrace{\mathbb{T}_h(m_F - n, m_D - n, n)\mu_t(m_F - n, m_F - n)}_{\text{leader innovation, adoption}}\\
&+ \sum_{n=1}^{m_D} \underbrace{\mathbb{T}_{\tilde{h}}(m_F, m_D + n, n)\mu_t(m_F, m_D + n)}_{\text{follower innovation, adoption without leapfrogging}}\\
&+ \sum_{n=m_D+1}^{m_F+\bar{m}} \underbrace{\mathbb{T}_{\tilde{h}}(m_F - (n - m_D), m_D - n, n)\mu_t(m_F - (n - m_D), m_D - n)}_{\text{follower innovation, adoption with leapfrogging}} \qquad (31)\\
&+ \sum_{n=1}^{-m_F+\bar{m}} \underbrace{\mathbb{T}_f(m_F + n, m_D, n)\mu_t(m_F + n, m_D)}_{\text{foreign firms innovation, adoption}}\\
&+ \underbrace{\mathbb{1}(m_F = 0) \cdot \phi}_{\text{exogenous spillover}} - \underbrace{(\sum_{n=1} \mathbb{T}_h(m_F, m_D, n) + \mathbb{T}_{\tilde{h}}(m_F, m_D, n) + \mathbb{T}_f(m_F, m_D, n) + \phi)\mu_t(\mathbf{m})}_{\text{subtracted mass}},
\end{aligned}$$

[45] It creates an interaction between trade policy and adoption. Since the adoption fee decreases and the adoption rate rises with import tariffs, the government may want to increase import tariffs to increase the adoption rate.

[46] Even if selling technology decreases 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 discuss in more detail in Appendix F.1.

where the first line is the added mass from the home leader's innovation and adoption. The second line is from the home follower's innovation and adoption, where the follower did not leapfrog the leader. The third line is also from home followers, but they leapfrog and become a leader in this case. The fourth line is from foreign incumbents and entrants with the same structure as domestic firms. The last line indicates the added mass from the exogenous spillover, which is added to $m_F = 0$, and 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 sector has different productivity even if they have the same gap $\mathbf{m}$. Let $Q_{\mathbf{m}t}$ be the average productivity of the home leader with gap $\mathbf{m}$. Then,

$$Q_{\mathbf{m}t} = \frac{\int_{\mathbf{m}(j)=\mathbf{m}} q_{hjt} dj}{\mu_{\mathbf{m}t}}. \tag{32}$$

Asset market clearing. The asset market clears in each period by the following equation:[47]

$$A_{Ht} = \int_0^1 \sum_{i=h,\tilde{h}} V_{ijt} dj \,, \tag{33}$$

where the right-hand side is the sum of the value of all domestic firms.

Labor market clearing. In each country labor market clears by the following:

$$L_H = \int_0^1 \sum_{i=h,\tilde{h}} (l_{ijt} + \alpha_{aH} \frac{a_{ijt}^{\gamma}}{\gamma} + \alpha_{rH} \frac{x_{ijt}^{\gamma}}{\gamma}) dj. \tag{34}$$

The left-hand side is the supply of labor, which is fixed over time, and the right-hand side is the demand for 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

Government budget balance. The government holds a balanced budget in each period, namely,

$$T_{Ht} = (1+\theta) \int_0^1 \sum_{i=h,\tilde{h}} (s_{Hat} \mathcal{F}_{ijt} + s_{Hat} \alpha_{Ha} \frac{a_{ijt}^{\gamma}}{\gamma} w_H + s_{Hrt} \alpha_{Hr} \frac{x_{ijt}^{\gamma}}{\gamma} w_H) dj \,, \tag{35}$$

where θ is the reduced form parameter of the deadweight cost of taxation. Specifically, the government needs to collect $1+\theta$ tax revenue to finance one unit of government expenditure. We use

[47] We do not allow international capital flows.

$\theta = 1$ as a baseline value following Feldstein (1999).[48]

$$\int_0^1 (p^*_{fjt} y^*_{fjt} + \sum_{i=h,\tilde{h}} a_{ijt} p_{ijt}) dj = \int_0^1 (\sum_{i=h,\tilde{h}} p^*_{ijt} y^*_{ijt} + a_{fjt} p_{fjt}) dj. \tag{36}$$

We can then define a Markov perfect equilibrium of the model as:

Definition 4.1. A Markov perfect equilibrium consists of $\{r_{ct}, w_{ct}, p_{ijt}, p^*_{ijt}, y_{ijt}, y^*_{ijt}, l_{ijt}, x_{ijt}, a_{ijt}, V_{ijt}, \mu_{\mathbf{m}t}, Q_{\mathbf{m}t}, C_{ct}, A_{ct}, T_{ct}\}^{t\in[0,\infty), j\in[0,1], c\in\{H,F\}}_{i\in\{h,\tilde{h},f\}, m\in\{-\bar{m},\cdots,\bar{m}\}}$ such that:

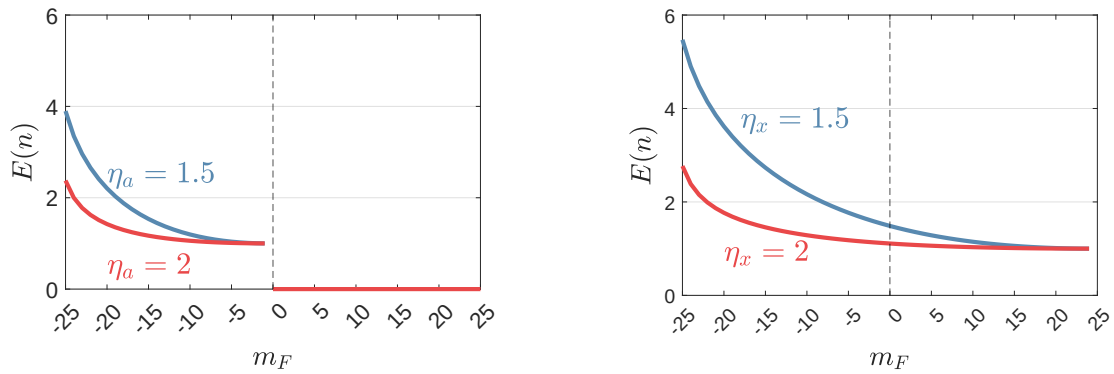
1. Given r_{ct}, household chooses C_{ct}, A_{ct} to maximize sum of discounted utility in equation (4) subject to the budget constraint in equation (5).
2. Given $\{p_{ijt}, p^*_{ijt}\}$, household chooses y_{ijt}, y^*_{ijt} to minimize expenditure in equation (7).
3. Given $\{w_{ct}, \mathbf{m}_{ijt}\}$, firm i in sector j chooses $p_{ijt}, p^*_{ijt}, l_{ijt}, l^*_{ijt}$ to maximize profit by solving equation (20), (21), and (22).
4. Given $\{r_{ct}, w_{ct}, \mathbf{m}_{ijt}, \mathcal{F}_{ijt}\}$, x_{ijt}, a_{ijt} solve firm's dynamic problem in equation (26) and (27) and V_{ijt} is determined in equation (25).
5. Given $\{V_{ijt}, \mathbf{m}_{ijt}\}$, $\mathcal{F}_{ijt}$ solve Nash Bargaining between buyer and seller in equation (29).
6. Given $\mu_{\mathbf{m}0}, Q_{\mathbf{m}0}$, $\{\mu_{\mathbf{m}t}\}_{t\in[0,\infty)}, \{Q_{\mathbf{m}t}\}_{t\in[0,\infty)}$ are consistent with x_{cijt}, a_{cijt} by equation (31).
7. w_{ct} clears labor market in each country and every period in equation (34).
8. r_{ct} clears asset market in each country and every period in equation (33).
9. T_{ct} balances government budget in every period in equation (35).

We define a balanced growth path equilibrium as follows:

Definition 4.2. Balanced growth path is the equilibrium defined in Definition 4.1 with $w_{ct}, C_{ct}, T_{ct}, Q_{\mathbf{m}t}$ grow at a rate g, and for all $\mathbf{m}$, $p_{i\mathbf{m}t}, p^*_{i\mathbf{m}t}, l_{i\mathbf{m}t}, l^*_{i\mathbf{m}t}, x_{i\mathbf{m}t}, a_{i\mathbf{m}t}, \mu_{\mathbf{m}t}$ are constant over time.

Inefficiency in the model. The model has several forces that make the competitive equilibrium not efficient. First, innovation and adoption generate intertemporal spillover through knowledge diffusion, which can potentially lead to underinvestment. While firms try to avoid generating spillover to other firms as it decreases their profit, the 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, the adoption fee increases with knowledge diffusion. This amplifies the discrepancy between

[48] Refer to Heckman et al. (1999), Heckman et al. (2010) for further discussion about deadweight loss of government financing.



A. Adoption B. Innovation

Figure 5: Expected Step Size over the Initial Productivity Gap with Foreign Firms

Notes: This figure plots the expected step size from innovation and adoption in the Y-axis and the initial productivity gap with the foreign firm in the X-axis over the different values of η_a, η_x. A negative gap denotes a domestic firm has lower productivity than a foreign firm. Panel A plots the case of adoption, and panel B plots the case of innovation. Since the distribution of adoption is truncated at $m_F = 0$, the same value of η makes different distribution between adoption and innovation.

the private and social value of adoption, which makes the underinvestment problem of adoption more severe than the innovation. Second, innovation and adoption have a business-stealing effect, which can potentially lead to overinvestment. 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. Firms might improve technology only marginally while spending substantial resources on innovation or adoption.[49] Lastly, firms have positive markup, which makes firms produce less than socially optimal.

5 Quantitative Exercise

Step size distribution from innovation $\mathbb{F}(n; m_{Fi})$ and that from adoption $\mathbb{G}(n; m_{Fi})$ are formally defined in Appendix C.6. $\mathbb{F}(n; m_{Fi})$ is defined by a single parameter η_x, and $\mathbb{G}(n; m_{Fi})$ is defined by η_a. $\eta_x, \eta_a > 0$ implies that the expected step size decreases with m_{Fi}, and the slope decreases with η_x, η_a. Figure 5 shows examples of the step size distribution over the productivity gap. The distribution of adoption is truncated at $m_F = 0$, meaning $G(n; m_F) = 0$ if $n \geq -m_F$. Therefore, the same η makes different distributions for adoption and innovation.

5.1 Step Size Distribution

5.2 Estimation

We estimate 20 parameters in three steps. Four parameters are determined directly from the data, such as populations and subsidy rates. Six parameters are externally calibrated. The remaining ten parameters are jointly estimated by simulated method of moments (SMM). Given a guess of parameters, we solve the transition of the model with the initial condition until it converges to the balanced growth path. In the initial state, Korean firms have lower productivity than foreign firms, and this difference is governed by a parameter that is jointly estimated. Along the transition, we run the same regression in the theory and the data. We then update parameters to minimize the distance between the moments from the model and the data. The computational algorithm to solve the transition is provided in Appendix D.2.

5.2.1 Parameters that are Directly from Data

We set the home country's labor supply $L_H = 1$ as a normalization and $L_F = 2$ to match Japan's relative population size. 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.[50,51] 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.

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).[52] Figure 6 shows the innovation and adoption subsidy rate over time.

We include s_{Hat}, s_{Hrt} into the model assuming perfect foresight of the agents. For country F, $s_{Fat} = 0, s_{Frt} = 0$.[53]

[49] When the elasticity of substitution is larger, this business stealing effect becomes stronger.

[50] 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.

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

[52] 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.

[53] Since we calibrate α_{Fa}, α_{Fr} different from home country to make two countries symmetric in the long run, ab-

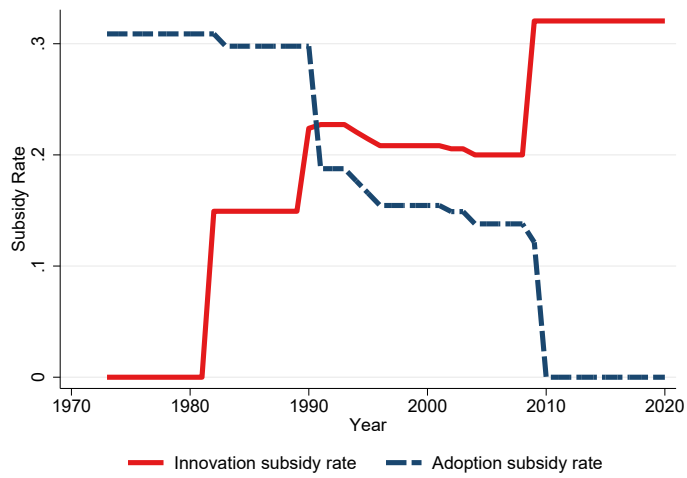


Figure 6: Innovation and Adoption Subsidy Rate in Korea

Notes: This figure plots the adoption subsidy rate in the dashed navy line and the innovation (R&D) subsidy rate in the solid red line in Korea over time. We calculate the innovation and adoption subsidy rate using using the formula from Bloom et al. (2002) using tax credit rate and corporate tax rate. Tax credit rate is from https://glaw.scourt.go.kr, R&D tax credit rate and corporate tax rate is from Choe and Lee (2012).

5.2.2 External Calibration

We use a discount rate $\rho = 0.03$, following common value in the literature. R&D and adoption cost curvature parameter γ is set to be 2 to match elasticity of successful innovation with respect to R&D as 0.5 (Blundell et al., 2002).[54] We impose $\sigma = 7$ following the average value in Broda and Weinstein (2006) for SITC 5 digit level. For iceberg trade cost between Korea and Japan, we use $D = 1.5$, following the estimates of trade cost between U.S. and Canada in Anderson and Van Wincoop (2004).

5.2.3 Simulated Method of Moments

Since the structure of firms is different in the two countries, we adjust the cost parameter for adoption and innovation in country F by assuming $\alpha_{Fr} = \alpha_F \cdot \alpha_{Hr}$, $\alpha_{Fa} = \alpha_F \cdot \alpha_{Ha}$ and adjust α_F to make the average productivity gap in the balanced growth path equal to zero.

The remaining ten parameters $\Theta = \{\lambda, \alpha_r, \alpha_a, \alpha_F, \eta_a, \eta_r, \xi, \delta, d, \phi\}$ are estimated to target 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.

$$\min_{\Theta} \sum_{i=1}^{10} \left(\frac{M_i^D - M_i(\Theta)}{\frac{1}{2}(M_i^D + M_i(\Theta))} \right)^2 . \tag{37}$$

stracting away from policy in country F does not change the results.

[54]For further discussion, refer to Akcigit et al. (2021).

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

Adoption fee / yearly sales. The adoption fee over the yearly sales in adoption contracts is 22.4% on average.[55] Likewise, we calculate the adoption fee over annualized sales in the model and compare both moments. The critical parameter determined by this moment is ξ which governs the bargaining power of the adopter.

Productivity gain from adoption and innovation over the initial gap. We replicate the regression (2) in the model, and compare the coefficients from Table B.2. We simulate 1,000,000 adopting firm and 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. Finally, we compare the regression coefficient in the model and the data in Table B.2. The key parameters identified by this moment are η_x, η_a which govern the slope of step size distribution from adoption and innovation (Figure 5).

Patent citation increase after adoption. To summarize the result in Figure 3, we run the difference-in-difference regression on patent citations from technology seller compared with control firms within 5 years from the first technology adoption in Table B.5 in Appendix B. To replicate the empirical result, we develop a simple model of patent citation. In the model, the home follower can receive knowledge diffusion from adopted technology. We assume they must 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 experiencing knowledge diffusion. We match $x \cdot \delta$, with 0.028, the coefficient in Table B.5 in Appendix B. The crucial parameter which is identified by this moment is δ, the probability of experiencing knowledge diffusion.

Long-run growth rate. The growth rate of Japan since 2010 is 1.6%, 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.

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% in 1985-1990.[56] These inform the scale parameter of innovation cost, α_r, and the scale parameter of adoption cost α_a. From equation

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

[56] We use the value in 1985-1990 as we have sector level R&D expense in that period. 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.

Table 3: Estimation Results

Parameter	Description	Value	Source
Directly From Data			
L_H	Labor in home country	1	Normalization
L_F	Labor in foreign country	2	Population in Japan
s_{Hat}, s_{Hrt}	Subsidy rate		Tax credit rate, corporate tax rate
Externally Calibrated			
ρ	Time preference	0.03	Literature
σ	Elasticity of substitution	7	Broda and Weinstein (2006)
ψ_H	Demand shifter of home good	0.25	Equal share
ψ_F	Demand shifter of foreign good	0.5	Equal share
D	Trade cost	1.5	Anderson and Van Wincoop (2004)
γ	Adoption / innovation cost curvature	2	Acemoglu et al. (2018)
Jointly Calibrated through SMM			
λ	Unit step size	1.047	
η_a	Slope of step size from adoption	1.201	
η_r	Slope of step size from innovation	1.772	
α_a	Adoption cost	1.177	
α_r	Innovation cost	1.683	Jointly Estimated through SMM
ξ	Bargaining power of adopter	0.464	
δ	Knowledge diffusion	0.231	
d	Initial productivity gap	-23.672	
α_F	Relative cost in F	5.702	
ϕ	Exogenous spillover	0.025	

(26), we can calculate the innovation expenditure function, which decreases with α_r. Likewise, α_a decreases the adoption rate and adoption expenditure which is the adoption rate times adoption fee.

GDP gap in 1973 and 2020. The initial log ratio of GDP per capita between Korea and Japan was 1.562 in 1973.[57] 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 $\mathcal{N}(d, 1)$.[58] 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 in 2020 is smaller.

Productivity gap in the long run. Since we assume two incumbents in Korea and one incumbent 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 α_F. When α_F is higher, the innovation and adoption cost in F is higher, and the long-run productivity is lower in F.

[57] GDP per capita is using purchasing power parity rates.
[58] For simplicity, we assume the variance to be one.

Table 4: Target Moments in Model and Data

Moment	Model	Data
Adoption fee / annual sale	0.221	0.224
β^a : productivity growth with gap (adoption)	-0.116	-0.120
β^i : productivity growth with gap (innovation)	-0.044	-0.046
β^s : Δ Patent citation after adoption	0.026	0.028
Long-run growth rate	0.017	0.016
Adoption / value added in manufacturing	0.016	0.015
R&D / value added in manufacturing	0.032	0.030
GDP gap in 1973	1.560	1.562
GDP gap in 2020	0.017	0.019
Long-run productivity gap	0.001	0.000

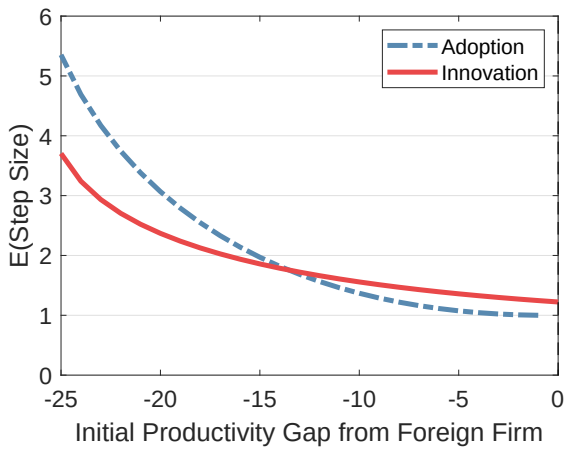
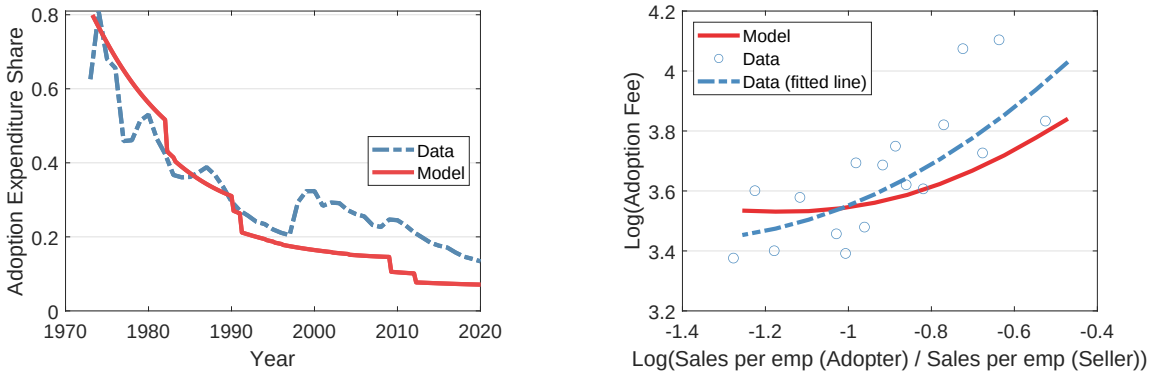


Figure 7: Step Size Distribution from Adoption and Innovation

Notes: This figure plots the expected step size from adoption (dashed blue line) and innovation (solid red line) over the initial productivity gap from the model. We impose $\eta_a = 1.201, \eta_r = 1.772$, which are the estimated values.

5.3 Estimation Results

Table 3 shows the estimation results. λ is estimated to be 1.047, which implies one step improvement increases labor productivity by 4.7%. $\eta_x > \eta_a$ implies the expected productivity gain from adoption is larger when the productivity gap with foreign firms is larger, and it is the opposite when the gap is smaller. Figure 7 shows the step size distribution from the estimated parameters, which is in line with empirical findings in figure 2. On the other hand, $\alpha_a < \alpha_r$ means adoption requires less labor. ξ, the bargaining power parameter of the adopting firm is 0.464, which implies that the adopter takes less than half of the total surplus from the adoption. δ, the probability of



A. Adoption Expenditure Share

B. Adoption Fee over Gap

Figure 8: Untargeted Moments

Notes: This figure plots the untargeted moments from the data and model. Panel A plots the adoption fee expenditure / (adoption fee + innovation cost) in the model (solid red line) along with the data (dashed blue line). Panel B plots the log (adoption fee) over the log ratio of sales per employment between domestic and foreign firms in the model (solid red line) along with the data (dashed blue line and circles).

getting knowledge diffusion is 0.231, which is much lower than one.[59] d, the initial productivity gap is -23.672, meaning the productivity of foreign firms is 2.97 times higher than that of Korean firms. α_F is 5.702, which implies F has a higher cost for innovation and adoption. The reason is that the entrant in F always has a higher incentive to innovate, and we target the long-run technology gap as zero. ϕ is 0.025, which implies firms are getting exogenous spillover with a probability of 0.025.

Table 4 shows the target moment from the data and the model. The model tightly matches the micro and macro moments in the data. In particular, the model can replicate Korea's catching up with Japan in a short period.

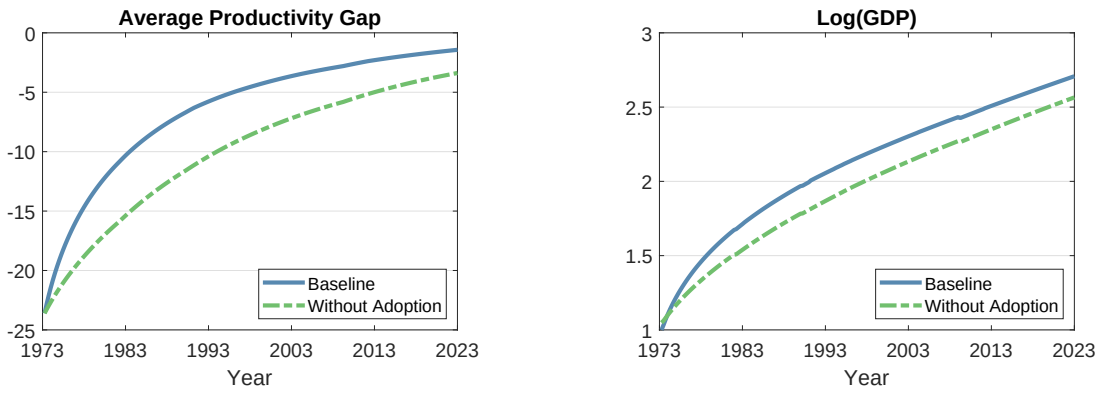
5.4 Validation

To validate the model, we present the model with two untargeted moments. The left panel of Figure 8 plots the adoption expenditure / (adoption expenditure + R&D expenditure) over time in the model and the data. Although we only target the average value of adoption and R&D / value added in 1985-1990, we can match the decreasing pattern of adoption expenditure share well.[60] This is because, in the model, as the firms are getting closer to the foreign firm, they are more likely to innovate instead of adopting foreign technologies.

The right panel of Figure 8 plots the log (adoption fee) over the log ratio of sales per employ-

[59] Most papers in the literature assume that potential entrant can always build on the incumbent technology, which fixes the probability of knowledge diffusion as one.

[60] While the policy partially generates the decreasing trend of adoption expenditure share, the model still produces decreasing adoption expenditure share without the policy change. Figure E.1 shows the case without both subsidies.



A. Average Productivity Gap

B. Log(GDP)

Figure 9: Baseline and Counterfactual without Adoption

Notes: This figure plots the average productivity gap and log(GDP) in the baseline case with adoption (blue line) and the counterfactual in which we shut down the adoption channel (dashed green line). We keep the same innovation subsidy in both cases. Panel A shows the average productivity gap between Korea and Japan over time. For instance, -10 means that the labor productivity of Korean firms divided by that of Japanese firms is λ^{-10} on average. The model has kinks when adoption and innovation subsidy change. Panel B shows $\log(\text{GDP})$ in two cases over time. Both graphs have kinks when the innovation subsidy change.

ment between domestic and foreign firms from the model and data. In the model, the adoption fee is larger when domestic firms are closer to foreign firms in terms of productivity. Since the value function changes more with relative productivity when firms are closer to each other, which makes the gain and loss from adoption is larger, which increases the adoption fee.

5.5 Contribution of Adoption and Innovation over Time

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 decompose TFP growth between adoption and innovation in each period.

The left panel of figure 9 shows the average productivity gap over time in the baseline case and the case where we shut down the adoption but keeps innovation subsidies. It shows that convergence is much slower without adoption, especially in the early years. This is because adoption provides a better way to reduce the gap from the foreign firm in the early period. The right panel of figure 9 compares $\log(\text{GDP})$ over time with the baseline case and the case without adoption. We find that Korea loses a substantial portion of GDP when we shut down GDP. In particular, the growth rate is much higher with adoption in the early period. GDP in 2023 would have been 13.3% lower, and consumption-equivalent welfare in the infinite horizon would have been 11.77% lower without adoption.

We then decompose the TFP growth between adoption and innovation over time. We define

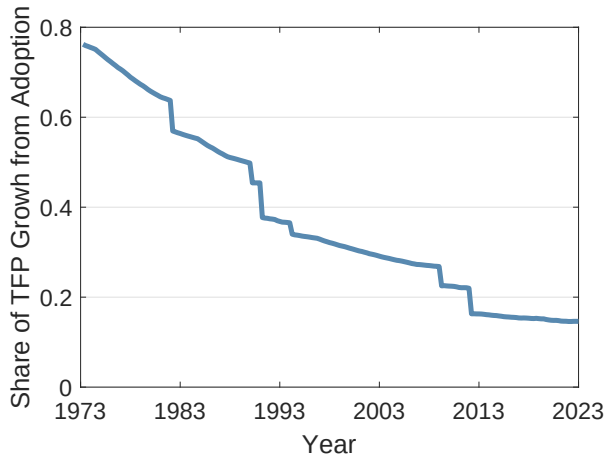


Figure 10: Share of TFP Growth from Adoption over Time

Notes: This figure plots the share of TFP growth from adoption, which is defined as TFP growth from adoption / (TFP growth from adoption + TFP from innovation). TFP is defined as $\exp(\int_0^1 \ln((\psi_H^{\frac{1}{\sigma}} q_{H1jt}^{\frac{\sigma-1}{\sigma}} + \psi_H^{\frac{1}{\sigma}} q_{H2jt}^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}})dj)$. It has kinks when adoption or innovation subsidy change.

TFP as below:

$$\text{TFP}_{Ht} = \exp(\int_0^1 \ln((\psi_H^{\frac{1}{\sigma}} q_{H1jt}^{\frac{\sigma-1}{\sigma}} + \psi_H^{\frac{1}{\sigma}} q_{H2jt}^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}})dj). \tag{38}$$

Specifically, we simulate TFP in the next period with innovation only and adoption only and get the TFP growth rate separately. Then, we decompose TFP growth between adoption and innovation.

Figure 10 shows the contribution of adoption on growth is 76% in 1973, whereas it becomes 15% in 2022. 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.

6 Policy Analysis

In this section, we start by discussing the policy implication of the model. Then, we evaluate the technology policies implemented in Korea since 1973, which started with an adoption subsidy and switched to an innovation subsidy as in Figure 6. Next, we study the optimal timing of the switch from adoption to innovation subsidy while fixing the subsidy rate. Finally, we study the joint optimal subsidy rate and timing to switch. In Appendix F.1, we study the effect of Japanese policy where the government prevents firms from exporting technology.

6.1 Policy Implications of the Model

As we discussed in Section 4, one of the reasons why the competitive equilibrium of our model is not efficient is that adoption and innovation have intertemporal spillovers through knowledge diffusion across domestic firms. The size of intertemporal spillover is proportional to the productivity gain from adoption and innovation. Since our empirical analysis suggests the productivity gain from adoption is larger than that from innovation at the early stages of development, the optimal subsidy rate is larger for adoption than innovation initially. As domestic firms catch up with foreign firms, the productivity gain from adoption diminishes, and the optimal adoption subsidy rate decreases while the optimal innovation subsidy rate increases. This logic leads to the optimal policy which depends on the productivity gap between domestic and foreign firms. We start by studying evaluating the actual policy in Korea, which has changed as the productivity of Korean firms converged with that of foreign firms.

6.2 Evaluation of Technology Policy in Korea

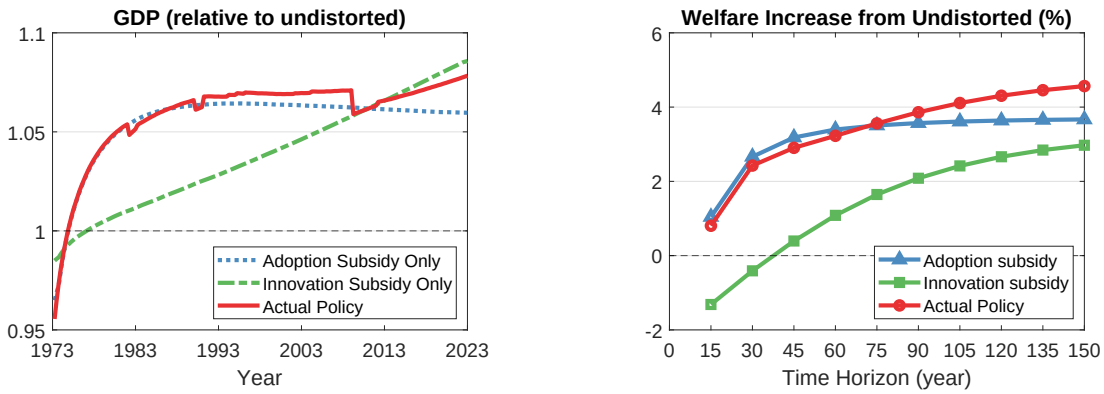
We include both adoption and innovation subsidies over the year from the data as in Figure 6 in the actual policy case. We compare the actual policy with three counterfactuals. First, we shut down both subsidies, which we consider an undistorted case. Second, the government subsidizes only adoption at 31%, the initial value in the actual policy. Lastly, the government subsidizes only innovation at 32%, the final value in the actual policy.[61]

The left panel of Figure 11 shows GDP relative to the undistorted case without both subsidies over time. When we subsidize adoption only, it generates a higher growth rate at the early stage. GDP becomes larger than case without policy. However, relative GDP eventually flattens and even decreases slightly, implying that subsidizing only adoption does not generate a significantly higher long-run growth rate. In another counterfactual subsidizing only innovation does not yield a higher growth rate at the beginning compared with the adoption subsidy case. However, it yields a higher growth rate at later stages of development. This is because subsidizing innovation in the early years can be distortive, allocating resources to innovation instead of adoption, even though adoption has a larger positive externality. Lastly, the actual policy yields GDP similar to the adoption subsidy case and also yields a higher growth rate at later stages of development.

The right panel of Figure 11 shows the welfare implication of the policies over the different time horizons. Specifically, we calculate the discounted sum of the utility of different time horizons. Then, we calculate the percentage increase from the undistorted case without both subsidies in terms of consumption units. The consumption-equivalent change Ψ is given such that

$$U_T \int_{t=0}^{T} \exp(-\rho t) \log(C_{Ht}) dt = \int_{t=0}^{T} \exp(-\rho t) \log(\hat{C}_{Ht}(1+\Psi)) dt \,, \tag{39}$$

[61] In Figure E.2, we compare the baseline case with the cases when we shut down either adoption or innovation subsidies to decompose the contribution of actual adoption and innovation subsidies.



A. Relative GDP

B. Welfare Increase (%)

Figure 11: Results of the Counterfactual Analysis

Notes: This figure evaluates the actual policy by comparing with counterfactuals. Panel A plots GDP in three scenarios divided by GDP in the undistorted case. The dotted blue line is when subsidizing only adoption at 31%, the dashed green line is when subsidizing only innovation at 32%, and the solid red line is when imposing the actual policy in Figure 6. Panel B plots welfare increase compared to the undistorted case in different time horizons. For instance, time horizon 15 means that we calculate discounted sum of utility from year 0 to 15. Welfare increase is calculated in consumption-equivalent unit using the equation (39).

where $\hat{C}_{Ht}$ is the consumption in the benchmark case. For example, $T = 15, \Psi = 0.03$ means the welfare within a 15 year horizon is equivalent to the case when we uniformly increase consumption by 3% in the benchmark case. When the time horizon is short such as 15 or 30 years, subsidizing innovation generates lower welfare than the undistorted case. This is because firms are investing much labor in innovation, which is not an efficient way to improve productivity compared with adoption at this stage. The result implies that when developing countries follow an innovation policy, a common policies in developed countries, it may reduce welfare in the short run, which makes it hard to sustain.

In the infinite horizon ($T = \infty$), the actual policy increases the consumption-equivalent welfare by 4.84%, which is higher than subsidizing only adoption (3.69%) or subsidizing only innovation (3.28%). This result suggests that the actual policy implemented in Korea was qualitatively close to the optimal policy.

6.3 Optimal Timing to Switch

The previous result suggests that the state-dependent policy, which switched from adoption to innovation subsidy generates higher welfare than other alternatives. Motivated by this, we study the optimal timing to switch from adoption to innovation subsidy. Specifically, we assume that the government starts with an adoption subsidy rate of 32% (maximum subsidy rate in the actual policy), and it can switch to an innovation subsidy of 32% in a single year. In the long run, it keeps the innovation subsidy rate at 32%. We find the optimal timing to switch to maximize infinite

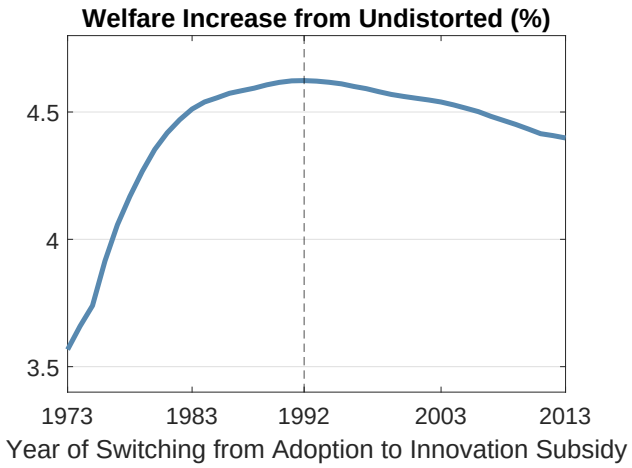


Figure 12: Welfare Increase over Different Year to Switch from Adoption to Innovation

Notes: This figure plots the welfare increase compared with the case without policy over different timings of switching. Welfare increase is in consumption-equivalent unit. We start with an adoption subsidy of 32% and an innovation subsidy of 0% and switch to an adoption subsidy of 0% and an innovation subsidy of 32% in a certain year. In 1992, the GDP per capita in Korea was 57% of that of Japan.

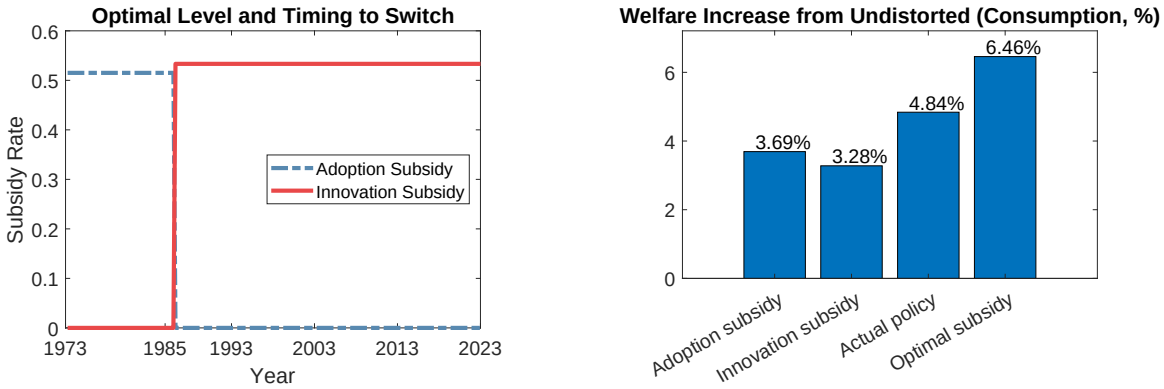
horizon welfare.

Figure 12 shows the welfare increase compared to the undistorted case in consumption units over different timing to switch. The result suggests that it was optimal to switch from adoption to innovation subsidy in 1992, which increases consumption-equivalent welfare by 4.62%. 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 innovation subsidies at a certain point. The actual policy in Korea decreased the adoption subsidy in 1991 and increased the innovation subsidy in 1989 (Figure 6). Our result suggests that the actual policy was close to the optimal in terms of timing to switch from adoption to innovation subsidy. However, the actual policy yielded higher welfare than this policy because the actual policy gradually changes subsidy rates over time, and also the sum of adoption and innovation subsidy rates is larger in some periods.

6.4 Optimal Rate of Subsidies and Timing to Switch

In this section, we study the optimal policy in a more general setting. We allow the government to choose the adoption subsidy rate, innovation subsidy rate, and the timing to switch from the adoption to the innovation subsidy.[62]

[62] We assume that the government can change the policy only once due to commitment issues or political costs.



A. Optimal Subsidy Rates

B. Welfare increase (%)

Figure 13: Optimal Subsidy Rates and Welfare Increase

Notes: This figure plots the optimal subsidy and welfare results. Panel A plots the optimal adoption (dashed blue line) and innovation subsidy rate (solid red line). We allow the government can choose an adoption rate, innovation rate, and year to change from adoption to innovation subsidy. The optimal policy is to start adoption subsidy at 52% and switch to innovation subsidy in 1985, at 53%. In 1985, the GDP per capita in Korea was 54% of that of Japan. Panel B plots the welfare increase from the benchmark case without both subsidies in consumption-equivalent units.

The left panel of Figure 13 shows the optimal subsidies over time. The optimal policy is to start the adoption subsidy at 52% and switch to an innovation subsidy in 1985 of 53%. The timing of the switch is earlier than the previous exercise because the adoption subsidy rate is higher, and Korea catches up with Japan more quickly. The right panel of Figure 13 plots the welfare increase in different policies. The optimal subsidy increases consumption-equivalent welfare by 6.46%, substantially higher than the actual policy.

To interpret the result to be applicable to other developing countries, we calculate the relative GDP per capita of Korea compared with Japan in the year of the switch. GDP per capita in Korea was 54% of that of Japan in 1985, which suggests that it could be better to switch from adoption to innovation subsidy when developing countries reach roughly half of GDP per capita of the frontier countries.[63]

In Appendix F.2, we study the optimal linear subsidy in which we allow the government to subsidize both adoption and innovation, and the subsidy rate is a linear function of time.

7 Conclusion

In this paper, we study the role of adoption and innovation in development and their policy implications over different stages of development. We build a new model where firms can innovate or adopt technologies from foreign firms. The novel part of the model is that it captures the incen-

[63]This conclusion depends on the cost parameter of adoption and innovation, which can depend on other variables such as human capital, quality of institutions.

tives of both buyers and sellers of technologies and studies strategic behavior between them. A novel firm-to-firm technology import dataset from Korea disciplines this crucial part of the model.

Using the quantified model, we evaluate the actual policy in Korea, which sheds light on the optimal state-dependent policy. Korea started with an adoption subsidy and then gradually switched to an innovation subsidy. The state-dependent policy generates a 4.84% increase in welfare, which is higher than other alternatives, such as subsidizing only adoption (3.69%) or subsidizing only innovation (3.28%). When the government subsidizes only innovation, welfare is smaller than the undistorted case without both subsidies over 30 years. Also, if the government subsidizes only adoption, it only increases short-run growth rate, not the long-run growth rate.

Many developing countries have been trying to improve their technology by following the technology policies of developed countries. However, there are necessary steps that developing countries should follow to develop. It is not easy to study state-dependent policies since it usually takes a long time for a country to develop. Since Korea started as a low-income country and became a high-income country in a short period, it provides important insights for other developing countries to design long-term policies over different stages of development. Our results suggest that governments in developing countries should start with adoption subsidies at a high rate (52%). Then, when the GDP per capita reaches roughly half of that of frontier countries, it needs to consider switching to an innovation subsidy.

We believe that our framework can be used to study broader questions. Other cross-country comparison would be interesting. What is the experience of other developing countries? Are there any fundamental factors that increase the effectiveness of technology adoption? These questions are important for giving general policy advice that can be helpful to other developing countries.

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A Appendix: Data

A.1 Technology Adoption data

Figure A.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 A.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.

We digitize technology transfer contracts between Korean and foreign firms from the national archives in Korea. Figure A.1 A.2 show an example of a document.

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. Table A.1 shows the industry composition of the contracts in which 95% of contracts are in manufacturing. Table A.2 shows the share of origin countries.

The average royalty rate is 3.28%. The average fixed fee is 1.29 million dollars, which accounts for 1.97% of yearly sales, and the average contract length is 5.13 years.[64]

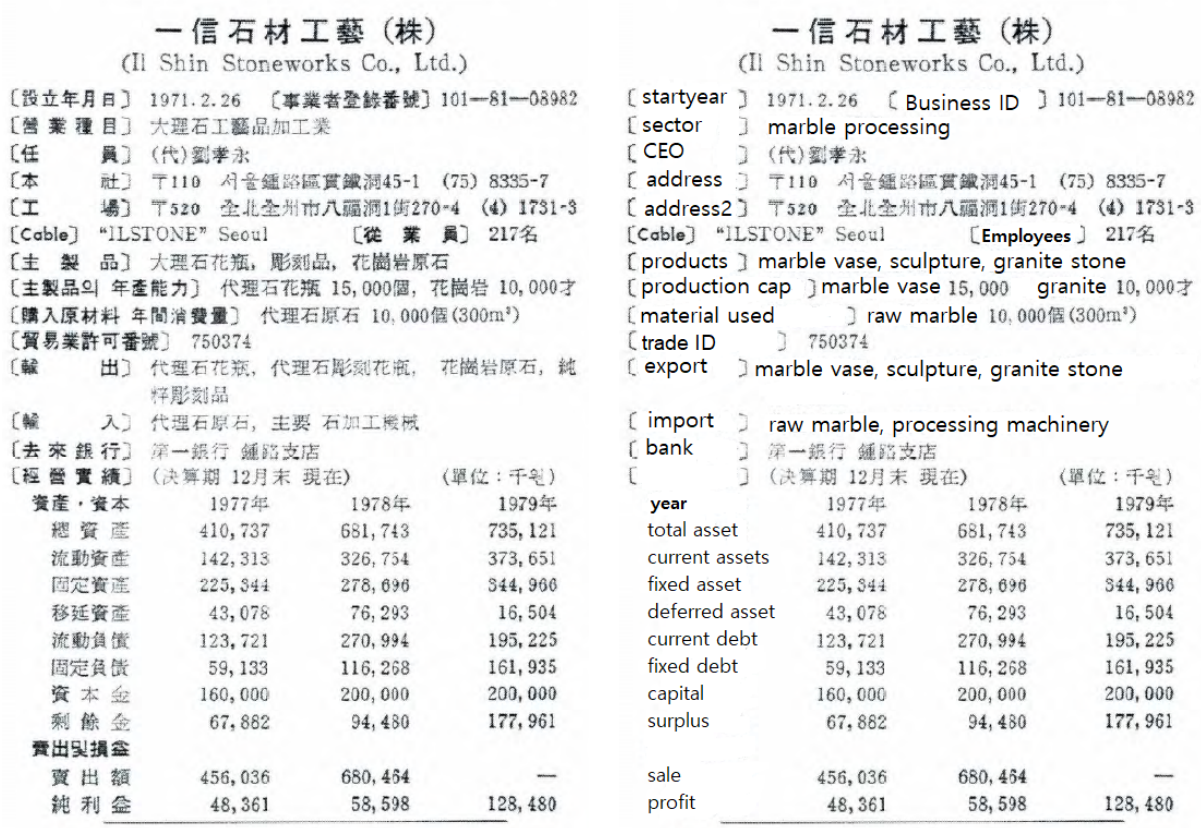
[64] 61.38% of contracts have royalty payments, 76.56% have fixed fees, and 37.97% have both.

Table A.1: Industry Composition of Technology Adoption

Sector	Frequency	Percent
Machinery	2,225	26.48
Electronics	2,090	24.87
Chemical manufacturing	1,359	16.17
Chemical fiber	414	4.93
Metal	412	4.90
Food	264	3.14
Non-metallic products	225	2.68
Shipbuilding	224	2.67
Pharmaceutical	204	2.43
Construction	151	1.80
Telecommunications	131	1.56
Electrics	92	1.09
Textile	66	0.79
Paper	35	0.42
Agriculture	30	0.36
Etc.	482	5.73
Total	8,404	100.00

Table A.2: Country Composition of Technology Adoption

Country	Frequency	Percent
Japan	4,177	50.02
United States	2,193	26.26
Germany (West)	461	5.52
France	339	4.06
United Kingdom	308	3.69
Italy	146	1.75
Switzerland	129	1.54
Netherlands	113	1.35
Canada	78	0.93
Sweden	57	0.68
Belgium	55	0.66
Norway	47	0.56
Denmark	44	0.53
Australia	37	0.44
Austria	26	0.31
Finland	23	0.28
Russia	21	0.25
Hong Kong	19	0.23
Singapore	11	0.13
Etc.	66	0.81
Total	8,350	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 A.3: Snapshot of Annual Reports of Korean Companies

A.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 A.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.[65] 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.

Variables. 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

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

Table A.3: Comparison between Adopting and Non-Adopting Firms

	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: This table shows the average of variables between adopting and non-adopting firms. We calculate average values for 1971-1993. Adopting firm is defined as a firm that has at least one adoption contract. Total assets, sales, and sales per employee are in a million dollar converted in 2015 values.

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.

A.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 8,404 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.

A.4 Summary Statistics

Table A.3 shows the summary statistics of adopting and non-adopting firms in 1971-1993. Adopting firms have at least one adoption contract in a given year. 6.21% of total firms adopt technology. They have a bigger size in terms of employment and total assets. Also, on average they have larger total sales and larger sales per employee. Lastly, we compare the patenting dummy variables between the two groups. Adopting firms are much more likely to apply for a patent.

A.5 Distribution of Variables of Adopting Firms and Non-adopting Firms

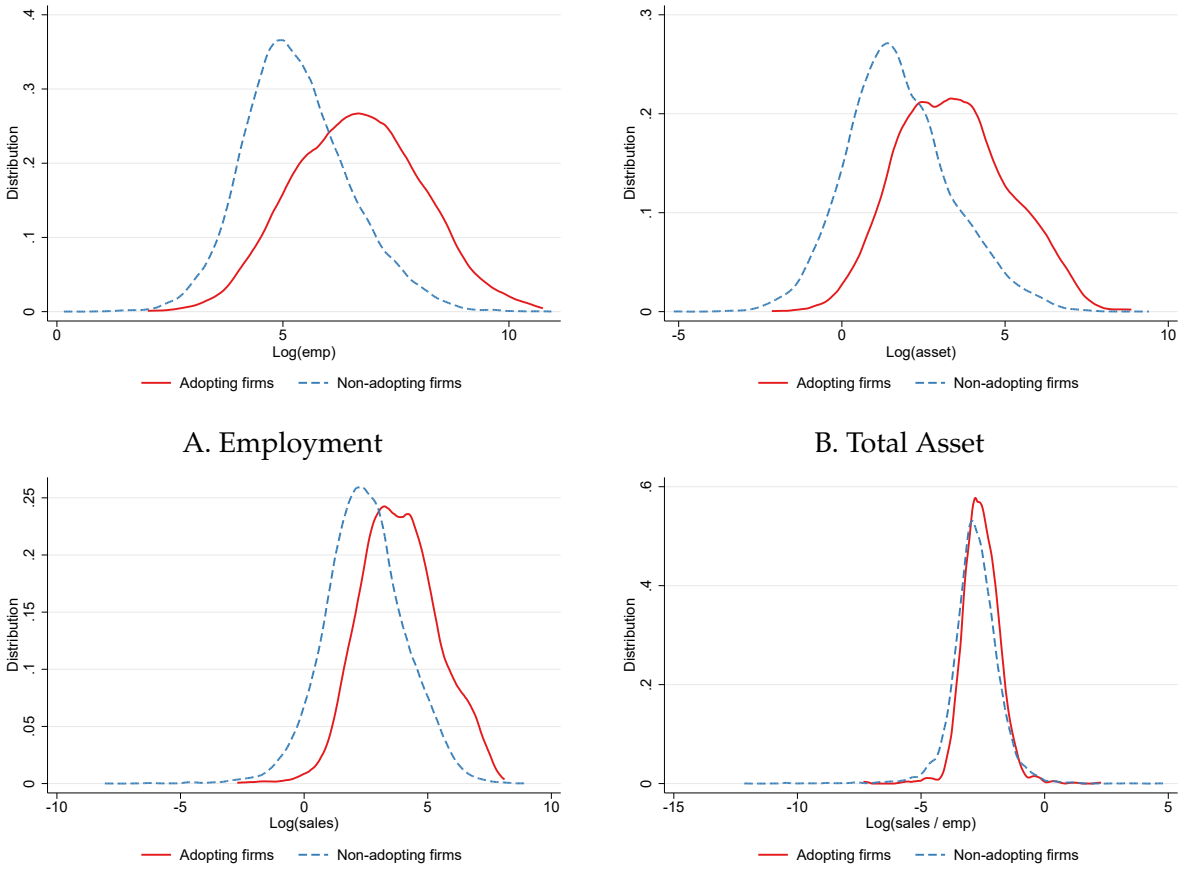


Figure A.4: Distribution of Adopting and Non-adopting Firms

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.

B Empirical Analysis: Robustness Checks and Additional Graphs

Figure B.1 plots the time-series trend regarding GDP ratio between Korea and Japan, and the adoption expenditure share. GDP ratio is real GDP per capita of Korea divided by real GDP per capita of Japan. The adoption expenditure share is the adoption expenditure divided by sum of adoption and R&D expenditure. Firms were relying more on adoption at the early period, and they gradually switched to innovation over time. The left panel of Figure B.2 plots adoption expenditure only to Japan, and the right panel of Figure B.2 plots adoption and R&D expenditure divided by GDP, separately.

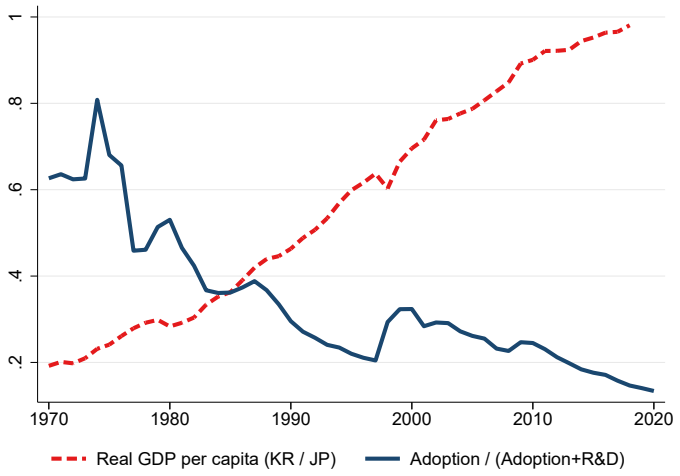


Figure B.1: GDP Gap and Adoption Expenditure Share over Time

Notes: This figure plots the ratio of real GDP per capita between Korea and Japan in the dashed red line and adoption expenditure / (adoption expenditure + R&D expenditure) in the solid navy line. Adoption expenditure is the 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), and R&D and adoption expense are from the Statistics Korea.

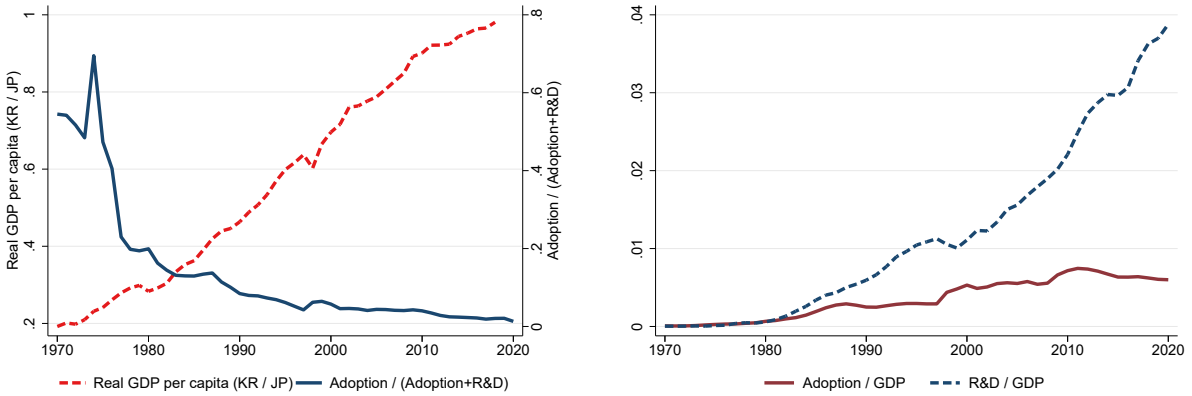


Figure B.2: Relative GDP per Capita, Adoption Expenditure, and R&D Expenditure over Time

Notes: The left panel plots the ratio of real GDP per capita between Korea and Japan in the dashed red line and adoption expenditure / (adoption expenditure + R&D expenditure) in the solid navy line. Adoption expenditure is the gross payment to only Japanse 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), and R&D and adoption expense are from the Statistics Korea. The right panel plots adoption expenditure (to all foreign firms) in the solid brown line, and R&D expenditure divided by GDP over time in the dashed navy line.

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

Table B.1: Regression of Patent / (Patent+Adoption) with Productivity Gap

	Innovation share	
	Sector-level	Firm-level
Gap	0.202***	0.0667***
	(0.0530)	(0.0161)
N	241	1,520
Adjusted R2	0.3625	0.2770
Sector FE	.	yes
Year FE	yes	yes

Standard errors in parentheses

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

Notes: In the first column, we regress the number of patents divided by the sum of the number of patents and the number of adoption contracts over the productivity gap at the sector-year. Productivity gap is the log value added per employment of Korea divided by that of Japan in each sector and year. Sector-level data is from STAN OECD data. We include year fixed effects. Second column is the same regression at the firm-level. 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.

Table B.2: Sales per Employee Growth over the Initial Productivity Gap

	Δ log(sales/emp)		
	Adopting	Innovating	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 (2). 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, and include sector and year fixed effects. Standard errors are clustered at the Korean firm level.

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

Table B.3: 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.

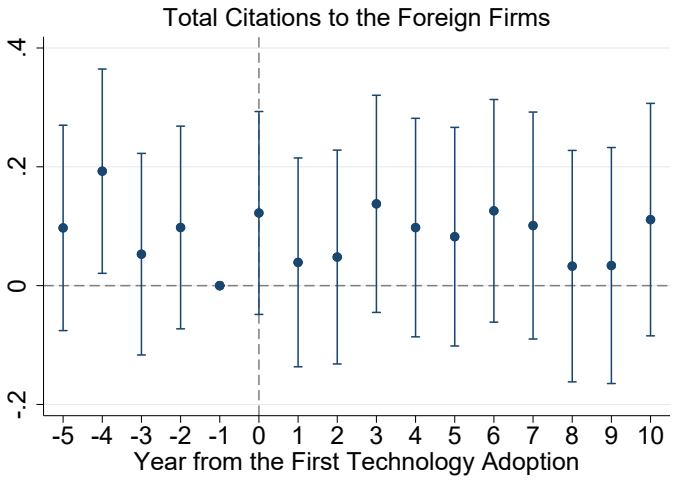


Figure B.3: Event Study Result of Patent Citations (placebo)

Notes: The figure plots β_k^{Seller} in equation (3), 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.

Table B.5 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.

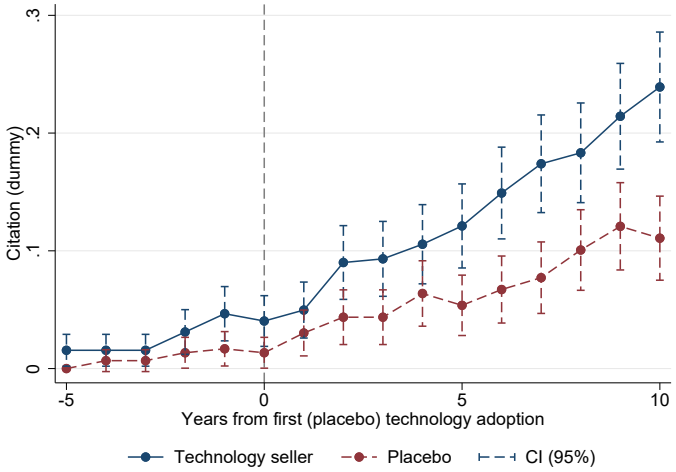


Figure B.4: Raw average of patent citations between two groups

Notes: The figure plots the average number of the citations from Korean never-adopters to the foreign firms that sold technology (solid navy line), and to the foriegn firms that did not (dashed red line). Vertical line is 95% confidence interval.

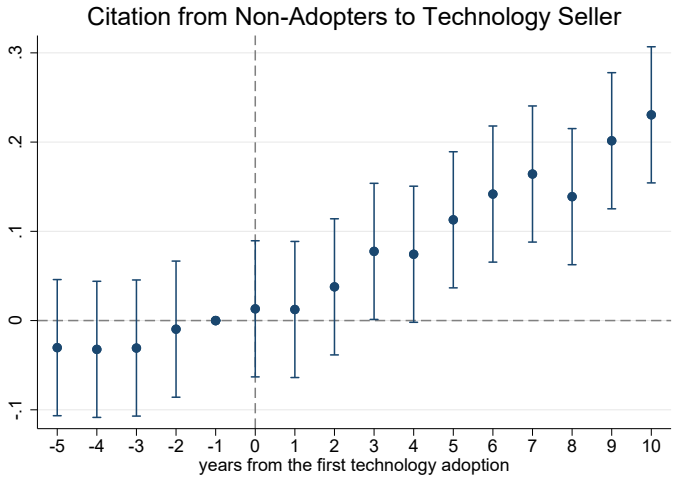


Figure B.5: Event study result of patent citations: intensive margin

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 B.4: 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

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

Table B.5: 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^{s} in equation (40), which is the average 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.

C Appendix: Model

C.1 Equations for Foreign Country

Final consumption C_{Ft} is given by

$$C_{Ft} = \exp(\int_0^1 \ln((\psi_H^{\frac{1}{\sigma}} y_{hjt}^{*\frac{\sigma-1}{\sigma}} + \psi_H^{\frac{1}{\sigma}} y_{\tilde{h}jt}^{*\frac{\sigma-1}{\sigma}} + \psi_F^{\frac{1}{\sigma}} y_{fjt}^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}})dj). \tag{41}$$

The price index of final consumption P_{Ft} is given by

$$P_{Ht} = \exp(\int_0^1 \ln((\psi_H^{\frac{1}{\sigma}} p_{ht}^{1-\sigma} + \psi_H^{\frac{1}{\sigma}} p_{\tilde{h}t}^{1-\sigma} + \psi_F^{\frac{1}{\sigma}} p_{ft}^{*1-\sigma})dj). \tag{42}$$

Productivity gap for the foreign firm is given by

$$\frac{q_{fj}}{q_{hj}} = \frac{\lambda^{N_{fj}}}{\lambda^{N_{hj}}} = \lambda^{\boldsymbol{m_{Ff}}}, \quad m_{Ff} \in \mathbb{Z}, \tag{43}$$

where we assume h is the leader without loss of generality.

Equilibrium. The expenditure in sector j by Household in country F is

$$\sum_{i=h,\tilde{h}} p_{ij} y_{ij} + p_{fj}^* y_{fj}^* = P_H C_H. \tag{44}$$

By solving the household utility maximization problem given the variety price, s_{ij}^*, the market share of firm $i \in \{h, \tilde{h}\}$ and s_{fj}, the market share of firm f in the foreign market are

$$s_{ij}^* = \frac{\psi_H p_{ij}^{*1-\sigma}}{\sum_{i=h,\tilde{h}} \psi_H p_{ij}^{*1-\sigma} + \psi_F p_{fj}^{1-\sigma}}, \qquad s_{fj} = \frac{\psi_F p_{fj}^{1-\sigma}}{\sum_{i=h,\tilde{h}} \psi_H p_{ij}^{*1-\sigma} + \psi_F p_{fj}^{1-\sigma}}. \tag{45}$$

And the demand y_{ij}^*, y_{fj} are:

$$y_{ij}^* = \frac{p_{ij}^{*-\sigma}}{\sum_{i=h,\tilde{h}} p_{ij}^{*1-\sigma} + p_{fj}^{1-\sigma}}, \qquad y_{fij} = \frac{p_{fj}^{-\sigma}}{\sum_{i=h,\tilde{h}}^2 p_{ij}^{*1-\sigma} + p_{fj}^{1-\sigma}}. \tag{46}$$

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

$$p_{ij}^* = \frac{1 - \frac{\sigma-1}{\sigma} s_{ij}^*}{\frac{\sigma-1}{\sigma}(1 - s_{ij}^*)} \frac{D \cdot w_H}{q_{ij}}, \qquad p_{fj} = \frac{1 - \frac{\sigma-1}{\sigma} s_{fj}}{\frac{\sigma-1}{\sigma}(1 - s_{fj})} \frac{w_F}{q_{fj}}. \tag{47}$$

The profit functions from country F are.

$$\pi_{ij}^* = \frac{s_{ij}^*(1 - \frac{\sigma-1}{\sigma})}{1 - \frac{\sigma-1}{\sigma} s_{ij}^*}, \qquad \pi_{fj} = \frac{s_{fj}(1 - \frac{\sigma-1}{\sigma})}{1 - \frac{\sigma-1}{\sigma} s_{fj}}. \tag{48}$$

Finally, the total profit of the firm f in sector j is

$$\Pi_{fj} = \pi_{fj} P_F Y_F + \pi^*_{fj} P_H Y_H. \tag{49}$$

C.2 Value Function

Value function of firm $\tilde{h}$ with a state variable $\mathbf{m}_{\tilde{h}} = \{m_{F\tilde{h}}, m_{D\tilde{h}}\}$ when $m_{D\tilde{h}} < 0$ is as below:

$$\begin{aligned}
& r_{Ht} V_{Ht}(\mathbf{m}_{\tilde{h}}) - \dot{V}_{Ht}(\mathbf{m}_{\tilde{h}}) \\
&= \max_{x_{Ht}(\mathbf{m}_{\tilde{h}}), a_{Ht}(\mathbf{m}_{\tilde{h}})} \underbrace{\Pi_{Ht}(\mathbf{m}_{\tilde{h}})}_{\text{profit}} - (1 - s_{Hrt}) \underbrace{\alpha_{Hr} \frac{x_{Ht}(\mathbf{m}_{\tilde{h}})^{\gamma}}{\gamma} w_{Ht}}_{\text{innovation cost}} - (1 - s_{Hat}) \underbrace{\alpha_{Ha} \frac{a_{Ht}(\mathbf{m}_{\tilde{h}})^{\gamma}}{\gamma} w_{Ht}}_{\text{adoption cost}} \\
&+ x_{Ht}(\mathbf{m}_{\tilde{h}}) \sum_n \tilde{f}(n; \mathbf{m}_{\tilde{h}}) \underbrace{[V_{Ht}(m_{F\tilde{h}} + n, m_{D\tilde{h}} + n) - V_{Ht}(\mathbf{m}_{\tilde{h}})]}_{\text{gain from innovation}} \\
&+ a_{Ht}(\mathbf{m}_{\tilde{h}}) \sum_n g(n; \mathbf{m}_{\tilde{h}}) [(\underbrace{V_{Ht}(m_{F\tilde{h}} + n, m_{D\tilde{h}} + n) - V_{Ht}(\mathbf{m}_{\tilde{h}})}_{\text{gain from adoption}} - (1 - s_{Hat}) \underbrace{\mathcal{F}_{Ht}(\mathbf{m}_{\tilde{h}})}_{\text{adoption fee}})] \\
&+ x_{Ht}(\mathbf{m}_h) \sum_n \tilde{f}(n; m_{Fh}) \underbrace{[V_{Ht}(m_{F\tilde{h}}, m_{D\tilde{h}} - n) - V_{Ht}(\mathbf{m}_{\tilde{h}})]}_{\text{loss from leader innovation}} \\
&+ a_{Ht}(\mathbf{m}_h) \sum_n \tilde{g}(n; m_{Fh}) \underbrace{[V_{Ht}(m_{F\tilde{h}}, m_{D\tilde{h}} - n) - V_{Ht}(\mathbf{m}_{\tilde{h}})]}_{\text{loss from leader adoption}} \\
&+ (x_{Ft}(\mathbf{m}_f) + \tilde{x}_{Ft}(\mathbf{m}_f)) \sum_n f(n; m_{Ff}) \underbrace{[V_{Ht}(m_{F\tilde{h}} - n, m_D) - V_{Ht}(\mathbf{m}_{\tilde{h}})]}_{\text{loss from foreign firm innovation}} \\
&+ a_{Ft}(\mathbf{m}_f) \sum_n g(n; m_{Ff}) \underbrace{[V_{Ht}(m_{F\tilde{h}} - n, m_D) - V_{Ht}(\mathbf{m}_{\tilde{h}})]}_{\text{loss from foreign firm adoption}} \\
&+ \phi \underbrace{(V_{Ht}(0, m_D) - V_{Ht}(\mathbf{m}_{\tilde{h}}))}_{\text{exogenous spillover}}].
\end{aligned} \tag{50}$$

Value function of foreign firm is as below:

$$
\begin{aligned}
& r_{Ft}V_{Ft}(\mathbf{m}_f) - \dot{V}_{Ft}(\mathbf{m}_f) \\
&= \max_{x_{Ft}(\mathbf{m}_f), a_{Ft}(\mathbf{m}_f)} \underbrace{\Pi_{Ft}(\mathbf{m}_f)}_{\text{profit}} - (1 - s_{Frt}) \underbrace{\alpha_{Fr} \frac{x_{Ft}(\mathbf{m}_f)^\gamma}{\gamma} w_{Ft}}_{\text{innovation cost}} - (1 - s_{Fat}) \underbrace{\alpha_{Fa} \frac{a_{Ft}(\mathbf{m}_f)^\gamma}{\gamma} w_{Ft}}_{\text{adoption cost}} \\
&+ x_{Ft}(\mathbf{m}_f) \sum_n f(n; m_{Ff}) \underbrace{[V_{Ft}(m_{Ff} + n, m_{Df}) - V_{Ft}(\mathbf{m}_f)]}_{\text{gain from innovation}} \\
&+ a_{Ft}(\mathbf{m}_f) \sum_n g(n; m_{Ff}) [(\underbrace{V_{Ft}(m_{Ff} + n, m_{Df}) - V_{Ft}(\mathbf{m}_f)}_{\text{gain from adoption}} - (1 - s_{Fat}) \underbrace{\mathcal{F}_{Ft}(\mathbf{m}_f)}_{\text{adoption fee}})] \\
&+ x_{Ht}(\mathbf{m}_h) \sum_n f(n; m_{Fh}) \underbrace{[V_{Ft}(m_{Ff} - n, m_{Df} - n) - V_{Ft}(\mathbf{m}_f)]}_{\text{loss from home leader innovation}} \\
&+ a_{Ht}(\mathbf{m}_h) \sum_n g(n; m_{Fh}) [\underbrace{V_{Ft}(m_{Ff} - n, m_{Df} - n) - V_{Ht}(\mathbf{m}_f)}_{\text{loss from home leader adoption}} + \underbrace{\mathcal{F}_{Ht}(\mathbf{m}_h)}_{\text{adoption fee}}] \\
&+ x_{Ht}(\mathbf{m}_{\tilde{h}}) \sum_n \tilde{f}(n; \mathbf{m}_{\tilde{h}}) \underbrace{[V_{Ft}(\min\{m_{Ff}, m_{Ff} + m_{Df} - n\}, \max\{m_{Df} - n, n - m_{Df}\}) - V_{Ft}(\mathbf{m}_f)]}_{\text{loss from home follower innovation}} \\
&+ a_{Ht}(\mathbf{m}_{\tilde{h}}) \sum_n \tilde{g}(n; \mathbf{m}_{\tilde{h}}) \underbrace{[V_{Ft}(\min\{m_{Ff}, m_{Ff} + m_{Df} - n\}, \max\{m_{Df} - n, n - m_{Df}\}) - V_{Ft}(\mathbf{m}_f)]}_{\text{loss from home follower adoption}} + \underbrace{\mathcal{F}_{Ht}(\mathbf{m}_{\tilde{h}})}_{\text{adoption fee}}] \\
&- \underbrace{\tilde{x}_{Ft}(\mathbf{m}_{\tilde{f}}) V_{Ht}(\mathbf{m}_h)}_{\text{replaced by entrant}}] + \phi \underbrace{(V_{Ht}(0, m_D) - V_{Ht}(\mathbf{m}_h))}_{\text{exogenous spillover}}].
\end{aligned}
\tag{51}
$$

Value function of potential entrant $\tilde{f}$ in country F is defined as below:

$$
\begin{aligned}
r_{Ft}\tilde{V}_{Ft}(\mathbf{m}_f) - \dot{\tilde{V}}_{Ft}(\mathbf{m}_f) &= \max_{\tilde{x}_{Ft}(\mathbf{m}_f)} -(1 - s_{Frt}) \underbrace{\tilde{\alpha}_{Fr} \frac{(\tilde{x}_{Ft}(\mathbf{m}_f))^\gamma}{\gamma} w_{Ft}}_{\text{innovation cost}} \\
&+ \tilde{x}_{Ft}(\mathbf{m}_f) \sum_n g(n; m_{Ff}) V_{Ft}(m_{Ff} + n, m_{Df}).
\end{aligned}
\tag{52}
$$

C.3 Adoption Fee

The adoption fee when the home follower $\tilde{h}$ adopts from foreign firm f is

$$\begin{aligned}
&\mathcal{F}_{Ht}(\mathbf{m}_{\tilde{h}}) = \underset{\mathcal{F}_{Ht}(\mathbf{m}_{\tilde{h}})}{\operatorname{argmax}}(\sum_n \tilde{g}(n;\mathbf{m}_{\tilde{h}})V_{Ht}(m_{F\tilde{h}}+n, m_{D\tilde{h}}+n) - \mathcal{F}_{Ht}(\mathbf{m}_{\tilde{h}}) - V_{Ht}(\mathbf{m}_{\tilde{h}}))^{\xi} \\
&\cdot (\sum_{n=1}^{m_{D\tilde{h}}} \tilde{g}(n;\mathbf{m}_{\tilde{h}})V_{Ft}(-m_{F\tilde{h}}, -m_{D\tilde{h}}-n) + \sum_{n=m_D+1}^{\bar{m}-m_{F\tilde{h}}} \tilde{g}(n;\mathbf{m}_{\tilde{h}})V_{Ft}(-m_{F\tilde{h}}-(n-m_{D\tilde{h}}), n-m_{D\tilde{h}}) \\
&+ \mathcal{F}_{Ht}(\mathbf{m}_{\tilde{h}}) - V_{Ft}(\mathbf{m}_f))^{1-\xi}
\end{aligned}$$

$$\begin{aligned}
&\mathcal{F}_{Ht}(\mathbf{m}_{\tilde{h}}) = (1-\xi)(\sum_n \tilde{g}(n;\mathbf{m}_{\tilde{h}})V_{Ht}(m_{F\tilde{h}}+n, m_{D\tilde{h}}+n) - V_{Ht}(\mathbf{m})) \\
&- \xi(\sum_{n=1}^{m_{D\tilde{h}}} \tilde{g}(n;\mathbf{m}_{\tilde{h}})V_{Ft}(-m_{F\tilde{h}}, -m_{D\tilde{h}}-n) + \sum_{n=m_D+1}^{\bar{m}-m_{F\tilde{h}}} \tilde{g}(n;\mathbf{m}_{\tilde{h}})V_{Ft}(-m_{F\tilde{h}}-(n-m_{D\tilde{h}}), n-m_{D\tilde{h}}) \\
&- V_{Ft}(\mathbf{m}_f)).
\end{aligned} \tag{53}$$

The adoption fee when the foreign firm f adopts technology from home leader h is

$$\begin{aligned}
&\mathcal{F}_{Ft}(\mathbf{m}_f) = \underset{\mathcal{F}_{Ft}(\mathbf{m}_f)}{\operatorname{argmax}}(\sum_n g(n;m_{Ff})V_{Ft}(m_{Ff}+n, m_{Df}) - \mathcal{F}_{Ft}(\mathbf{m}_f) - V_{Ft}(\mathbf{m}_f))^{\xi} \\
&\cdot (\sum_n g(n;m_{Ff})V_{Ht}(m_{Fh}-n, m_{Dh}) + \mathcal{F}_{Ft}(\mathbf{m}_f) - V_{Ht}(\mathbf{m}_h))^{1-\xi} \\
&\mathcal{F}_{H\mathbf{m}t} = (1-\xi)(\sum_n g(n;m_{Ff})V_{Ft}(m_{Ff}+n, m_{Df}) - V_{Ft}(\mathbf{m}_f)) \\
&- \xi(\sum_n g(n;m_{Ff})V_{Ht}(-m_{Fh}-n, m_{Dh}) - V_{Ht}(\mathbf{m}_h)).
\end{aligned} \tag{54}$$

C.4 Optimal Policy Function

The optimal innovation rate and adoption rate of home follower $\tilde{h}$ is

$$\begin{aligned}
x_{Ht}(\mathbf{m}_{\tilde{h}}) &= \{\frac{1}{(1-s_{Hrt})\alpha_{Hr}w_{Ht}} \sum_n \tilde{f}(n;\mathbf{m}_{\tilde{h}})[V_{Ht}(m_{F\tilde{h}}+n, m_{D\tilde{h}}+n) - V_{Ht}(\mathbf{m}_{\tilde{h}})]\}^{\frac{1}{\gamma-1}} \\
a_{Ht}(\mathbf{m}_{\tilde{h}}) &= \{\frac{1}{(1-s_{Hat})\alpha_{Ha}w_{Ht}} \sum_n \tilde{g}(n;\mathbf{m}_{\tilde{h}})[V_{Ht}(m_{F\tilde{h}}+n, m_{D\tilde{h}}+n) - V_{Ht}(\mathbf{m}_{\tilde{h}}) - (1-s_{Hat})\mathcal{F}_{Ht}(\mathbf{m}_{\tilde{h}})]\}^{\frac{1}{\gamma-1}}.
\end{aligned} \tag{55}$$

Likewise, the optimal innovation and adoption rate of foreign incumbent is

$$x_{Ft}(\mathbf{m}_f) = \{\frac{1}{(1-s_{Frt})\alpha_{Fr}w_{Ft}}\sum_n f(n;m_{Ff})[V_{Ft}(m_{Ff}+n,m_{Df}) - V_{Ft}(\mathbf{m}_f)]\}^{\frac{1}{\gamma-1}}$$
$$a_{Ft}(\mathbf{m}_f) = \{\frac{1}{(1-s_{Fat})\alpha_{Fa}w_{Ft}}\sum_n g(n;m_{Ff})[V_{Ft}(m_{Ff}+n,m_{Df}) - V_{Ht}(\mathbf{m}_f) - (1-s_{Fat})\mathcal{F}_{Ft}(\mathbf{m}_f)]\}^{\frac{1}{\gamma-1}}. \tag{56}$$

Lastly, the optimal innovation rate of foreign entrant is

$$\tilde{x}_{Ft}(\mathbf{m}_f) = \{\frac{1}{(1-s_{Frt})\alpha_{Fr}w_{Ft}}\sum_n f(n;m_{Ff})V_{Ft}(m_{Ff}+n,m_{Df})\}^{\frac{1}{\gamma-1}}. \tag{57}$$

C.5 Other Equilibrium Conditions

Asset market clearing. The asset market clears in each period by the following equation:

$$A_{Ft} = \int_0^1 \sum_{i=f,\tilde{f}} V_{ijt}dj\,, \tag{58}$$

where the right-hand side is the sum of the value of all foreign firms.

Labor market clearing. In each country labor market clears by the following:

$$L_{Ft} = \int_0^1 (l_{fjt} + \alpha_{aF}\frac{a_{fjt}^{\gamma}}{\gamma} + \sum_{i=f,\tilde{f}} \alpha_{rF}\frac{x_{ijt}^{\gamma}}{\gamma})dj. \tag{59}$$

C.6 Step Size Distribution

We use the functional form of step size distribution in Akcigit et al. (2021) and Olmstead-Rumsey (2022). We assume that the step size distribution of adoption and innovation depends on the gap with the foreign firm. Specifically, the expected step size decreases with m_F.

We first define the baseline function $f(n) = f(n;-\bar{m})$ which is the probability of improving n steps for the firms that are furthest from the foreign firm, namely $m_F = -\bar{m}$, as

$$f(n) = c_0 n^{-\eta}, \qquad n \in \{1,\cdots,\bar{n}\}\,, \tag{60}$$

where c_0 is decided such that $\sum_{n=1}^{\bar{n}} f(n) = 1$. As m_F increases, the probability of improving multiple steps decreases while the probability of improving one step increases.

To be specific, we define $f(n;m_F)$, the probability of improving n step when the current gap

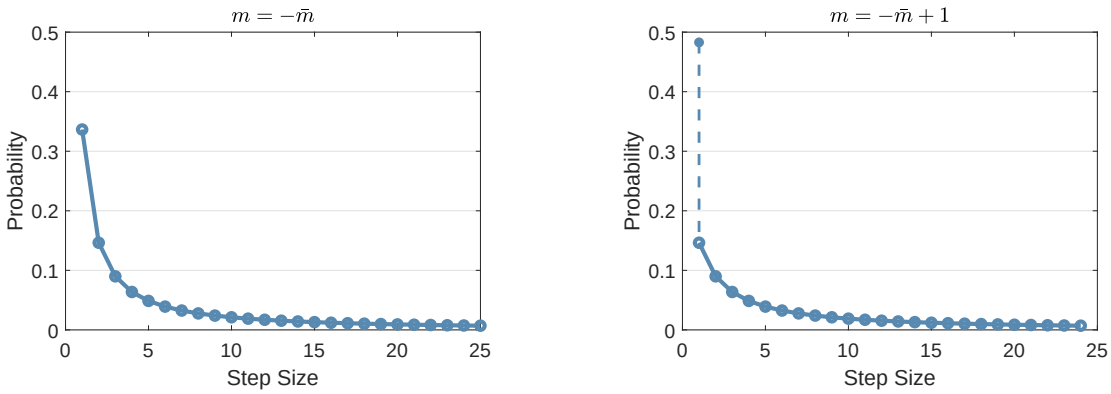


Figure C.1: Probability Mass Function of Step Size

Notes: This figure plots the probability mass function of step size. The left panel is when $m_F = -\bar{m}$, which is equal to $f(n) = c_0 n^{-\eta}$. The right panel is when $m_F = -\bar{m} + 1$. The probability of improving one step is $f(1) + f(2)$. The probability of improving $n > 1$ step is $f(n+1)$. We set $\eta = 1.2$

with the foreign firm is m_F, as the following:

$$f(n; m_F) = \begin{cases} f(1 + (m_F + \bar{m})) + \sum_{s=1}^{m_F+\bar{m}} f(s) & \text{for} \quad n = 1 \\ f(n + (m_F + \bar{m})) & \text{for} \quad n \in \{2, \cdots, \bar{n}\}, \end{cases} \tag{61}$$

where $(m_F + \bar{m})$ is the distance from the furthest position $-\bar{m}$, which makes the probability of improving the same number of steps lower as the firm gets closer to foreign firms. On the other hand, the probability of improving one step has additional term $\sum_{s=1}^{m_F+\bar{m}} f(s)$, which makes the probability of improving just one step higher as the firm gets closer to foreign firms. Figure C.1 shows an example of probability mass function when $m_F = -\bar{m}$ and $m_F = -\bar{m} + 1$.

The expected step size decreases with m_F, and the slope decreases with η as we can see in figure 5. Due to the additive feature of the distribution, we only need to pin down one parameter, η, which governs the degree of advantage of backwardness.[66] We use the same functional form for both $g(n; m_F)$ (adoption) and $f(n; m_F)$ (innovation), but use different slope parameter, η_a for adoption and η_r for innovation, which will be estimated using data.

D Details on Numerical Solution

This section provides details on the numerical solution of the model. $\bar{m}_F$ is the maximum technology gap from the foreign firm and is set to be 25 for a computational reason. We increase $\bar{m}_F$ until the point in which it does not affect key results. $\bar{m}_D$ is set to be 5.

[66] When $\eta \to \infty$, the model becomes a step-by-step model with only one step improvement and has no advantage of backwardness.

D.1 Balanced Growth Path

On the balanced growth path, wage and consumption in each country grow at the same rate g, while the distribution of productivity gap $\mu_t(\mathbf{m})$, innovation rate $x_{ct}(\mathbf{m}_i)$, adoption rate $a_{ct}(\mathbf{m}_i)$, and the relative price P_{Ft}[67] stay the same. Therefore, it is useful to divide equation (25) 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.

$$\begin{aligned}
\Pi_{Ht}(\mathbf{m}_i) &= \pi_{Ht}(\mathbf{m}_i)\cdot C_{Ht} + \pi^*_{Ht}(\mathbf{m}_i)\cdot P_{Ft}C_{Ft} \\
\frac{\Pi_{Ht}(\mathbf{m}_i)}{C_{Ht}} &= \pi_{Ht}(\mathbf{m}_i) + \pi^*_{Ht}(\mathbf{m}_i)\cdot\frac{1-\psi_{Ht}}{\psi_{Ht}}\,,
\end{aligned} \tag{62}$$

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

$$\begin{aligned}
&(r_{Ht}-g_t)v_{Ht}(\mathbf{m}) \\
&= \max_{x_{Ht}(\mathbf{m}_h),a_{Ht}(\mathbf{m}_h)} \pi_{Ht}(\mathbf{m}_h) + \pi^*_{Ht}(\mathbf{m}_h)\cdot\frac{1-\psi_{Ht}}{\psi_{Ht}} \\
&- (1-s_{Hrt})\alpha_{Hr}\frac{(x_{Ht}(\mathbf{m}_h))^\gamma}{\gamma}\omega_{Ht} - (1-s_{Hat})\alpha_{Ha}\frac{(a_{Ht}(\mathbf{m}_h))^\gamma}{\gamma}\omega_{Ht} \\
&+ x_{Ht}(\mathbf{m}_h)\sum_n f(n;m_{Fh})[V_{Ht}(m_{Fh}+n,m_{Dh}+n) - V_{Ht}(\mathbf{m}_h)] \\
&+ a_{Ht}(\mathbf{m}_h)\sum_n g(n;m_F)[(V_{Ht}(m_{Fh}+n,m_{Dh}+n) - V_{Ht}(\mathbf{m}_h) - (1-s_{Hat})\mathcal{F}_{Ht}(\mathbf{m}_h))] \\
&+ x_{Ht}(\mathbf{m}_{\tilde{h}})\sum_n \tilde{f}(n;\mathbf{m}_{\tilde{h}})[V_{Ht}(m_{Fh},m_{Dh}-n) - V_{Ht}(\mathbf{m}_h)] \\
&+ a_{Ht}(\mathbf{m}_{\tilde{h}})\sum_n \tilde{g}(n;\mathbf{m}_{\tilde{h}})[V_{Ht}(m_{Fh},m_{Dh}-n) - V_{Ht}(\mathbf{m}_h)] \\
&+ (x_{Ft}(\mathbf{m}_f) + \tilde{x}_{Ft}(\mathbf{m}_f))\sum_n f(n;m_{Ff})[V_{Ht}(m_{Fh}-n,m_{Dh}) - V_{Ht}(\mathbf{m}_h)] \\
&+ a_{Ft}(\mathbf{m}_f)\sum_n g(n;m_{Ff})[V_{Ht}(m_{Fh}-n,m_{Dh}) - V_{Ht}(\mathbf{m}_h) + \mathcal{F}_{Ft}(\mathbf{m}_h)\frac{1-\psi_{Ht}}{\psi_{Ht}}] \\
&+ \phi(V_{Ht}(0,m_{Dh}) - V_{Ht}(\mathbf{m}_h)).
\end{aligned} \tag{63}$$

Note that from the household Euler equation (8), 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 make a guess of value function for each $\mathbf{m}$, and iterate until it converges using the equation (63). After the normalized value functions converges, we check the labor market clearing condition from equation (34) for each country, and check the trade balance condition from equation (36). We

[67] Note that we normalize price index of home country $P_{Ht} = 1$.

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 $\{\mu_t(\mathbf{m})\}_{t=0}^{t=T}$ 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 $\{\mu_t(\mathbf{m})\}_{t=0}^{t=T}$.
6. Get the distance $\|\mathbb{X}_t^0 - \mathbb{X}_t^1\|$ between the guess and implied value.[68]
7. Update the guess as below until $\|\mathbb{X}_t^0 - \mathbb{X}_t^1\| < \epsilon$

$$\mathbb{X}_t^{i+1} = (1-\Delta)\mathbb{X}_t^i + \Delta\tilde{\mathbb{X}}_t^{i+1}\,, \tag{64}$$

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

8. Once we find the equilibrium $\mathbb{X}$, we simulate 1,000,000 firms using the distribution $\mu_{H\mathbf{m}t}$, and calculate C_{Ht}.

[68] We use Euclidean norm.

E Additional Figures in Quantitative Exercise

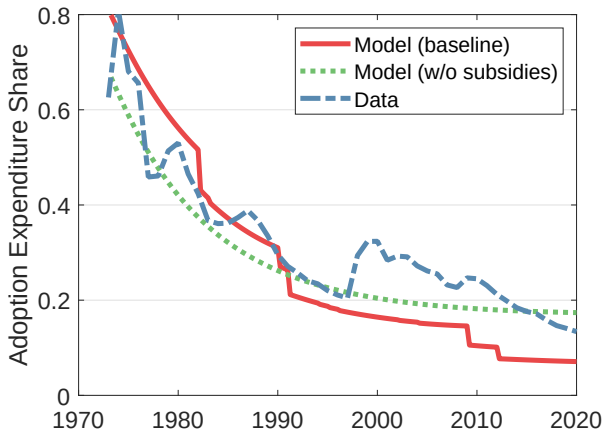
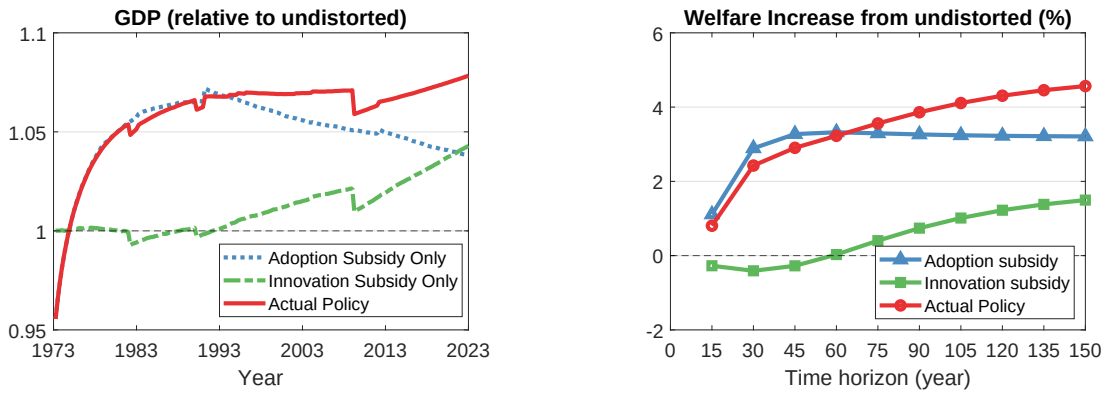


Figure E.1: Adoption Expenditure Share in the Model and the Data

Notes: This figure plots the adoption fee expenditure / (adoption fee + innovation cost) in the model and the data. The solid red line is the baseline with actual subsidies, the dotted green line is counterfactual without both subsidies, and the dashed blue line is data.

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.



A. Relative GDP

B. Welfare increase (%)

Figure E.2: Results of the Counterfactual Analysis

Notes: This figure evaluates the actual policy by comparing with counterfactuals. Panel A plots GDP in three scenarios divided by GDP in the benchmark case without both subsidies. The dotted blue line is when we shut down innovation subsidy, dashed green line is when we shut down adoption subsidy, and the solid red line is following the actual policy in figure 6. Panel B plots welfare increase compared to the case without subsidies in different time horizons. Welfare increase is calculated in consumption-equivalent unit using the equation (39).

F Additional Policy Exercise

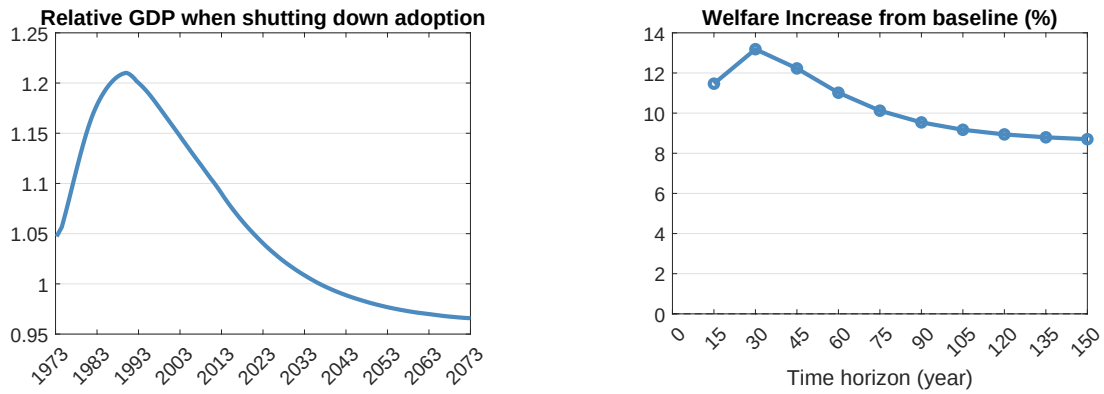
F.1 Japan's Policy to Prevent Exporting Technology

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.[69]

As an example, we study the counterfactual where Japanese firms cannot export technology to Korean firms and compare the GDP of Japan with the baseline case with adoption. Case without adoption keeps the same innovation rate.

The left panel of figure F.1 shows that in the short-run, Japan has higher GDP when shutting down the adoption channel compared with the benchmark case with adoption. But in the long run, it has lower GDP because the long-run growth rate is lower without adoption. The right panel of figure F.1 shows that Japan has higher welfare if it closes technology export. In the inifite time horizon, it has 8.54% higher welfare when it shuts down exporting technology compared with the benchmark case.

[69]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 F.1: 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 baseline case. Case without adoption keeps the same innovation subsidy rate in Korea. Panel B plots welfare increase compared with the case without a policy in different time horizons. Welfare is in consumption-equivalent unit.

F.2 Optimal Linear Subsidy

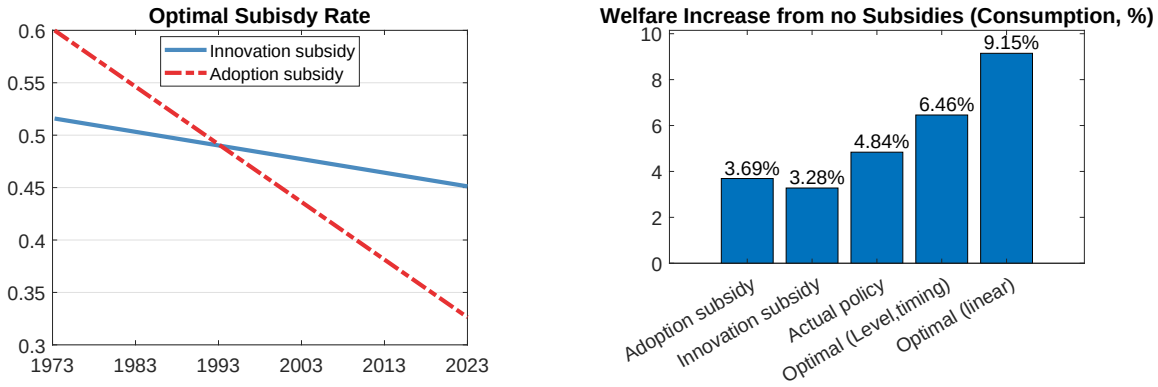
In this section, we allow the government to choose adoption and innovation subsidy as a linear function of year. The functional form is the following.

$$\begin{aligned} s_{at} &= A_a + \beta_a \cdot t \\ s_{rt} &= A_r + \beta_r \cdot t. \end{aligned} \tag{65}$$

We choose four parameters to maximize the welfare in the infinite horizon. The optimal policy parameters are $A_a = 0.6013, \beta_a = -0.0055, A_r = 0.5162, \beta_r = -0.0013$.

Figure F.2 shows the optimal subsidy and the welfare increase. Both the adoption and innovation subsidy decrease over time. This is because the step size from adoption and innovation decreases over time, which also decreases the intertemporal spillover. As the relative productivity gain from innovation increases over time, the relative subsidy rate for innovation increases over time.

The optimal linear subsidy increases consumption-equivalent welfare by 9.15%, which is higher than the actual policy (4.84%), and the case where the government could choose the rate and timing to switch (6.46%). This is because, in the previous exercise, we limit the government to subsidize only adoption or only innovation each year. Also, the smooth policy change generates a smoother consumption path, while the case in which the government change only once generates a discrete jump in consumption.



A. Optimal Subsidy

B. Welfare increase (%)

Figure F.2: Optimal Linear Subsidy and Welfare Increase

Notes: This figure plots the optimal linear subsidy and welfare results. Panel A plots the optimal adoption and innovation subsidy rate. We allow the government can choose subsidy rate as a linear function of year. The optimal adoption subsidy rate is $s_{at} = 0.6013 - 0.0055 \cdot t$ and the optimal innovation subsidy rate is $s_{rt} = 0.5162 - 0.0013 \cdot t$. Panel B plots the welfare increase from the benchmark case without both subsidies in consumption-equivalent units.