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

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ABSTRACT: Should policymakers in developing countries prioritize foreign technology adoption over domestic innovation? How might this depend on development stages? Using historical technology transfer data from Korea, we find that greater productivity gaps with foreign firms correlate with faster productivity growth after adoption, despite lower fees. Furthermore, non-adopters increased patent citations to foreign sellers, suggesting knowledge spillovers. Motivated by these findings, we build a two-country growth model with innovation and adoption. As the gaps narrow, productivity gains and spillovers from adoption diminish and foreign sellers strategically raise fees due to intensified competition, which renders adoption subsidies less effective. Korea's shift from adoption to innovation subsidies substantially contributed to growth and welfare. We also explore the optimal policy and its interaction with import tariffs.

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

Prepared by Jaedo Choi and Younghun Shim[1]

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1 Introduction

Policymakers in developing countries often provide subsidies to firms to upgrade their technologies and stimulate economic growth. They typically consider two options: promoting domestic innovation or facilitating the adoption of advanced foreign technologies. Because of government budget constraints, they have to allocate limited resources between these two options. Given the constraints, in order to design more effective technology policies, it is important to understand the relative benefits and costs of adoption versus innovation. Should policymakers in developing countries prioritize adoption over innovation? If so, when is it optimal to switch the focus from adoption to innovation?

This paper studies how adoption and innovation contribute to aggregate growth, depending on stages of economic development. We develop and estimate a two-country endogenous growth model with firm-level adoption and innovation, in which adoption costs are endogenously determined by the strategic interaction between technology sellers and buyers. The key theoretical goal is to analyze the relative benefits and costs of adoption versus innovation during an economy's transition from developing to developed stages. The model is disciplined by a unique historical dataset on firm-to-firm technology transfers. We use this model to perform policy analysis of adoption and innovation subsidies.

Our setting is Korea from the 1970s to the 1990s, which provides an ideal context for two reasons. First, Korea is renowned not only for its remarkable long-term economic growth but also for its exceptional transformation into one of the world's most innovative countries.[1] Second, the Korean government proactively implemented a policy that initially subsidized adoption but gradually shifted its emphasis to domestic innovation as the country began closing the gap with the foreign technological frontier. This type of state-dependent technology policy has been implemented not only in Korea but also more recently in other developing countries.[2] Therefore, our setting allows us to document how firms source their technological advancements as a country progresses from developing to developed stages and provides an opportunity to evaluate the impacts of the stage-dependent technology policy.

We begin by documenting two novel stylized facts about technology adoption using historical data. The dataset covers the universe of Korean firms' technology transfer contracts with foreign firms and their patents, which allows us to observe firms' sources of technological development across 25 years during Korea's growth miracle period. Under technology transfer contracts, foreign firms share technology blueprints and provide training services in return for an adoption fee. The first fact that emerges from the data is that productivity growth after adoption was larger when Korean firms' productivity lagged further behind that of foreign firms, yet adoption fees paid to foreign firms were lower. In contrast, gains from innovation do not exhibit a such pattern.

[1] The share of patents by Korean firms in the US Patent Office was less than 0.01% in the 1970s, but increased to 7% in the 2010s, which made it the third largest after the US and Japan.

[2] For example, Brazil shifted from an adoption-centered to an innovation-centered policy in 2001 (De Souza, 2021). Similarly, China initially promoted technology adoption through foreign direct investment (FDI), and transitioned to an innovation-driven development agenda in 2016 as part of the 13th Five-Year Plan.

Second, we provide empirical evidence on knowledge spillovers from adoption. Using matching-based event study specifications and patent citation flows, we compare two observationally similar foreign firms: One is involved in technology transfer, and the other is not. Korean firms that had never adopted foreign technologies began citing more foreign sellers' patents after they engaged in technology transfer for the first time. This differential increase in citation flows to sellers provides empirical support for knowledge spillovers from adoption.

Motivated by these facts, we construct a two-country growth model with adoption and innovation, building on the Schumpeterian step-by-step innovation model. Firms can improve their productivity through adoption of foreign firms' technologies or through their own innovation. Firms strategically decide on adoption and innovation while anticipating their competitors' moves. Adoption differs from innovation in three ways. First, adoption features a stronger magnitude of the advantages of backwardness (Gerschenkron, 1962). When productivity levels lag further behind, adoption is more likely to enable larger jumps in terms of productivity compared to innovation. Second, despite this advantage of adoption, there is a fundamental limitation: Adoption cannot make domestic firms more productive beyond the levels of foreign sellers, whereas innovation does not have such a limitation. And third, adoption entails additional fees to foreign sellers.

Adoption fees are endogenously determined by Nash bargaining between domestic buyers and foreign sellers. The trade-off for foreign sellers for selling technologies is that they receive adoption fees from domestic buyers after transactions, but adoption reduces their future profits. This reduction is due to increased competition with domestic firms in the global market, because adoption narrows productivity gaps between foreign sellers and domestic buyers. This competition effect becomes more pronounced as productivity gaps become even narrower, which prompts foreign firms to charge higher adoption fees to compensate for the anticipated future loss.

Adoption and innovation generate within-country knowledge spillovers. With positive probability, a domestic follower can learn a domestic leader's technology and improve on the leader's technology through either innovation or adoption. This intertemporal spillover creates room for government subsidies to improve welfare. Due to the differential magnitude of the advantages of backwardness, spillovers from adoption are initially greater than those from innovation. However, spillovers from adoption diminish as the gaps narrow, because the advantages of backwardness become weaker with narrow gap, and adoption does not yield a higher productivity level than that of a foreign seller. Therefore, the effectiveness of adoption or innovation subsidies varies depending on the size of the gaps.

We calibrate our model to firm-level data and solve for the transition of the model from the initial state in which Korean firms have lower productivity than foreign firms on average to a balanced growth path. We then simulate moments from the model on this transition path and estimate parameters to align data moments with their counterparts in the model. In particular, we infer the magnitude of the advantages of backwardness of adoption and within-country spillovers by targeting the two stylized facts. The calibrated model successfully replicates Korea's catching-up period and matches untargeted moments well.

Using the calibrated model, we conduct three quantitative exercises. First, we decompose aggregate total factor productivity (TFP) growth between adoption and innovation. Our findings reveal that in 1973, innovation contributed 8% of TFP growth in 1973, but its contribution increased to 74% in 2023. As productivity converged with that of foreign firms, relative productivity gains from adoption decreased while adoption fees increased. This caused Korean firms to increase their innovation rates while decreasing their adoption rates, which resulted in a larger contribution of innovation to TFP growth in the later period.

Second, we evaluate the state-dependent technology policies implemented by the Korean government since 1973. The government initially supported adoption through tax credits, then gradually reduced the adoption subsidy rate while increasing the innovation subsidy rate after launching the innovation subsidy program in 1982. We compare this actual policy with two alternative scenarios: one that allocates the entire budget to adoption subsidies and the other to innovation subsidies. In both scenarios, the budget-to-GDP ratio remains the same as in the baseline with the actual policy. We find that the actual policy increased consumption-equivalent welfare by 4.3% compared with the scenario with no subsidies, and surpassed the welfare gains of subsidizing only adoption (2.7%) or only innovation (3.5%).

Third, we explore the effects of a foreign policy that prohibits technology transfers to Korea, motivated by the ongoing debate regarding the US government's ban on transferring high-tech sector technologies to China. A foreign government has an incentive to restrict technology transfers due to the externality wherein foreign incumbents do not internalize future losses from potential entrants and might oversell technologies beyond the foreign country's socially optimal level. In this counterfactual, Korea's welfare decreases by 6.7%, while the foreign country's welfare increases by 4.6%. Despite the overall gains, this policy involves short- and long-run trade-offs for the foreign country. In the short run, the foreign country gains from less competition, but in the long run, they lose because Korea's lower productivity level reduces their export market and diminishes their chances of adoption from Korea.

Fourth, we quantitatively explore the optimal policy. The government maximizes the discounted sum of utility by adjusting the subsidy distribution between adoption and innovation at 10-year intervals while maintaining the budget-to-GDP ratio consistent with the actual policy. The optimal policy starts by allocating a larger budget to adoption subsidies, followed by a gradual shift toward innovation subsidies in 2003—a transition occurring later than in the actual policy. This policy leads to a 5.3% increase in welfare, which surpasses the improvement achieved by the actual policy.

Finally, we examine how technology policies interact with trade policies. A protective trade policy regime results in foreign firms' charging lower adoption fees due to reduced competition between domestic and foreign firms. This, in turn, prompts domestic firms to increase investment in adoption, and align adoption rates more closely with the socially optimal level. If Korea's import tariff rates were maintained at their initial level for all periods—which would represent a more protective trade policy regime (22 percentage points higher than the 2010s level)—the optimal policy would have reduced the budget share allocated to adoption subsidies.

Related literature Our paper contributes to several strands of the literature. First, it is related to the quantitative literature on technology policy based on models of firm innovation and dynamics in general equilibrium (e.g., Jones and Williams, 2000; Impullitti, 2010; Aw et al., 2011; Acemoglu et al., 2018; Atkeson and Burstein, 2019; Akcigit et al., 2021; Chen et al., 2021; De Souza, 2021; Akcigit et al., 2022; Liu and Ma, 2022). Whereas previous papers have primarily focused on innovation policies in developed countries, this paper also focuses on adoption policies in developing countries and the timing with respect to switching from adoption to innovation subsidies. Building on the idea of the advantages of backwardness, originally recognized by Gerschenkron (1962), Acemoglu et al. (2006) theoretically characterize the optimal timing to switch from adoption to innovation subsidies. However, the magnitude of the advantages has been less understood due to limited data on technology transfers. Our contribution lies in the novel quantification of the relative benefits and costs of adoption versus innovation in the long run, the welfare impact of the actual state-dependent policy implemented, and optimal policies using our quantitative model disciplined by micro-level data.

Second, this paper contributes to the literature on international knowledge diffusion (e.g., Grossman and Helpman, 1991; Eaton and Kortum, 2001; Alvarez et al., 2017; Buera and Oberfield, 2020; Rachapalli, 2021; Hsieh et al., 2023; Santacreu, 2015, 2022; Sampson, 2023). Previous papers have used sectoral measures of adoption and diffusion, such as patents (Eaton and Kortum, 1999); trade flows (Lind and Ramondo, 2023); or licensing payment data (Santacreu, 2022). In contrast, we document micro-level details on technology transfer pricing using firm-to-firm data. Theoretically, we also show that strategic interactions between technology sellers and buyers are crucial for understanding firm-level pricing and adoption patterns in the data.

Third, our model is related to the literature on models of growth through step-by-step innovation (e.g., Acemoglu and Akcigit, 2012; Akcigit et al., 2024; Olmstead-Rumsey, 2022; Liu et al., 2022; Akcigit and Ates, 2023; Cavenaile et al., 2023; Sui, 2023). Our model combines a step-by-step innovation model in a closed economy (Aghion et al., 2001) and one in an open economy (Akcigit et al., 2021) by introducing one foreign and two domestic firms, which allows us to capture richer strategic interaction and spillovers between them while enabling the model to be more tightly connected to the second fact on within-country spillovers. In particular, Akcigit et al. (2021) explore innovation and trade policies in an open economy. We extend their model by endogenizing technology adoption decisions instead of assuming exogenous learning of other firms' technologies, and investigate how the timing to switch from adoption to innovation subsidies interacts with trade policies.

Lastly, this paper is related to the macroeconomic literature on Korea's growth miracle (e.g. Lucas, 1993; Young, 1995; Ventura, 1997; Connolly and Yi, 2015; Itskhoki and Moll, 2019; Choi and Levchenko, 2021; Kim et al., 2021; Lane, 2022; Choi et al., 2023). Lane (2022), Choi and Levchenko (2021), and Kim et al. (2021) study Korea's sector-specific and temporary industrial policy in the

1970s, the heavy chemical industry (HCI) Drive. The most closely related paper is our other paper, Choi and Shim (2022), in which we study the role of technology adoption in industrialization during the HCI Drive and one aspect of the HCI Drive, which temporarily promoted technology adoption by heavy manufacturing sector firms. In contrast, this paper studies a different technology policy whose focus shifted from adoption to innovation subsidies between the 1970s and 2010s and applied to all manufacturing firms rather than specifically focusing on heavy manufacturing sectors. Also, unlike papers that study the HCI Drive in the 1970s, this paper focuses on the 1980s and 1990s, during which Korea transitioned from a middle-income to a high-income country and strategic interactions between Korean and foreign firms became more pronounced.

Structure The remainder of the paper is organized as follows. Section 2 introduces the main data set used for empirical and quantitative analysis, along with the policy's background. Section 3 presents two motivating facts. Section 4 describes the two-country growth model, which incorporates endogenous adoption and innovation decisions, and aligns with the two facts. Section 5 outlines the calibration procedure. Section 6 presents the quantitative results and policy counterfactuals, and Section 7 concludes.

2 Background and Data

2.1 Data

We construct our main dataset by combining technology adoption, patent, and balance sheet datasets based on firm names and business IDs. The data cover manufacturing firms and the sample period is 1970–1993. Construction of the data is detailed in Appendix A.

Technology adoption We use the firm-to-firm technology adoption dataset constructed by Choi and Shim (2022) and expand it by incorporating additional information on foreign firms and the adoption fees they charge, as well as extending the sample period.[3] This dataset includes all technology transfers between Korean and foreign firms from 1970 to 1993 and comprises 8,346 contracts, of which 75% matched with firm-level balance sheet data.[4] Of these, 95% were related to know-how transfers—providing technical and training services, sharing information, or transfers of blueprints—42% involved both know-how transfers and licensing rights for patents or trademarks; 4% were exclusively for licensing. These transactions occurred between independent entities, with foreign firms sharing technology in exchange for monetary compensation. We exclude contracts between subsidiaries and headquarters within multinational firms from our sample, which accounted for only 3% of all contracts.

[3] From 1962 to 1993, under the Foreign Capital Inducement Act, Korean firms were mandated to submit documents pertaining to transactions with foreign entities. The National Archives of Korea preserved these documents, which form the basis of our dataset. Appendix Figure A.1 shows an example of these documents.

[4] Admittedly, this dataset only captures official measures of technology adoption from foreign countries. Other forms, such as diffusion from foreign direct investment (FDI), transfers between Korean firms, or unofficial adoption through reverse engineering, are not included. However, the role of FDI was limited in Korea due to government regulation on FDI (Kim, 1997, p. 42-43). Also, estimated adoption fees between domestic firms were only 6.3% of the total expenses (Lee, 2022). Later, unofficial adoption activities will be modeled as exogenous knowledge diffusion.

Table 1: Examples of Technology Adoption Data

Buyer	Seller	Contract Length (year)	Date	Technology	Contents	Fee
Samsung	Nippon Electronic (Japan)	10	02/24/1978	Color TV	Know-how Transfer, Licensing	Fixed $800,000
LG	Hitachi (Japan)	9	04/01/1978	Color TV	Know-how Transfer, Licensing	Fixed $100,000 Royalty 3%
Hyundai Heavy Manufacturing	Technigaz (France)	10	09/14/1978	LNG Carrier	Know-how Transfer	Fixed FFR 1,835,000
Haengnam Electronics	EPH (US)	2	12/18/1978	Alumina	Know-how Transfer	Fixed $131,000
Hyundai Motor Company	Kyukoto Engineering (Japan)	3	06/14/1979	Concrete mixer	Know-how Transfer	Royalty 5%

Table 1 shows examples of the information available in this data. The data includes information on adoption fees, names of Korean buyers and foreign sellers, contract duration, and the years when the contracts were established. The contracts specified either a fixed fee, a royalty rate, or both as payments from adopting firms to foreign sellers. The fixed fee refers to a lump sum payment, while the royalty rate is a percentage of sales a buyer agrees to pay annually for the duration of the contract. The costs of these contracts were sizable. The average annual royalty rate was 3% with a 5-year contract length, and fixed fees account for 10% of yearly sales on average.[5] The distribution of foreign countries in the contracts is concentrated, with Japanese and US firms accounting for 50% and 26%, respectively (Appendix Table A.1).

Patent To measure innovation by Korean firms, we use patent data from the Korean Intellectual Property Office (KIPO) and apply the cleaning process described by Lee et al. (2020). KIPO started in 1945 and includes the universe of patents registered in Korea by domestic and foreign firms. The application year is used as the year of innovation, and the business ID of the assignee is used to merge with other data. A limitation of KIPO data is the absence of citation information until the 1990s. To supplement this, we incorporate data from the United States Patent and Trademark Office (USPTO), which includes all patent citations made by patents that are registered in the USPTO since 1975.

Balance sheet Our firm balance sheet data includes information on sales, fixed assets, employment, and sectors. We use two primary data sources to construct firm-level balance sheet data for Korean firms. Initially, for the period from 1970 to 1982, we use balance sheet information from the Annual Reports of Korean Companies constructed by Choi and Shim (2022). These reports cover firms with more than 50 employees, and represent approximately 70% of the manufacturing gross output on average across the years. For the period 1983-1993, we obtain balance sheet information from KIS-VALUE that covers firms with assets of more than 3 billion Korean won (2.65 million

[5]Total adoption fees account for 7.4% of foreign firms' sales on average.

Table 2: Summary Statistics

	Ever-Adopted	Never-Adopted	Ever-Patented	Never-Patented	All
Emp.	1,184	297	1,747	338	626
Asset	185	19	315	24	74
Sales	205	31	319	35	102
Sales per Emp.	0.18	0.15	0.20	0.15	0.17
Patenting (yearly dummy)	0.07	0.01	0.18	N/A	0.03
Adopting (yearly dummy)	0.18	N/A	0.19	0.04	0.06
# of Unique Firms	1,180	5,613	471	6,322	6,793
# of Obs.	18,679	34,549	8,394	44,834	53,228

Notes. This table presents average values for various firm groups between 1970 and 1993. Ever-adopted refers to firms that engaged in at least one adoption contract during the sample period, whereas ever-patented firms registered at least one patent. All nominal values are converted to 2015 US million dollars.

dollars in 2015) since 1983.

We use foreign firms' balance sheet data from Compustat North America and Global, which provide information on publicly listed firms starting from 1950 and 1987, respectively. Of 22,587 unique firms, 769 firms have ever sold technology to Korean firms.

Aggregate and sectoral data We supplement firm-level microdata with aggregate and sectoral data sets. We obtain aggregate expenditures on adoption and R&D (innovation) from Statistics Korea. When measuring aggregate adoption expenditure, we use total payments to foreign countries for the use of intellectual property. We obtain real GDP per capita from the Maddison Project (Bolt and Van Zanden, 2020; Cha et al., 2020), input-output (IO) tables from the Bank of Korea, and trade data from Comtrade.

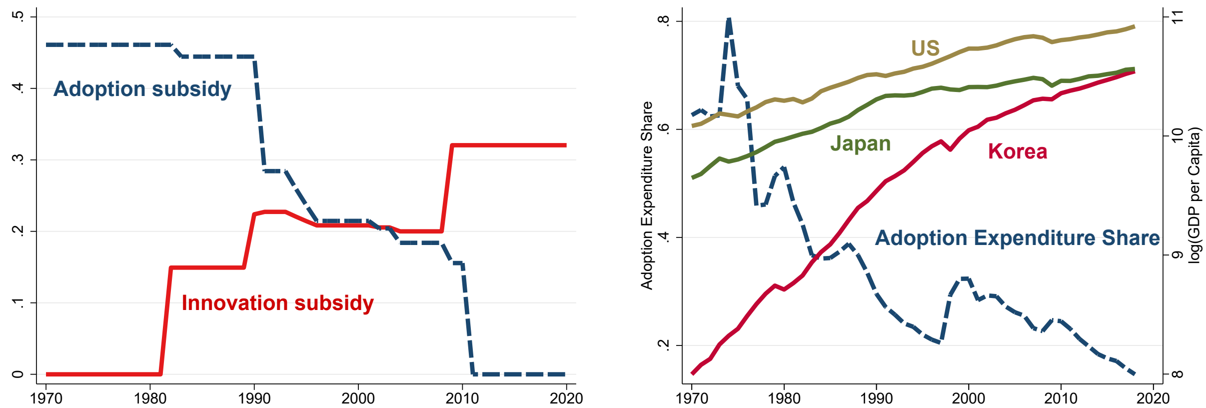
Summary statistics Table 2 reports summary statistics of groups of firms based on their ever-adoption or -patenting status. Ever-adopters and ever-patenting firms were larger than the other groups measured by sales, employment, and assets. They also had higher labor productivity, defined as sales per employee, and were more likely to adopt foreign technology or register for a patent in a given year. Appendix Table A.3 reports summary statistics of foreign firms and compares technology sellers and others. Foreign sellers were larger than other firms.

2.2 Background

In 1966, the Korean government began to provide tax credits for adoption fees paid to foreign sellers, including fixed fees and royalty payments.[6] From 1966 to 1982, the government granted a corporate tax exemption for 100% of adoption fees for 5 years post-adoption contract signing,

[6]Tax credits for adoption fees were provided under Article 24 of the Foreign Capital Inducement Act, enacted in 1966, titled "On tax exemptions for expenses for the adoption of foreign technologies." It is important to note that this subsidy policy differs from the HCI Drive, which has recently been studied by Choi and Levchenko (2021); Kim et al. (2021); Choi and Shim (2022); Lane (2022). The policy analyzed in this paper is a long-term technology policy that covers all manufacturing sectors. In contrast, the HCI Drive is a sector-specific policy that promoted heavy manufacturing sectors—including chemicals, electronics, machinery, and transportation equipment—within the broader manufacturing sector.

Figure 1: State-Dependent Technology Policy in Korea



A. Adoption/Innovation Subsidy Rate

B. Log Real GDP Per Capita

Notes. Panel A plots calculated adoption and innovation subsidy rates (equation (1)) in dashed navy and solid red lines over time, respectively. Panel B illustrates the real GDP per capita for the US, Japan, and Korea using solid lines, and Korea's adoption expenditure share with the dashed line. The adoption expenditure share is the amount of adoption fees paid to foreign firms divided by the sum of adoption and R&D expenditures.

followed by a 50% exemption in subsequent years. Given the average contract duration of 5.7 years, we calculate that 94% of adoption fees were eligible for a tax credit. From 1983 to 1990, the exemption was limited to the initial 5 years, which reduced the eligibility rate to 90%. In 1991, the policy was further restricted to cover only advanced technology. For contracts between 1991 and 1993, the data show whether each contract received tax credits. Of all contracts during this period, 42% received tax credits. Based on this observation, we set 42% as the share of adoption fees that were eligible for tax credits after the 1991 policy reform. The government ceased providing tax credits for adoption fees in 2010. Tax credit rates represent the amount of tax deduction per unit of spending on adoption. Therefore, the tax credit rate for adoption is calculated as corporate tax rates multiplied by the share of expenditure eligible for tax exemption; we obtain information on corporate tax rates from Choe and Lee (2012).

The government also subsidized innovation through R&D tax credits.[7] This initiative commenced in 1982 with a tax credit rate of 10%, which meant that the corporate tax on R&D expenditures was reduced by 10%. The tax credit rate was raised to 15% in 1990 and to 25% in 2009 (Choe and Lee, 2012).

Following Bloom et al. (2002), we calculate subsidy rates for adoption and innovation R&D using information on corporate tax and tax credit rates for adoption and innovation:

$$\text{Adoption (or innovation) subsidy rate}_t = \frac{\text{Adoption (or innovation) tax credit rate}_t}{1 - \text{Corporate tax rate}_t}. \tag{1}$$

[7]An R&D tax credit was offered under Article 14 of the Tax Reduction and Exemption Regulation Act beginning in 1982. At the Technology Promotion and Expansion Conference in 1982, President Chun stated, "Korea needs to transition from the imitation stage of the 70s to creativity and innovation in the 80s."

The calculated subsidy rates represent reductions in unit costs of adoption or innovation produced by the tax system.[8] Panel A of Figure 1 illustrates calculated subsidy rates for both adoption and innovation over time. The figure shows the pattern whereby the policy shifted its focus to innovation as the country grew and caught up with other developed economies in terms of real GDP per capita (Panel B). To examine the importance of adoption over time, we calculate the ratio of aggregate adoption expenditures to the sum of adoption and innovation R&D expenditures. Consistent with the shift, the aggregate share of adoption expenditures declined over time, which demonstrates that adoption played a more important role when more distant from the foreign frontiers.

3 Motivating Facts

In this section, we present two empirical facts on adoption. First, we find that when Korean firms lagged more behind foreign firms in terms of productivity, productivity growth after adoption was larger, while despite the higher gains, adoption fees paid to foreign firms were lower. Second, we present empirical evidence on knowledge spillovers from adoption using patent citation flows.

3.1 Productivity Gap, Productivity Growth after Adoption and Innovation, and Adoption Fee

Productivity gap and productivity growth after adoption and innovation To document the relationships between productivity gaps and productivity growth after adoption and innovation, we estimate

$$\log \frac{z_{i,t+5}}{z_{it}} = \beta_1 \log \mathrm{Gap}_{it} + \beta_2 \left(\log \mathrm{Gap}_{it} \times \mathbb{1}[\mathrm{Adopt}_{it}]\right) + \beta_3 \left(\log \mathrm{Gap}_{it} \times \mathbb{1}[\mathrm{Innovate}_{it}]\right) + \beta_4 \mathbb{1}[\mathrm{Adopt}_{it}] + \beta_5 \mathbb{1}[\mathrm{Innovate}_{it}] + \mathbf{X}_{it}'\boldsymbol{\gamma} + \boldsymbol{\delta} + \epsilon_{it}. \quad (2)$$

$\log z_{i,t+5}/z_{it}$ is the 5-year growth of Korean firm i's productivity z_{it}, where z_{it} is measured as sales per employee or revenue-based TFP ($\mathrm{TFP}^{\mathrm{rr}}$). We estimate the production function following the control function approach (Olley and Pakes, 1996; Ackerberg et al., 2015). We use investment as a proxy variable and obtain $\mathrm{TFP}^{\mathrm{rr}}$ as residuals of the estimated production function.[9] Gap_{it} is tech-

[8] Let v be the before-tax marginal value from innovation or adoption, τ^c the corporate tax rate, A_d the depreciation allowance, and A_c the tax credit rate for innovation or adoption. Firms equate marginal gains and costs from innovation or adoption, $(1-\tau^c)v = (1 - A_d - A_c)$, where $(1-\tau^c)v$ represents the after-tax value from innovation or adoption, and $(1 - A_d - A_c)$ is the marginal cost including depreciation allowance and tax credit. Following Impullitti (2010), we assume full expensing and set $A_d = \tau^c$. Then, the equation becomes

$$v = 1 - \frac{A_c}{1-\tau^c}.$$

The term $1 - \frac{A_c}{1-\tau^c}$ represents the effective marginal cost to obtain the marginal gain v from innovation or adoption. Therefore, $\frac{A_c}{1-\tau^c}$ represents the effective subsidy rate.

[9] We follow İmrohoroğlu and Tüzel (2014) when cleaning Compustat data. Details on the estimation can be found in Appendix B.1.

Table 3: Productivity Gap and Productivity Growth after Adoption and Innovation

Dep.	△ log sales per emp.				△ log TFP^{rr}			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\log \text{Gap}_{it}$	-0.214***	-0.234***	-0.463***	-0.470***	-0.251***	-0.292***	-0.498***	-0.505***
	(0.009)	(0.009)	(0.013)	(0.013)	(0.009)	(0.010)	(0.013)	(0.013)
$\log \text{Gap}_{it} \times \mathbb{1}[\text{Adopt}_{it}]$	-0.088***	-0.087***	-0.065**	-0.086***	-0.069**	-0.083***	-0.061**	-0.079***
	(0.032)	(0.031)	(0.027)	(0.029)	(0.030)	(0.028)	(0.024)	(0.026)
$\log \text{Gap}_{it} \times \mathbb{1}[\text{Innovate}_{it}]$	0.029	0.035	0.000	-0.008	0.036	0.046*	0.011	-0.000
	(0.025)	(0.025)	(0.020)	(0.021)	(0.025)	(0.026)	(0.021)	(0.022)
$\mathbb{1}[\text{Adopt}_{it}]$	0.146***	0.154***	0.196***	-0.076*	0.132***	0.125***	0.161***	-0.092**
	(0.038)	(0.038)	(0.033)	(0.044)	(0.032)	(0.032)	(0.029)	(0.043)
$\mathbb{1}[\text{Innovate}_{it}]$	0.035	0.044	0.074**	0.070*	0.034	0.034	0.072**	0.065**
	(0.042)	(0.043)	(0.036)	(0.037)	(0.038)	(0.039)	(0.031)	(0.033)
Year FE	✓	✓			✓	✓		
Sector FE		✓				✓		
Sector-year FE			✓	✓			✓	✓
Foreign country-year FE				✓				✓
Adj. R^2	0.18	0.19	0.32	0.32	0.19	0.21	0.36	0.36
# Cl. (domestic firm)	2,217	2,217	2,217	2,217	2,217	2,217	2,217	2,217
N	12,824	12,824	12,812	12,812	12,824	12,824	12,812	12,812

Notes. Standard errors in parentheses are clustered at Korean firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. This table reports estimates from equation (2). In columns 1–4 and 5–8, dependent variables are growth rates of sales per employee and TFP^{rr}, respectively. Columns 1–4 and 5–8 define the gap as the ratio of sales per employee and TFP^{rr} between Korean and foreign frontier firms, respectively. $\mathbb{1}[\text{Adopt}_{it}]$ and $\mathbb{1}[\text{Innovate}_{it}]$ are dummies that take values of 1 if Korean firm i engaged in at least one technology transfer contract or filed at least one patent for the first time, respectively. Columns 1 and 5 include year fixed effects. Columns 2 and 6 include year and sector fixed effects. Columns 3 and 7 include sector-year fixed effects. Columns 4 and 8 include sector-year fixed effects and foreign country-year fixed effects, interacted with the adoption dummy. Columns 1–4 and 5–8 include log initial sales per employee and TFP^{rr}, respectively. All specifications include the 5-year growth rate of fixed assets.

nological distance between Korean firm i and the foreign frontier firm. Following the literature (e.g., Gorodnichenko et al., 2010; Hashmi, 2013), we measure the gap as the ratio of productivity between firm i and foreign frontier firm f, z_{it}/z_{ft}, where we define the frontier firm as a foreign firm with the highest sales per employee or TFP^{rr} within each sector-year. $\mathbb{1}[\text{Adopt}_{it}]$ and $\mathbb{1}[\text{Innovate}_{it}]$ are dummies that take values of 1 if Korean firm i engaged in at least one technology transfer contract or filed at least one patent for the first time, respectively. $\mathbf{X}_{it}$ are the observables. In $\mathbf{X}_{it}$, we include $\log z_{it}$ to account for the mean reversion and growth rate of fixed assets over 5 years to account for capital growth. We include additional fixed effects $\boldsymbol{\delta}$ depending on specifications. Standard errors are clustered at the Korean firm level.

Table 3 reports the results. In column 1, in which we include year fixed effects, the estimated coefficient of $\log \text{Gap}_{it} \times \mathbb{1}[\text{Adopt}_{it}]$ is negative and statistically significant at the 1% level. 1% higher productivity gap was associated with 0.09 percentage point lower productivity growth after adoption, which implies that Korean firms experienced faster post-adoption productivity growth if they were initially more distant from foreign firms' productivity levels. For example, the gap of Samsung Electronics, one of the firms that experienced large productivity growth, decreased by around 100% between 1970 and 1981, when the innovation tax credit started to be provided. This estimate implies that adopting foreign technology would have been associated with 9 percentage point lower productivity growth for Samsung in 1981 than in 1970.

In columns 2–3, we also include sector and sector-year fixed effects. In column 4, we incorporate technology sellers' country-year fixed effects, interacted with the adoption dummies, to account for technological heterogeneity across countries. The estimates remain stable across different specifications. However, unlike adoption, the coefficients of $\log \text{Gap}_{it} \times \mathbb{1}[\text{Innovate}_{it}]$ reveal no significant correlations between the gap and post-innovation productivity growth.

In columns 5–8, we use revenue-based TFP as dependent variables instead of sales per employee, and define the gap based on it. We obtain a similar pattern, and estimates of the interaction terms between the gap and adoption and innovation dummies were within one standard deviation of those in columns 1–4. We repeat our analysis using DHS growth (Davis et al., 1998). Our results remain robust to using the alternative growth (Appendix Table B.1).

Productivity gap and adoption fee To investigate the relationship between adoption fees and productivity gaps, we estimate

$$\log \mathcal{F}_{ift} = \beta \log \text{Gap}_{it} + \boldsymbol{\delta} + \epsilon_{ift}, \tag{3}$$

where $\mathcal{F}_{ift}$ are the adoption fees Korean firm i paid to foreign seller f in year t. We consider fixed fees as a baseline for the dependent variable, and perform robustness checks using royalty rates.[10] We control for additional fixed effects $\boldsymbol{\delta}$ depending on specifications. ϵ_{ift} is the error term. We two-way cluster standard errors at both the Korean and foreign firm level.

Table 4 reports the results. In column 1, in which we include year fixed effects, the estimated coefficient was 0.138, which implies that a 1% increase in the gap is associated with a 0.14% increase in fixed fees. We obtain similar estimates when also controlling for sector fixed effects in column 2. In column 3, we include sector-year fixed effects and exploit only variation within sector-year. With sector-year fixed effects, we obtain an even higher correlation. In column 4, we include both sector-year and foreign country-year fixed effects. Our results remain robust to controlling for technological heterogeneity across countries. In columns 5–8, we repeat the exercise using the gap based on revenue TFP. The positive correlations remain robust.

Combined with the previous results, these findings indicate that technology buyers tend to pay a higher price for technology when their productivity levels are closer to sellers', despite potentially smaller productivity gains from adoption. This implies that the productivity gap may affect either the marginal gain from adopting technology, the marginal cost from sharing technology, or both, and highlight strategic interactions that will be explored in our model.

In Appendix Table B.2, we estimate royalty payments using firm sales and royalty rates and repeat these exercises. Again, we find positive correlations between the gap and payment to foreign firms.

[10] The reason we chose fixed fees as the baseline is that royalty rates do not specify explicit amounts of payment from Korean to foreign firms.

Table 4: Productivity Gap and Adoption Fee

Dep.	log Fixed fee							
Gap	Sales per emp.				TFP^{rr}			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\log \text{Gap}_{it}$	0.138***	0.111***	0.448***	0.419***	0.188***	0.112***	0.444***	0.429***
	(0.039)	(0.035)	(0.088)	(0.093)	(0.046)	(0.042)	(0.101)	(0.103)
Year FE	✓	✓			✓	✓		
Sector FE		✓				✓		
Sector-year FE			✓	✓			✓	✓
Foreign country-year FE				✓				✓
Adj R^2	0.05	0.11	0.18	0.20	0.05	0.11	0.17	0.20
# Cl. (Korean firm)	475	474	455	444	475	474	455	444
# Cl. (Foreign firm)	1,602	1,602	1,557	1,469	1,602	1,602	455	444
N	2,485	2,484	2,425	2,323	2,485	2,484	2,425	2,323

Notes. Standard errors in parentheses are two-way clustered at the domestic and foreign firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. This table shows the result of equation (3), in which we regress the fixed fee of adoption on the log productivity gap. Columns 1 and 5 include year fixed effects. Columns 2 and 6 include year and sector fixed effects. Columns 3 and 7 include sector-year fixed effects. Columns 4 and 8 include sector-year fixed effects and foreign country-year fixed effects. In columns 1–4 and 5–8, the gap is measured based on the ratio of sales per employee and revenue-based TFP between the Korean firm (buyer) and the foreign firm (seller), respectively.

3.2 Knowledge Spillovers from Adoption

The second fact concerns knowledge spillovers from adoption. We follow the literature (e.g., Jaffe et al., 1993; Aghion et al., 2019) and use patent citations to measure knowledge spillovers. Consider two foreign firms—for example, one that has sold technology to a Korean firm and another that has not. If Korean firms that have never adopted any foreign technologies begin citing this foreign firm's patents more frequently after its technology transfer, compared with the patents of the foreign non-seller, we interpret this as indicative of knowledge spillovers.

We employ a matching-based event study design. We compare two observationally similar foreign firms, one that has sold technology (the seller group) and another that has never sold technology (the control group). Our matching involves two steps. We first exactly match the country and primary patent field (IPC 3-digit). Each foreign firm is assigned the most frequently occurring 3-digit IPC class in its patent portfolio. Then, we distance match based on observables, including patents and citations.[11] The event year is defined as the year in which a matched seller sells its technology to any Korean firm for the first time. We assign the same event year as a placebo year for the control group. We obtain 213 matches with 412 unique firms.

[11]We restrict the set of countries to the US, Japan, UK, and France and require each IPC 3-digit to have more than 20 observations. We exactly match each foreign seller to its counterpart in the control group based on IPC 3-digits and countries. For distance matching, we use three variables: cumulative patent stock, new patents invented in a given year, and new citations received (excluding self-citations) in a given year. We distance match based on these three variables 1 year before the event and their last 4 years of growth. We trim the top 98% of outliers in terms of the distance to improve the quality of matching.

Using the matched sample, we consider the following specification:

$$\mathbb{1}[\text{Citation}^{\text{Kor}}_{fmt} > 0] = \sum_{\tau=-7}^{11} \beta_\tau \big(D^\tau_{mt} \times \mathbb{1}[\text{Seller}_{ft}]\big) + \delta_{fm} + \delta_{mt} + \epsilon_{fmt}, \tag{4}$$

where f denotes a foreign firm, m match, and t year. The dependent variable, $\mathbb{1}[\text{Citation}^{\text{Kor}}_{fmt} > 0]$, is a dummy that indicates whether any Korean firms that have never adopted any foreign technologies during the sample period cite patents from foreign firm f in year t. D^τ_{mt} are event dummies defined as $D^\tau_{mt} = \mathbb{1}[t - \tau = t(m)]$, where $t(m)$ is the event year of match m. We include time-invariant firm-match fixed effects δ_{fm} and match-year fixed effects δ_{mt}. δ_{fm} are identified from firms in the control group that were matched with multiple sellers. ϵ_{fmt} is an error term. We two-way cluster standard errors at both foreign firm and match level.

To examine the average effect, we run

$$\mathbb{1}[\text{Citation}^{\text{Kor}}_{fmt} > 0] = \beta^{DD}\big(\mathbb{1}[\text{Seller}_{fmt}] \times \text{Post}_{mt}\big) + \delta_{fm} + \delta_{mt} + \epsilon_{fmt}, \tag{5}$$

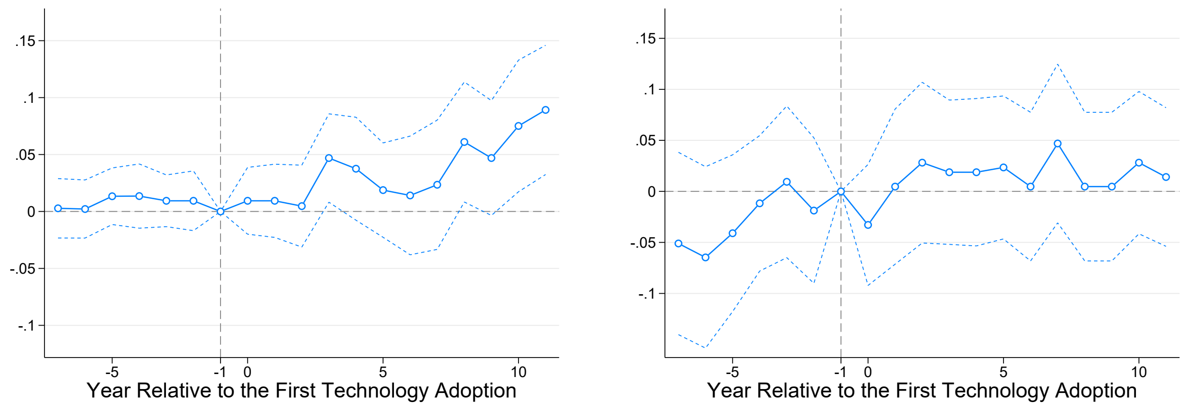
where Post_{mt} is a dummy that takes the value of 1 if the event happens to match m.

We check the balance of observables between the two groups. There are no statistically significant differences between the two groups in terms of observables, and the observables do not predict treatment status (Appendix Tables B.3 and B.4). The raw average number of the dependent variable of the two groups shows that the two groups' citations received by never-adopting Korean firms followed similar trends before the events and started to diverge only after the events, revealing no pretrends (Appendix Figure B.1). Note that we employ a stacked-by-event design (e.g., Cengiz et al., 2019), and our event study coefficients are identified by comparing firms that switched to the seller group and those that have never sold technologies to Korean firms. Therefore, our design addresses potential issues related to the presence of heterogeneous treatment effects (e.g., Borusyak et al., forthcoming).

Panel A of Figure 2 presents the estimated β_τ that captures the citation patterns, before and after the events, between the two groups.[12] There were no pretrends before the events. Eleven years after the event, the probability of citation by never-adopting Korean firms to the seller group's patents increased by around 10%, compared with the control group. Table 5 reports average effects over different time horizons. The estimated coefficients are larger and more precisely estimated with longer horizons, which implies that knowledge spillovers occur with lags. These results are consistent with the fact that Korean firms build on technology adopted by other Korean firms. The potential existence of knowledge spillovers implies a positive externality associated with adoption.

To further validate the results, we conduct a placebo exercise to examine whether the results

[12] The identifying assumption for the causal interpretation is that conditional on the controls and the fixed effects, seller and control groups are ex ante similar in terms of both observables and unobservables, and foreign firms' time-varying unobservables are uncorrelated with the adoption events.



A. Baseline B. Placebo

Figure 2: Knowledge Spillovers from Technology Adoption. Event Study Specification

Notes. This figure plots estimates of β_τ in Equation (4) and 95% confidence intervals based on standard errors two-way clustered at foreign firm and match level. In Panels A and B, dependent variables are a dummy of positive citations from never-adopting Korean firms and a dummy of positive citations from non-Korean firms, respectively. The X-axis is the year relative to the event. β_{-1} is normalized to zero. All specifications include firm-match and match-year fixed effects.

Table 5: Knowledge Spillovers from Technology Adoption: Average Effects

Dep.	$\mathbb{1}[\text{Citation}^{\text{Kor}}_{fmt} > 0]$	
Time horizon	$-7 \leq \tau \leq 5$	$-7 \leq \tau \leq 11$
	(1)	(2)
$\mathbb{1}[\text{Treated}_{ft}] \times \mathbb{1}[\text{Post}_{mt}]$	0.02**	0.03***
	(0.01)	(0.01)
Firm-match FE	✓	✓
Match-year FE	✓	✓
Adj. R^2	0.41	0.51
# Cl. (Foreign firm)	412	412
# Cl. (Match)	213	213
N	5,404	7,960

Notes. Standard errors in parentheses are two-way clustered at the foreign firm and match level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. This table reports estimates of β^{DD} of Equation (5). Dependent variables are a dummy of positive citations from never-adopting Korean firms. All specifications include firm-match and match-year fixed effects.

are driven by unobserved shocks that affect both the contracts of foreign firms and citations received. For example, if Sony's new technologies were unexpectedly superior, Korean firms might have become more likely to adopt technologies from Sony, and citations to Sony by non-Korean firms could have increased after the adoption year. As a placebo exercise, we replicate the same regression using the number of citations received from firms in all other countries except Korea. Panel B shows no clear differences in citations received by non-Korean firms between the two groups, which rules out the alternative explanation.

Results are robust to alternative numbers of matching and alternative long-run difference specifications with the inclusion of additional controls and unit-specific random trends (Appendix Table B.5).[13]

4 Model

In this section, motivated by the two empirical facts, we develop a dynamic general equilibrium model with adoption and innovation.

4.1 Setup

Time is continuous, $t \in (-\infty, \infty)$. There are two countries, Home and Foreign $C \in \{H, F\}$, and a continuum of sectors $j \in [0, 1]$. In Home H, there are two firms, h and $\tilde{h}$ in each sector j. We call a firm a leader if it has the highest productivity in its sector and the other a follower. In Foreign F, there is one incumbent firm f in each sector j. Instead of the follower, there is a potential entrant $\tilde{f}$ that can enter and replace the incumbent by innovating. $\mathcal{I}_C$ is a set of operating firms in country C, $\mathcal{I}_H = \{h, \tilde{h}\}$ and $\mathcal{I}_F = \{f\}$.

Two Home firms and a Foreign incumbent produce a unique variety. Each variety is tradable across countries subject to iceberg costs $\tau \geq 1$ and import tariffs rates $t_t^C \geq 0$.

There are representative households in each country who own all domestic firms and are immobile across countries. They supply labor inelastically by L_C. There is no trade in assets, ruling out international borrowing and lending.

4.2 Household

A representative household in Home has the following utility function:

$$U_{Ht} = \int_t^{\infty} \exp(-\rho(s-t)) \ln C_{Hs} \mathrm{d}s,$$

where C_{Hs} is final consumption and $\rho > 0$ is the discount factor. The budget constraint of a household is $r_{Ht}A_{Ht} + w_{Ht}L_H = P_{Ht}C_{Ht} + T_{Ht} + \dot{A}_{Ht}$, where r_{Ht} is interest rate, w_{Ht} is wage, P_{Ht} is price of the aggregate output, T_{Ht} is the lump-sum transfer, and A_{Ht} is asset. $\dot{A}_{Ht}$ is the time derivative of A_{Ht}. A household's utility maximization gives the following Euler equation:

$$\frac{\dot{C}_{Ht}}{C_{Ht}} = \rho - \left(r_{Ht} - \frac{\dot{P}_{Ht}}{P_{Ht}} \right). \tag{6}$$

[13] Specifically, we consider the number of matches of 2 and 5. We run a long-run difference model between 1 year before and 11 years after the events: $\triangle \mathbb{1}[\text{Citation}^{\text{Kor}}_{fmt} > 0] = \beta \text{Seller}_{fmt} + \mathbf{X}'_{fm}\boldsymbol{\gamma} + \delta_m + \epsilon_{fmt}$. Depending on specifications, to allow for heterogeneous trends that depend on observables, we include inverse hyperbolic sine transformation of the initial citations received and log of the initial patent stock. To control for unit-specific trends, we stack two long-differences pre- and post-events and control for firm-match time-invariant fixed effects.

4.3 Firms

Aggregate output Varieties produced by firms are aggregated as an aggregate output Y_{Ct} with a Cobb-Douglas aggregator across sectors and a CES aggregator within sectors:

$$Y_{Ht} = \exp\left(\int_0^1 \ln\left(\psi_H^{\frac{1}{\sigma}} y_{hjt}^{\frac{\sigma-1}{\sigma}} + \psi_H^{\frac{1}{\sigma}} y_{\tilde{h}jt}^{\frac{\sigma-1}{\sigma}} + \psi_F^{\frac{1}{\sigma}} (y^*_{fjt})^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \mathrm{d}j\right).$$

y_{ijt} and y^*_{fjt} are the quantities demanded for varieties produced by Home firm $i \in \mathcal{I}_H$ and Foreign firm f in Home, respectively. The superscript asterisk denotes varieties that are exported. ψ_H and ψ_F are demand shifters for Home and Foreign varieties. σ is the elasticity of substitution. Varieties within sectors are imperfect substitutes for each other, $1 < \sigma < \infty$. The price of the aggregate output in Home is

$$P_{Ht} = \exp\left(\int_0^1 \ln\left(\psi_H^{\frac{1}{\sigma}} p_{hjt}^{1-\sigma} + \psi_H^{\frac{1}{\sigma}} p_{\tilde{h}jt}^{1-\sigma} + \psi_F^{\frac{1}{\sigma}} (p^*_{fjt})^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \mathrm{d}j\right).$$

p_{ijt} and p^*_{fjt} are the prices of varieties charged by Home and Foreign firms.

Production The production function of firm i is

$$\mathcal{Y}_{ijt} = z_{ijt} l_{ijt}.$$

$\mathcal{Y}_{ijt}$ is firm i's total output produced, z_{ijt} productivity, and l_{ijt} labor inputs.

Market structure and pricing Firms compete on prices á la Bertrand, taking into account that their pricing decisions affect their demand schedule. With the CES aggregator, Home firms, $i \in \mathcal{I}_H$, and Foreign firm f demand schedule in Home is given as

$$y_{ijt} = \frac{\psi_H p_{ijt}^{-\sigma}}{\sum_{i' \in \mathcal{I}_H} \psi_H p_{i'jt}^{1-\sigma} + \psi_F (p^*_{fjt})^{1-\sigma}} P_{Ht} Y_{Ht}, \qquad y^*_{fjt} = \frac{\psi_F (p^*_{fjt})^{-\sigma}}{\sum_{i' \in \mathcal{I}_H} \psi_H p_{i'jt}^{1-\sigma} + \psi_F (p^*_{fjt})^{1-\sigma}} P_{Ht} Y_{Ht}.$$

Under Bertrand competition, firms charge variable markups. The optimal prices charged by firms in Home are expressed as

$$p_{ijt} = \underbrace{\frac{1 - \frac{\sigma-1}{\sigma} s_{ijt}}{\frac{\sigma-1}{\sigma}(1 - s_{ijt})}}_{=\mathcal{M}_{ijt}} \frac{w_{Ht}}{z_{ijt}}, \qquad p^*_{fjt} = \underbrace{\frac{1 - \frac{\sigma-1}{\sigma} s^*_{fjt}}{\frac{\sigma-1}{\sigma}(1 - s^*_{fjt})}}_{=\mathcal{M}^*_{fjt}} \frac{\tau(1 + t^H_t) w_{Ft}}{z_{fjt}}.$$

Markups charged by Home and Foreign firms, $\mathcal{M}_{ijt}$ and $\mathcal{M}^*_{fjt}$, are functions of their Home market shares s_{ijt} and s^*_{fjt}, which are defined as follows:

$$s_{ijt} = \frac{p_{ijt} y_{ijt}}{\sum_{i' \in \mathcal{I}_H} p_{i'jt} y_{i'jt} + p^*_{fjt} y^*_{fjt}}, \qquad s^*_{fjt} = \frac{p^*_{fjt} y^*_{fjt}}{\sum_{i' \in \mathcal{I}_H} p_{i'jt} y_{i'jt} + p^*_{fjt} y^*_{fjt}}.$$

Both iceberg costs $\tau > 1$ and import tariffs $t_t^H > 0$ act as cost shifters in export markets. Home firms' operating profits in Home and Foreign are

$$\pi_{ijt} = \frac{s_{ijt}}{\sigma - (\sigma - 1)s_{ijt}} P_{Ht} Y_{Ht}, \qquad \pi_{ijt}^* = \frac{s_{ijt}^*}{\sigma - (\sigma - 1)s_{ijt}^*} P_{Ft} Y_{Ft}.$$

Their total operating profits are $\Pi_{ijt} = \pi_{ijt} + \pi_{ijt}^*$.

Resource constraint Given that outputs are demanded in both countries, firms are subject to the following resource constraints: $\mathcal{Y}_{ijt} = y_{ijt} + \tau y_{ijt}^*$, $i \in \{h, \tilde{h}, f\}$.

Innovation, adoption, and step size All three firms can innovate and adopt technology from firms in another country to improve their productivity. To focus on foreign adoption, we assume that firms can only make technology contracts with foreign firms and not with firms within the same country.

Each firm chooses an innovation rate at a cost in labor:

$$\alpha_{Cr} \frac{x_{ijt}^{\gamma_r}}{\gamma_r}. \tag{7}$$

α_{Cr} governs the scale of innovation R&D cost in country C. Each firm also chooses an adoption rate a_{ijt} at costs of labor with the same functional form:[14]

$$\alpha_{Ca} \frac{a_{ijt}^{\gamma_a}}{\gamma_a}. \tag{8}$$

Unlike innovation, adoption requires extra one-time adoption fees $\mathcal{F}_{ijt}$ to sellers in addition to the adoption labor costs in equation (8). If either of the firms does not agree on a contract's terms, adoption does not happen, and both have no change in their values. Adoption fees are determined through Nash bargaining between adopters and sellers, which we will discuss later.

Once a firm chooses innovation and adoption rates by x_{ijt} and a_{ijt}, with probability x_{ijt} or a_{ijt}, it improves its productivity by

$$z_{ij,t+\triangle t} = \lambda^{n_{ijt}} z_{ijt}.$$

n_{ijt} is the number of steps in firm i's improvement in period t and λ is a unit step size. n_{ijt} is a stochastic variable that determines the number of steps in improvement. We can express firms' productivity levels as $\lambda^{N_{ijt}}$, where N_{ijt} is the cumulative number of steps firms have taken until period t, $N_{ijt} = \int_0^t n_{ijs} \mathrm{d}s$. Then, productivity gap m_{ijt}^F between Home firm i and Foreign firm f and m_{ijt}^D between Home firms, measured in steps, can be written as follows:

$$\frac{z_{ijt}}{z_{fjt}} = \frac{\lambda^{N_{ijt}}}{\lambda^{N_{fjt}}} = \lambda^{m_{ijt}^F} \quad \text{and} \quad \frac{z_{ijt}}{z_{-i,jt}} = \frac{\lambda^{N_{ijt}}}{\lambda^{N_{-i,jt}}} = \lambda^{m_{ijt}^D}, \qquad m_{ijt}^F, m_{ijt}^D \in \mathbb{Z}, \qquad i \in \mathcal{I}_H.$$

[14] Adoption labor costs can be interpreted as arising from the fact that adoption requires researchers who investigate, learn, and implement foreign technologies.

For a Foreign firm, we define its gaps with two Home firms:

$$\frac{z_{fjt}}{z_{ijt}} = \frac{\lambda^{N_{fjt}}}{\lambda^{N_{ijt}}} = \lambda^{m^i_{fjt}}, \quad m^i_{fjt} \in \mathbb{Z}, \quad i \in \mathcal{I}_H.$$

$m^F_{ijt} > 0$ and $m^D_{ijt} > 0$ imply that Home firm i has higher productivity than a Foreign firm and its domestic competitor. We assume there is a sufficiently large and exogenously given limit in these productivity gaps, denoted by $\bar{m}$; that is, $\mathbf{m}_{ijt} = \{m^F_{ijt}, m^D_{ijt}\} \in \{-\bar{m}, \ldots, \bar{m}\}^2$ and $\mathbf{m}_{fjt} = \{m^h_{fjt}, m^{\tilde{h}}_{fjt}\} \in \{-\bar{m}, \ldots, \bar{m}\}^2$. Due to the symmetry across sectors, $\mathbf{m}_{hjt}$ is the only state variable relevant to firm-specific payoffs independent of sector j, so we will drop the subscripts j and t when sector-specific values are denoted by productivity gaps.

Conditional on m^F_i, step size distributions for adoption and innovation are given by two fixed probability mass distributions: $n_i \sim f(n; m^F_i)$ and $n_i \sim g(n; m^F_i)$, respectively. $f(n; m^F_i)$ has positive masses for $n \in \{1, \ldots, \bar{m} - m^F_i + 1\}$, where the largest step they can make is bounded by $\bar{m} - m^F_i + 1$.[15] Because lagged Home firms ($m^F_i < 0$) cannot improve productivity higher than that of a Foreign seller's level via adoption, $g(n; m^F_i)$ has positive masses only for $n \in \{1, \ldots, -m^F_i\}$ but $g(n; m^F_i) = 0$ for $n \in \{-m^F_i + 1, \ldots, \bar{m} - m^F_i + 1\}$. Also, when Home firms are more productive than a Foreign firm ($m^F_i > 0$), Home firms have nothing to learn from a Foreign firm ($g(n; m^F_i) = 0$ if $m^F_i > 0$, $n > 0$), so they only innovate and do not adopt.

We impose that $\mathbb{E}_f[n; m^F_i] \geq \mathbb{E}_f[n; m'^F_i]$ and $\mathbb{E}_g[n; m^F_i] \geq \mathbb{E}_g[n; m'^F_i]$ hold for $m^F_i \leq m'^F_i$. This condition implies that firms are more likely to draw larger step size from adoption and innovation when they lag further behind, which captures the notion of the advantages of backwardness. Suppose $\mathbb{E}_g[n; m^F_i] - \mathbb{E}_g[n; m'^F_i] \geq \mathbb{E}_f[n; m^F_i] - \mathbb{E}_f[n; m'^F_i]$ holds for $m^F_i \leq m'^F_i$. This implies that the advantages of backwardness from adoption are larger than those from innovation. While we do not impose this a priori, when calibrating the model to the relevant moments, it is revealed that the advantages of backwardness are stronger for adoption than innovation.

It is also noteworthy that adopters do not necessarily catch up with Foreign firms after a single adoption. Because improvement steps from adoption are stochastic, Home firms may have to make several adoption contracts to fully catch up with Foreign levels. This is a more flexible assumption compared with other models that incorporate technology adoption or imitation. If we set $g(1; m^F_i) = 1$, our model aligns with the case described by König et al. (2022), in which adoption (imitation) results in only a single step of improvement, irrespective of gaps. If we assume $g(-m^F_i; m^F_i) = 1$, our model corresponds to cases in Perla and Tonetti (2014) and Benhabib et al. (2021), in which firms reach the same level of productivity as another firm after a single adoption.[16]

For a Foreign firm, step size distributions can be similarly expressed as $f(n_f; \min\limits_{i \in \mathcal{I}_H}\{m^i_f\})$ and

[15] When a firm is in the most advanced position $m^F_i = \bar{m}$, the firm can only improve one step, and when a firm is at the most laggard position $m^F_i = -\bar{m}$, it can improve up to $2\bar{m} + 1$.

[16] If $g(-m^F_i; m^F_i) = 1$, this implies that both gains for adopters and losses for sellers always decrease in m^F_i. This leads to adoption fees always decreasing in m^F_i, contradicting the pattern observed in the data (Table 4). Our more flexible specification of the adoption step size distribution can better match the observed empirical pattern.

$g(n_f; \min_{i \in \mathcal{I}_H}\{m_f^i\})$, where its distributions depend on its gap with a Home leader.

To summarize, adoption and innovation differ in three ways. First, adoption cannot increase adopters' productivity beyond that of sellers. Second, step size distributions of adoption and innovation can vary in terms of the magnitude of the advantages of backwardness. Lastly, adoption requires that additional adoption fees be paid to foreign sellers.

Knowledge spillovers We allow for two types of exogenous knowledge spillovers. The first is within-country spillovers between a Home leader and a Home follower, motivated by the second empirical finding in Section 3.2. A follower can receive knowledge spillovers from a leader. With probability δ, a follower can attain a leader's productivity level and improve on it when innovating or adopting. If $\delta = 1$, a follower can always build on a leader's technology; this is the common assumption in the quality ladder model literature (e.g., Aghion and Howitt, 1992; Akcigit et al., 2021).

The second is across-country spillovers. With probability $\phi > 0$, all firms across countries gain access to frontier technology without any costs and come to have the same productivity level. ϕ accounts for unobserved spillovers outside of official adoption contracts, such as espionage or reverse engineering. Also, the existence of across-country spillovers ensures a non-degenerate stationary distribution of productivity gaps (e.g., Aghion et al., 2001).[17]

Potential entrants In Foreign, there is a potential entrant $\tilde{f}$ that can innovate on top of the incumbent's productivity. When an entrant innovates, it replaces the incumbent and the incumbent exits. For simplicity, we exclude the option for potential entrants to adopt from other firms. The innovation R&D cost for the entrant is the same as that for the incumbent. With probability $\tilde{x}_{ijt}$, the potential entrant improves on the incumbent's productivity with the same innovation step size distribution $f(n_f; \min_{i \in \mathcal{I}_H}\{m_f^i\})$.

Government policy The Home government subsidizes κ_{Hat} and κ_{Hrt} fractions of Home firms' total adoption and innovation costs. The Foreign government does not provide any subsidies except for imposing import tariffs.

4.4 Equilibrium

In this section, we define a Markov perfect equilibrium in which firms' strategies depend only on productivity gaps, which are payoff-relevant state variables.

Value function We define state variables for Home firm i as $\mathbf{m}_i = \{m_i^F, m_i^D\}$, $i \in \mathcal{I}_H$ and Foreign firm f as $\mathbf{m}_f = \{m_f^h, m_f^{\tilde{h}}\}$. Note that $\mathbf{m}_h$, $\mathbf{m}_{\tilde{h}}$, and $\mathbf{m}_f$ convey the same information because each can be deduced from the other, and vice versa.[18]

[17] Suppose a Foreign firm initially has higher productivity than Home firms. In this class of models, when $\phi = 0$, a Foreign firm always has a higher innovation rate than Home firms. Consequently, a Foreign firm's productivity would always be higher than the other two, since there are not enough reflective forces. This leads to a degenerate stationary distribution in which a Foreign firm has the maximum gap while the Home firms have the minimum gap.

[18] Suppose productivities of firms h, $\tilde{h}$, and f are λ^3, λ^2, and λ^1, respectively. Then the state variables $\mathbf{m}_h$, $\mathbf{m}_{\tilde{h}}$, and $\mathbf{m}_f$ are $\{2, 1\}$, $\{1, -1\}$, and $\{-2, -1\}$, respectively. From $\mathbf{m}_h = \{2, 1\}$, we can deduce $\mathbf{m}_{\tilde{h}} = \{1, -1\}$ and $\mathbf{m}_f = \{-2, -1\}$.

The value function of Home firm $i \in \mathcal{I}_H$ can be expressed as follows:

$$
\begin{aligned}
&r_{Ht} V_{it}(\mathbf{m}_i) - \dot{V}_{it}(\mathbf{m}_i) \qquad (9)\\
&= \max_{x_{it}(\mathbf{m}_i), a_{it}(\mathbf{m}_i)} \Bigg\{ \underbrace{\Pi_{Ht}(\mathbf{m}_i)}_{\text{Profit}} - \underbrace{(1-\kappa_{Hrt})\alpha_{Hr}\frac{x_{it}(\mathbf{m}_i)^{\gamma_r}}{\gamma_r} w_{Ht}}_{\text{Innovation R\&D cost}} - \underbrace{(1-\kappa_{Hat})\alpha_{Ha}\frac{a_{it}(\mathbf{m}_i)^{\gamma_a}}{\gamma_a} w_{Ht}}_{\text{Adoption labor cost}} \\
&+ x_{it}(\mathbf{m}_i) \sum_n \tilde{f}(n; \mathbf{m}_i) \underbrace{\left[V_{it}(m_i^F + n, m_i^D + n) - V_{it}(\mathbf{m}_i)\right]}_{\text{Gain from innovation}} \\
&+ a_{it}(\mathbf{m}_i) \Big[\sum_n \tilde{g}(n; \mathbf{m}_i) \underbrace{\left[V_{it}(m_i^F + n, m_i^D + n) - V_{it}(\mathbf{m}_i)\right]}_{\text{Gain from adoption}} - \underbrace{(1-\kappa_{Hat})\mathcal{F}_{it}(\mathbf{m}_i)}_{\text{Adoption fee payment}} \Big] \\
&+ x_{-it}(\mathbf{m}_{-i}) \sum_n \tilde{f}(n; \mathbf{m}_{-i}) \underbrace{\left[V_{it}(m_i^F, m_i^D - n) - V_{it}(\mathbf{m}_i)\right]}_{\text{Loss from Home competitor innovation}} \\
&+ a_{-it}(\mathbf{m}_{-i}) \sum_n \tilde{g}(n; \mathbf{m}_{-i}) \underbrace{\left[V_{it}(m_i^F, m_i^D - n) - V_{it}(\mathbf{m}_i)\right]}_{\text{Loss from Home competitor adoption}} \\
&+ \big(x_{ft}(\mathbf{m}_f) + \tilde{x}_{ft}(\mathbf{m}_f)\big) \sum_n f(n; \min_{i \in \mathcal{I}_H} \{m_f^i\}) \underbrace{\left[V_{it}(m_i^F - n, m_i^D) - V_{it}(\mathbf{m}_i)\right]}_{\text{Loss from foreign innovation}} \\
&+ a_{ft}(\mathbf{m}_f) \Big[\sum_n g(n; \min_{i \in \mathcal{I}_H} \{m_f^i\}) \underbrace{\left[V_{it}(m_i^F - n, m_i^D) - V_{it}(\mathbf{m}_i)\right]}_{\text{Loss from foreign adoption}} + \underbrace{\mathbb{1}[m_i^D \geq 0] \times \mathcal{F}_{ft}(\mathbf{m}_f)}_{\text{Adoption fee receipt}} \Big] \\
&+ \phi \underbrace{\left[V_{it}(0,0) - V_{it}(\mathbf{m}_i)\right]}_{\text{Exogenous spillover}} \Bigg\}.
\end{aligned}
$$

where $\tilde{f}(n; \mathbf{m}_i)$ and $\tilde{g}(n; \mathbf{m}_i)$ are transition probabilities from one state to another:

$$
\begin{aligned}
\tilde{f}(n; \mathbf{m}_i) &= \mathbb{1}[m_i^D > 0] f(n; m_i^F) + \mathbb{1}[m_i^D \leq 0] \Big\{ (1-\delta) f(n; m_i^F) + \delta f(n + m_i^D; m_i^F - m_i^D) \Big\} \\
\tilde{g}(n; \mathbf{m}_i) &= \mathbb{1}[m_i^D > 0] g(n; m_i^F) + \mathbb{1}[m_i^D \leq 0] \Big\{ (1-\delta) g(n; m_i^F) + \delta g(n + m_i^D; m_i^F - m_i^D) \Big\}.
\end{aligned}
$$

The first and second terms of the transition probabilities reflect cases in which a firm is a leader ($\mathbb{1}[m_i^D > 0]$) and a follower ($\mathbb{1}[m_i^D \leq 0]$), respectively. The second term inside the bracket is a mixture of $f(n; m_i^F)$ and $f(n + m_i^D; m_i^F - m_i^D)$ due to within-country spillovers, where the latter is a distribution shifted by $-m_i^D$ from $f(n; m_i^F - m_i^D)$.

In the Bellman equation, $x_{it}(\mathbf{m}_i)$ and $a_{it}(\mathbf{m}_i)$ are firm i's optimal innovation and adoption rates that maximize its value. The second line includes operating profits and innovation and adoption labor costs net subsidy rates. The next two lines capture value increases from innovation and adoption, respectively. $(1-\kappa_{Hrt})\mathcal{F}_{it}(\mathbf{m}_i)$ is an endogenous adoption fee net of subsidy rates. The next two lines represent the value decrease from innovation and adoption by a Home competitor $-i$, where $x_{-it}(\mathbf{m}_{-i})$ and $a_{-it}(\mathbf{m}_{-i})$ denote the competitor's innovation and adoption rates. As the competitor improves its productivity by n steps, it decreases firm i's value due to heightened competition, represented by $m_i^D - n$.

The following two lines denote the value decrease due to Foreign firms' (incumbent and entrant) innovation and adoption. An n-step improvement in a Foreign firm's productivity decreases Home firm i's value by shifting from m_i^F to $m_i^F - n$. The last line captures the across-country spillover. The value functions of Foreign incumbents and entrants are expressed in Appendix C.1.

Optimal innovation and adoption rate From the value function and first order conditions, the optimal innovation rate of Home firm i can be expressed as

$$x_{ijt} = x_{it}(\mathbf{m}_i) = \left(\frac{\sum_n \tilde{f}(n; \mathbf{m}_i) \big[V_{it}(m_i^F + n, m_i^D + n) - V_{it}(\mathbf{m}_i) \big]}{(1 - \kappa_{Hrt}) \alpha_{Hr} w_{Ht}} \right)^{\frac{1}{\gamma_r - 1}} . \tag{10}$$

Likewise, its optimal adoption rate is

$$a_{ijt} = a_{it}(\mathbf{m}_i) = \left(\frac{\sum_n \tilde{g}(n; \mathbf{m}_i) [V_{it}(m_i^F + n, m_i^D + n) - V_{it}(\mathbf{m}_i)] - (1 - \kappa_{Hat}) \mathcal{F}_{it}(\mathbf{m}_i)}{(1 - \kappa_{Hat}) \alpha_{Ha} w_{Ht}} \right)^{\frac{1}{\gamma_a - 1}} . \tag{11}$$

The optimal innovation and adoption rates of Foreign firms are derived in Appendix C.2.

Adoption fee The adoption fee is a one-time payment that internalizes a Home adopter's future gains and a Foreign seller's losses.[19] The adoption fee is jointly determined by Home and Foreign firms based on Nash bargaining:

$$\begin{aligned} \mathcal{F}_{ijt} = \mathcal{F}_{it}(\mathbf{m}_i) = & \underset{\mathcal{F}_{it}(\mathbf{m}_i)}{\operatorname{argmax}} \Big(\sum_n \tilde{g}(n; \mathbf{m}_i) \big[V_{it}(m_i^F + n, m_i^D + n) - V_{it}(\mathbf{m}_i) \big] - (1 - \kappa_{Hat}) \mathcal{F}_{it}(\mathbf{m}_i) \Big)^{\xi} \\ & \times \Big(\sum_n \tilde{g}(n; \mathbf{m}_i) \big[V_{ft}(m_f^i - n, m_f^{(-i)}) - V_{ft}(\mathbf{m}_f) \big] + \mathcal{F}_{it}(\mathbf{m}_i) \Big)^{1-\xi} . \end{aligned}$$

$0 \leq \xi \leq 1$ is the bargaining power of adopters. $\sum_n \tilde{g}(n; \mathbf{m}_i) V_{it}(m_h^F + n, m_h^D + n)$ is the expected new value of Home firm i after adoption. The net value from adoption is the new value minus an adoption fee after subsidy, $(1 - \kappa_{Hat}) \mathcal{F}_{it}(\mathbf{m}_i)$. Likewise, the expected loss of Foreign seller f due to heightened competition is $\sum_n \tilde{g}(n; \mathbf{m}_i) V_{ft}(m_f^i - n, m_f^{(-i)})$, but it receives an adoption fee $\mathcal{F}_{it}(\mathbf{m}_i)$. Both firms' outside options are their current values $V_{it}(\mathbf{m}_i)$ and $V_{ft}(\mathbf{m}_f)$. Taking the first order condition, we obtain that

$$\begin{aligned} \mathcal{F}_{it}(\mathbf{m}_i) = & \Big((1 - \xi) \sum_n \tilde{g}(n; \mathbf{m}_i) \big[V_{it}(m_i^F + n, m_i^D + n) - V_{it}(\mathbf{m}_i) \big] \\ & - \xi \sum_n \tilde{g}(n; \mathbf{m}_i) \big[V_{ft}(m_f^i - n, m_f^{(-i)}) - V_{ft}(\mathbf{m}_f) \big] \Big) / \left(1 - (1 - \xi) \kappa_{Hat}\right) . \end{aligned} \tag{12}$$

[19] To focus on the interaction between Home adopters and Foreign sellers, we impose three assumptions on the bargaining process. First, both adopters and sellers cannot make contracts contingent on future behaviors. For example, sellers cannot prohibit adopters from exporting. This is very rare in the data; only 1.3% of contracts restrict adopters' future exports. Second, a Foreign seller cannot promise not to sell their technology to another Home firm. This assumption can be micro-founded if a seller cannot commit to its future behavior. Lastly, a Foreign firm cannot bargain with two Home firms simultaneously.

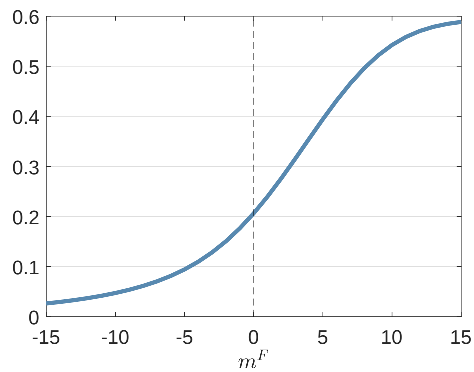


Figure 3: Profit Function over the Productivity Gap with Foreign Firms

Notes. This figure plots the profits of a Home firm on the Y-axis and the productivity gap with a Foreign firm on the X-axis while holding other variables constant. The gap between Home firms is set at zero. $\sigma = 6$, $\tau = 1.2$, $t_t^C = 0$, $\lambda = 1.1$.

Adoption fees are higher when Foreign firms lose more and Home firms gain more from contracts because Foreign firms want to be compensated more for larger losses, and Home firms are willing to pay more for larger gains. Notably, within-country spillovers are also factored into the equilibrium price since they are included in the value functions of both foreign and domestic firms. Adoption fees when Foreign firms adopt technology are detailed in Appendix C.3.

Adoption fees vary across productivity gaps due to two forces: the advantage of backwardness and the competition effect. When they are more lagged behind, Home firms' gains from adoption are larger due to the advantage of backwardness, which leads to higher adoption fees. On the other hand, with narrower gaps, even small productivity improvement from adoption can enable Home firms to take larger market shares from Foreign firms, which causes Foreign firms to demand larger compensation and, in turn, higher adoption fees. Figure 3 shows an example of a Home firm's profit function over gaps with a Foreign firm while holding other variables constant. The slope of the profit function is flatter when more lagged behind but becomes steeper as gaps narrow to zero. This is because small productivity improvements can take large market shares from a Foreign firm as competition intensifies. Therefore, adoption fees can either increase or decrease with gaps, depending on which forces dominate.

The equilibrium adoption fee is also influenced by the subsidy rate. This occurs because a subsidy increases the buyer's surplus, which is then partially passed on to the seller through a higher price. The extent to which the adoption fee responds to changes in the subsidy rate is determined by bargaining power. Specifically, when the bargaining power of the adopting firm, ξ, approaches zero, the elasticity reaches its maximum and the adoption fee increases with the subsidy rate by $\frac{1}{1-\kappa_{Hat}}$. Conversely, when ξ converges to zero, the subsidy rate does not affect the adoption fee. Thus, adoption subsidies are more effective when adopting firms possess greater bargaining power, since this minimally impacts the adoption fee.

Total surplus—the sum of Home and Foreign firms' net value increases from an adoption contract—should be positive for the contract to occur. The size of the total surplus depends on several forces. First, with a lower Home wage than the Foreign wage, Home firms can produce more output than Foreign firms using the same technologies, which increases the total surplus from potential contracts. Second, higher trade costs lead to more market segmentation, which reduces Foreign firms' profits in the Home market. As a result, Foreign firms may prefer to sell their technology, and collect adoption fees while Home firms use the adopted technologies for production. In such a case, the total surplus from potential contracts is larger because contracts help circumvent trade costs. Finally, a lower elasticity of substitution weakens competition and boosts Foreign firms' motivation to sell their technology.

Distribution of productivity gaps We describe the law of motion for productivity gap distributions. We define $\mathbb{T}_{it}(n;\mathbf{m}_i)$ and $\mathbb{T}_{ft}(n;\mathbf{m}_f)$ as probabilities that Home firm $i \in \mathcal{I}_H$ and Foreign firm f will improve productivity n steps conditional on $\mathbf{m}_i$ and $\mathbf{m}_f$, respectively:

$$\mathbb{T}_{it}(n;\mathbf{m}_i) := \tilde{f}(n;\mathbf{m}_i)x_{it}(\mathbf{m}_i) + \tilde{g}(n;\mathbf{m}_i)a_{it}(\mathbf{m}_i),$$
$$\mathbb{T}_{ft}(n;\mathbf{m}_f) := f(n;\min_{i\in\mathcal{I}_H}\{m_f^i\})(x_{ft}(\mathbf{m}_f) + \tilde{x}_{ft}(\mathbf{m}_f)) + g(n;\min_{i\in\mathcal{I}_H}\{m_f^i\})a_{ft}(\mathbf{m}_f).$$

Let $\mu_t = \mu_t(\mathbf{m}_h)$ denote shares of sectors whose gaps between firms are positioned at $\mathbf{m}_h$ in t. Because each $\mathbf{m}_h$, $\mathbf{m}_{\tilde{h}}$, and $\mathbf{m}_f$ convey the same information and implies the other two, without loss of generality, $\mathbf{m}_h$ can represent the states of each sector. The law of motion for $\mu_t(\mathbf{m}_h)$ is

$$\begin{aligned}
\dot{\mu}_t(\mathbf{m}_h) = & \sum_{n=1}^{m_h^F+\bar{m}} \underbrace{\mathbb{T}_{ht}(n;m_h^F-n,m_h^D-n)\mu_t(m_h^F-n,m_h^D-n)}_{\text{Innovation/adoption by firm } h} \qquad (13)\\
& + \sum_{n=1}^{m_{\tilde{h}}^D+\bar{m}} \underbrace{\mathbb{T}_{\tilde{h}t}(n;m_{\tilde{h}}^F-n,m_{\tilde{h}}^D-n)\mu_t(m_h^F,m_h^D+n)}_{\text{Innovation/adoption by firm } \tilde{h}} + \sum_{n=1}^{m_f^h+\bar{m}} \underbrace{\mathbb{T}_{ft}(n;m_f^h-n,m_f^{\tilde{h}}-n)\mu_t(m_h^F+n,m_h^D)}_{\text{Innovation/adoption by firm } f}\\
& + \underbrace{\phi\mathbb{1}[\mathbf{m}_h=\mathbf{0}]}_{\text{Exogenous spillover}} - \underbrace{\left(x_{ht}(\mathbf{m}_h)+a_{ht}(\mathbf{m}_h)+x_{\tilde{h}t}(\mathbf{m}_{\tilde{h}})+a_{\tilde{h}t}(\mathbf{m}_{\tilde{h}})+x_{ft}(\mathbf{m}_f)+\tilde{x}_{ft}(\mathbf{m}_f)+\phi\right)\mu_t(\mathbf{m}_h)}_{\text{Subtracted mass}}.
\end{aligned}$$

The first line captures sectors whose state variables become $\mathbf{m}_h$ at t due to Home firm h's innovation and adoption; the second line due to innovation and adoption of Home firm $\tilde{h}$; and the third line due to Foreign incumbent f and entrants. In the fourth line, exogenous cross-country spillovers cause all firms to have the same productivity level. The last line captures sectors that moved to other values of state variables due to firms' innovation and adoption and spillovers. Along the balanced growth path, $\dot{\mu}_t(\mathbf{m}_h) = 0$ for all $\mathbf{m}_h$.

Market clearing Asset markets clear in each period: $A_{Ct} = \int_0^1 \sum_{i\in\mathcal{I}_C} V_{ijt}\mathrm{d}j$, where the right-hand side is the sum of the values of all firms in country C. Goods markets clear according to

$$\sum_{i\in\mathcal{I}_C} p_{ijt}y_{ijt} + p^*_{fjt}y^*_{fjt} = P_{Ct}Y_{Ct} = P_{Ct}C_{Ct}, \qquad \forall j \in [0,1].$$

Labor markets clear as

$$L_{Ct} = \int_0^1 \sum_{i\in\mathcal{I}_C} \left(l_{ijt} + \alpha_{Ca}\frac{a_{ijt}^{\gamma_a}}{\gamma_a} + \alpha_{Cr}\frac{x_{ijt}^{\gamma_r}}{\gamma_r} \right) \mathrm{d}j.$$

The right-hand side is the sum of labor demand for production, innovation, and adoption.

The governments hold balanced budgets in each period:

$$T_{Ct} = (1+\theta)\int_0^1 \sum_{i\in\mathcal{I}_C} \left(\kappa_{cat}a_{ijt}\mathcal{F}_{ijt} + \kappa_{Cat}\alpha_{Ca}\frac{a_{ijt}^{\gamma_a}}{\gamma_a}w_{Ct} + \kappa_{crt}\alpha_{Cr}\frac{x_{ijt}^{\gamma_r}}{\gamma_r}w_{ct} \right) - \frac{t_t^C}{1+t_t^C}\sum_{i\in\mathcal{I}_{-C}} p^*_{ijt}y^*_{ijt}\mathrm{d}j.$$

θ is a reduced form parameter for the deadweight cost of taxation, which implies that the government needs to collect $1+\theta$ tax revenues to finance one unit of government expenditure. $\theta > 0$ introduces the inefficiency of technology policies due to this deadweight cost. The second term is revenues from import tariffs.

Trade is balanced in every period:

$$\int_0^1 \Big[\sum_{i\in\mathcal{I}_{-C}} p^*_{ijt}y^*_{ijt} + \sum_{i\in\mathcal{I}_C} a_{ijt}\mathcal{F}_{ijt} \Big] \mathrm{d}j = \int_0^1 \Big[\sum_{i\in\mathcal{I}_C} p^*_{ijt}y^*_{ijt} + \sum_{i\in\mathcal{I}_{-C}} a_{ijt}\mathcal{F}_{ijt} \Big] \mathrm{d}j.$$

The condition includes trade not only in goods but also technologies.

Equilibrium We formally define a Markov perfect equilibrium of the model:

Definition 4.1. A Markov perfect equilibrium consists of $\{r_{Ct}, w_{Ct}, p_{ijt}, p^*_{ijt}, x_{ijt}, a_{ijt}, \mathcal{F}_{ijt}, T_{Ct}, C_{Ct}, Y_{Ct}, A_{Ct}, \mu_{\mathbf{m}t}\}_{i\in\{h,\tilde{h},f,\tilde{f}\},\mathbf{m}\in\{-\bar{m},\ldots,\bar{m}\}^2}^{t\in[0,\infty),j\in[0,1],c\in\{H,F\}}$, such that:

- (Static equilibrium) A representative household maximizes the sum of discounted utility subject to the budget constraint; firms maximize profits; goods, labor, and asset markets clear; and trade and government budgets are balanced in each country and period.
- (Dynamic equilibrium) x_{ijt} and a_{ijt} solve the firm's dynamic problem (Equations (10) and (11)); $\mathcal{F}_{ijt}$ solves Nash bargaining between buyers and sellers (Equation (12)); and $\{\mu_{\mathbf{m}0}\}$, $\{\mu_{\mathbf{m}t}\}_{t\in[0,\infty)}$ is consistent with x_{ijt} and a_{ijt} (Equation (13)).

We then define a balanced growth path equilibrium as follows:

Definition 4.2. A balanced growth path is the equilibrium defined in Definition 4.1, in which $\{w_{Ct}, V_{ijt}, \mathcal{F}_{ijt}, T_{Ct}, C_{Ct}, Y_{Ct}, A_{Ct}\}$ grow at a constant rate g, and r_{Ct} and μ_t are constant over time.

4.5 Taking Stock

4.5.1 Relationships to the Two Empirical Findings

The key feature of the model is that relative gains and costs from adoption over innovation vary across productivity gaps. The advantages of backwardness and strategic competition are crucial for understanding these gains and costs and enabling the model to align with the first fact, that larger gaps were associated with larger productivity growth after adoption but lower adoption fees. If adoption yields stronger advantages of backwardness than innovation, the model can generate positive relationships between productivity gains from adoption and technological distance. Also, if the competition effect dominates, narrower productivity gaps lead forward-looking Foreign firms to charge higher adoption fees, responding to heightened competition. This generates negative relationships between adoption fees and technological distance. The second fact is incorporated as knowledge spillovers from adoption between Home firms.

4.5.2 Market Failures

Several market failures prevent the competitive equilibrium from being efficient. First, positive externalities arise due to knowledge spillovers within and across countries. Own innovation or adoption increases competitors' future productivity through intertemporal spillovers, which leads to underinvestment by firms in adoption and innovation. In particular, the magnitude of within-country spillovers is proportional to expected productivity gains times the parameter δ, and these spillovers depend on gaps. With larger gaps, because productivity gains from adoption are larger than those from innovation due to the stronger advantages of backwardness, spillovers from adoption are also larger, which renders subsidizing adoption more effective in this stage.

Second, innovation and adoption have business-stealing effects. Firms may invest excessive resources in them for marginal productivity improvements, which enable them to capture a sizable portion of other firms' market shares. However, from the perspective of the social planner, only aggregate productivity and output matter; and a specific firm's gain in market shares is irrelevant.

Lastly, oligopolistic power leads firms to produce less than the socially optimal level.

4.5.3 Discussions of Model Assumptions

To focus on foreign adoption, we assume that a Home follower does not adopt technologies from a Home leader. This assumption not only simplifies the model and its computation but also aligns with the fact that only small fractions of total adoption fees were used for domestic transfers. For example, estimated adoption fees between domestic firms were only 6.3% of total expenses (Lee, 2022). Moreover, even when domestic adoption is allowed in the model, technology transfer between domestic firms does not occur in equilibrium with the calibrated parameters. This is because they face the same wage and trade costs, which reduces the total surplus generated by adoption contracts.

Another assumption is the absence of new firm entries in Home, which means that the model does not account for growth contributions from entrants. However, our data shows that the shares of new firms in technology adoption and patents were modest at 3.2% and 1.5%, respectively. Therefore, the contribution from the entry margin would be quantitatively limited.

5 Taking the Model to the Data

5.1 Parametrization

Before calibrating the model, we impose more structure on it.

Step size distributions We parameterize adoption and innovation step size distributions following Akcigit et al. (2021). We first define fixed probability mass distributions $h_r(n')$ and $h_a(n')$, which are later used to construct $f(n; m_i^F)$ and $g(n; m_i^F)$, respectively:

$$h_r(n') = \begin{cases} c_r \cdot (n')^{-\eta_r} & \text{if} \quad 1 \le n' \le 2\bar{m}+1 \\ 0 & \text{if} \quad 2\bar{m}+1 \le n' \end{cases}, \qquad h_a(n') = \begin{cases} c_a \cdot (n')^{-\eta_a} & \text{if} \quad 1 \le n' \le \bar{m} \\ 0 & \text{if} \quad \bar{m}+1 \le n' \end{cases},$$

where $c_r = (\sum_{n'=1}^{2\bar{m}+1} (n')^{-\eta_r})^{-1}$ and $c_a = (\sum_{n'=1}^{\bar{m}} (n')^{-\eta_a})^{-1}$ are normalizing constants. Because $\eta_r, \eta_a > 0$, $h_r(n')$ and $h_a(n')$ decrease in n'. Next, we define

$$\mathbb{H}_r(m_i^F) = \begin{cases} \sum_{n'=1}^{m_i^F+\bar{m}} h_r(n') & \text{if} \quad -\bar{m}+1 \le m_i^F \le \bar{m} \\ 0 & \text{otherwise} \end{cases},$$

$$\mathbb{H}_a(m_i^F) = \begin{cases} \sum_{n'=1}^{m_i^F+\bar{m}} h_a(n') & \text{if} \quad -\bar{m}+1 \le m_i^F \le -1 \\ 0 & \text{otherwise} \end{cases}.$$

Using $h_r(n')$ and $\mathbb{H}_r(m_i^F)$, we parameterize $f(n; m_i^F)$ as

$$f(n; m_i^F) = \begin{cases} h_r(n + m_i^F + \bar{m}) + \mathbb{H}_r(m_i^F) & \text{if} \quad n = 1 \\ h_r(n + m_i^F + \bar{m}) & \text{if} \quad 2 \le n \le \bar{m} - m_i^F + 1 \\ 0 & \text{otherwise} \end{cases}.$$

This parametrization captures the notion of the advantages of backwardness. $\mathbb{H}_r(m_i^F)$ ensures that the probability of $n = 1$, the minimal step that can be made from innovation, rises with an increase in m_i^F. Also, for $n \ge 2$, $h_r(n + m_i^F + \bar{m})$ decreases with m_i^F. Therefore, with higher m_i^F, firms are more likely to draw the minimal step by $n = 1$ and less likely to draw larger steps $n \ge 2$, which causes the expected step size $\mathbb{E}[n; m_i^F]$ to decrease in m_i^F.

Innovation step size distributions $f(n; m_i^F)$, defined for each m_i^F, are parameterized by a single parameter η_r due to the additive nature. The parameter η_r governs the strength of the advantage of backwardness. Higher η_r makes $\mathbb{E}_f[n; m_i^F]$ decrease in m_i^F more rapidly. Because estimates of the interaction term between gaps and innovation dummies are close to zero and statistically insignificant in Table 3, we impose that innovation does not feature advantages of backwardness by setting $\eta_r \to \infty$.[20] When $\eta_r \to \infty$, step size from innovation is always fixed to 1, regardless of the current gaps, as in the standard step-by-step model with only one step improvement (e.g., Aghion et al., 2001) and innovation does not feature advantages of backwardness.

For adoption, we parameterize $g(n; m_i^F)$ similarly:

$$g(n; m_i^F) = \begin{cases} h_a(n + m_i^F + \bar{m}) + \mathbb{H}_a(m_i^F) & \text{if} \quad n = 1 \quad \text{and} \quad -\bar{m} \leq m_i^F \leq -1 \\ h_a(n + m_i^F + \bar{m}) & \text{if} \quad 2 \leq n \leq -m_i^F \quad \text{and} \quad -\bar{m} \leq m_i^F \leq -1 \\ 0 & \text{otherwise} \end{cases}.$$

One important distinction between adoption and innovation is that $g(n; m_i^F)$ takes positive masses only when Home firms have lower productivity than Foreign firms $m_i^F < 0$. Furthermore, the maximum step n from adoption is $-m_i^F$, which reflects the fact that adoption cannot enable Home firms to surpass Foreign firms' productivity levels.

Also, adoption step size distributions $g(n; m_i^F)$, defined for each m_i^F, are parametrized by a parameter η_a. Because $f(n; m_i^F)$ and $g(n; m_i^F)$ are governed by the different parameters η_r and η_a, adoption and innovation have different magnitudes of the advantages of backwardness. For example, $\eta_a < \eta_r$ implies that adoption features stronger advantages of backwardness.

Panel A of Figure 4 illustrates the expected step size of adoption $\mathbb{E}_g[n; m_i^F]$ over m_i^F for different values of η_a. The expected step size decreases in m_i^F more rapidly with lower η_a. In Panel B of Figure 4, we compare the expected step sizes of innovation and adoption, conditional on current gaps, over m_i^F. Because $\eta_r \to \infty$, the expected step size from innovation is always one regardless of current gaps. However, because $\eta_a < \eta_r$, even though the adoption step size distribution is truncated at $m^F = 0$, adoption has a higher expected step size than innovation when the firm is more lagged behind.

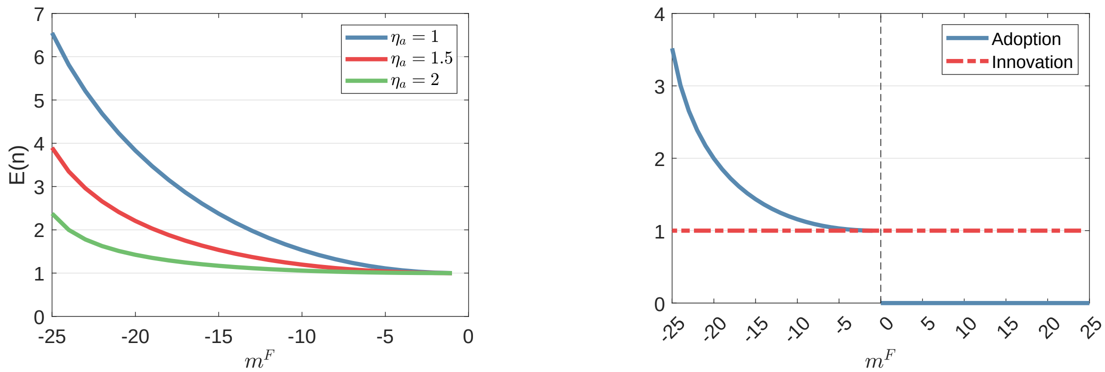
Initial and maximum productivity gap The initial productivity gap between Home and Foreign firms is assumed to follow a normal distribution with a mean of d and a standard deviation of 1, $\mathcal{N}(d, 1)$, across sectors $j \in [0, 1]$. $d < 0$ indicates that Home firms' productivity lags behind Foreign firms', with greater values implying more significant lags.

We set the maximum gaps between Foreign incumbents and Home leaders and between Home leaders and followers to 25 and 5, respectively, for computational simplicity. We obtain these numbers by incrementally increasing the maximum gaps until they no longer significantly affect key results.

Foreign adoption and innovation costs Finally, we assume that Foreign firms' adoption labor cost and innovation R&D cost are proportional to Home firms' costs by a factor of α_F: $\alpha_{Fr} = \alpha_F \times \alpha_{Hr}$ and $\alpha_{Fa} = \alpha_F \times \alpha_{Ha}$. We impose this symmetry due to the lack of information on Foreign firms' adoption activities.

[20] Computationally, we approximate $\eta_r \to \infty$ by setting $\eta_r = 100$.

Figure 4: Advantages of Backwardness and Model Parameters



A. $\mathbb{E}_g[n; m_i^F]$ with different η_a

B. Innovation vs. Adoption

Notes. Panel A compares the expected size from adoption $\mathbb{E}_g[n; m_i^F]$ over m_i^F for different values of η_a. A negative m_i^F implies that a Home firm has lower productivity than a Foreign firm. Panel B compares the expected step size from innovation and adoption, $\mathbb{E}_f[n; m_i^F]$ and $\mathbb{E}_g[n; m_i^F]$, over m_i^F, where $\eta_r \to \infty$ and $\eta_a = 1.596$.

5.2 Calibration

We calibrate 23 parameters in three steps. We take 6 parameters directly from the data, externally calibrate 7 parameters, and jointly estimate the remaining 10 parameters by simulated method of moments (SMM). Given a guess of the parameters, we solve for transitions of the model with the initial conditions until it converges to the balanced growth path. Along transitions, we compute model moments based on the guess and then update the guess to minimize the distance between model moments and their data counterparts. We incorporate time-varying policies, including adoption and innovation subsidies and import tariffs, while assuming agents' perfect foresight. We provide a computational algorithm for solving transitions in Appendix D.2.

Home and Foreign correspond to Korea and Japan, respectively, since Japan is the largest source of foreign technologies for Korean firms. We set the year 1973 as the initial year.

5.2.1 Parameters that Directly Match the Data

We take the 6 parameters $\{L_H, L_F, \kappa_{Hat}, \kappa_{Hrt}, t_t^H, t_t^F\}$ directly from the data. We set Korea's labor endowment $L_H = 1$ as normalization and $L_F = 2$ to match Japan's relative population size. We use subsidy rates κ_{Hat} and κ_{Hrt} calculated from tax credit data (Figure 1).

For import tariffs t_t^H and t_t^F, we use import-weighted average tariff across sectors. For Korea, between 1973 and 1988, we collect product-level import tariffs from the Korea Customs Service.[21] For Japan during the same period, we use the average import tariff from Yi (2003). From 1988 on-

[21] Raw data are at Customs Co-operation Council Nomenclature (CCCN) 4-digit level, which we aggregate using import values.

ward, we rely on World Development Indicators provided by the World Bank and obtain average tariff rates for both Korea and Japan over the sample period. Appendix Figure D.1 reports the average import tariffs for both Korea and Japan. Between 1973 and 2023, Korea's tariffs decreased from 27% to 5%, while Japan's tariff decreased from 8% to 3%. Korea's tariffs were much higher than Japan's in the 1970s and gradually converged toward Japan's level.

5.2.2 External Calibration

We externally calibrate the 7 parameters $\{\rho, \psi_H, \psi_F, \gamma_r, \gamma_a, \sigma, \theta\}$. We use a discount rate of $\rho = 0.03$, which is a commonly used value in the literature. To achieve symmetry between the two countries, we set $\psi_H = 0.25$ and $\psi_F = 0.5$, since Home has two operating firms and Foreign has only one. We set the curvature parameters for innovation R&D costs γ_r to 2 to match the elasticity of successful innovation with respect to R&D (Blundell et al., 2002; Akcigit et al., 2021). Due to limited information on the curvature of the adoption labor cost, we set the same curvature parameter value for adoption, $\gamma_a = 2$. We choose $\sigma = 6$ to align with the average value found by Broda and Weinstein (2006) in the 1980s. We set $\theta = 1$ following Feldstein (1999), which implies that the government needs to collect 2 units of tax revenues to finance 1 unit of expenditure.

5.2.3 Simulated Method of Moments

We estimate the remaining 10 parameters, $\mathbf{\Theta} = \{\lambda, \alpha_r, \alpha_a, \alpha_F, \eta_a, \tau, \xi, \delta, d, \phi\}$, by targeting 10 data moments. We choose $\mathbf{\Theta}$ that minimizes the distance between model moments $M_i(\mathbf{\Theta})$ and their data counterpart M_i^D:

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

Although these parameters are jointly estimated, we heuristically discuss the most relevant moments for each parameter.

Ratio of adoption fee to yearly sales We calculate total adoption fees as the sum of royalty rate times sales and fixed fees in the data. Using these calculated adoption fees, we compute the average ratio of the total adoption fee to yearly sales, which is 22.4%. This moment is informative on the parameter ξ that governs the bargaining power of adopters because higher ξ corresponds to lower adoption fees.

Productivity gain from adoption over the initial gap Using model-simulated data, we run the same specification in column 3 of Table 3 with sector-year fixed effects. We match the coefficient of the interaction term between the productivity gap and the adoption dummy. This moment identifies η_a because it is related to the magnitude of the advantages of backwardness due to adoption.

Patent citation increase after adoption We pin down δ, which governs the strength of knowledge spillovers between Korean firms, by targeting the average increase in the probability of being cited by 0.02 within 5 years from the first technology adoption (column 1 of Table 5).

One issue is that the model abstracts away from patent citations. To better align the model with the second empirical finding, we develop a simple microfoundation for patent citations similar to that of Akcigit and Kerr (2018), and use this microfoundation to map the model to the data. In the microfoundation, a Home follower must cite a Foreign firm's patents when receiving knowledge spillovers from adopted technologies and innovating on this knowledge. Increased citations from a Home follower to a Foreign firm are represented as $\bar{x} \times \delta$, where $\bar{x}$ is the average innovation rate and δ is the probability of receiving knowledge spillovers. Based on this mapping, we calibrate δ to match the average effect of $\bar{x} \times \delta = 0.02$. For further details on the patent citation model, refer to Appendix C.4.

Manufacturing shares of exports to value-added Between 1970 and 1993, the average manufacturing shares of exports to value-added were 0.392. We use this moment to calibrate iceberg costs τ, with higher shares corresponding to lower τ.

R&D and adoption fee expenditures as a share of manufacturing value-added We target the average manufacturing shares of innovation R&D and adoption fee expenditures to manufacturing value-added in 1985 and 1990 to pin down the scale parameters of innovation and adoption costs, α_r and α_a, respectively. When calculating these shares, we also use manufacturing R&D expenses in 1985 and 1990 obtained from The Ministry of Science and Technology (1990).[22] The shares of innovation R&D and adoption fee expenditures were 2.97% and 1.48%, respectively.

Long-run GDP growth rate We target the GDP per capita growth rate since 2010 in Japan and Korea, with an average of 2.1%. This moment is informative on the unit step size of adoption and innovation λ that governs the long-run growth rate of the balanced growth path.

Real GDP per capita ratio between Korea and Japan in 1973 and 2020 In 1973, the initial real GDP per capita ratio between Korea and Japan was 0.21, which pins down the parameter d related to the average initial productivity gap between the two countries across sectors. By 2020, this ratio had risen to 0.981. The 2020 ratio is informative on the exogenous spillover parameter ϕ, because higher ϕ implies faster convergence and the GDP ratio will be closer to 1 in 2020.

Productivity ratio in the long run To ensure symmetry in productivity levels along the balanced growth path, we adjust foreign R&D cost parameter α_F and target the long-run productivity ratio between the Home leader in Korea and the incumbent in Japan to 1.[23] Higher α_F results in higher innovation and adoption costs in Japan, and therefore lower long-run productivity.

5.3 Estimation Results

Table 6 reports the estimation results. The estimate of η_a that governs the magnitude of the advantages of backwardness relative to innovation is 1.596. Our estimate of 1.596 is within the range of

[22] Here, we calibrate the model using R&D expenses from The Ministry of Science and Technology (1990), because it reports R&D expenses separately for manufacturing, service, and commodity sectors, whereas the data from the Statistics Korea, used in Panel B of Figure 1, only report total expenses. However, using different sources is unlikely to be a concern because manufacturing expenses explain the majority (93%) of total expenses.

[23] Because there are two firms in Korea and one firm in Japan, the two countries have different innovation and adoption rates, even with the same cost parameters.

Table 6: Estimation Results

Parameter	Description	Value	Source
Directly From Data			
L_H	Home labor endowment	1	Normalization
L_F	Foreign labor endowment	2	Population in Japan
$\kappa_{Hat}, \kappa_{Hrt}$	Subsidy rate		Tax credit rate, corporate tax rate
t_t^H, t_t^F	Import tariff rate		Average import tariff rate
Externally Calibrated			
ρ	Time preference	0.03	Literature
σ	Elasticity of substitution	6	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
γ_a, γ_r	Adoption / innovation cost curvature	2	Acemoglu et al. (2018)
θ	Deadweight cost of taxation	1	Feldstein (1999)
Jointly calibrated through SMM			
λ	Unit step size	1.056	
η_a	Slope of step size from adoption	1.596	
α_a	Adoption cost	1.334	
α_r	Innovation cost	1.569	
τ	Iceberg trade cost	1.568	Jointly Estimated through SMM
ξ	Bargaining power of adopter	0.556	
δ	Knowledge diffusion	0.252	
d	Initial productivity gap	-17.551	
α_F	Relative cost in F	6.168	
ϕ	Exogenous spillover	0.037	

Notes. This table reports calibrated values of the parameters and the summary of the calibration strategy.

previous estimates in the literature: Olmstead-Rumsey (2022) and Akcigit et al. (2022) impose the same functional forms for innovation step size distributions and obtain estimates of 0.8–1.7 and 1.2, respectively.

The estimate for λ is 1.056, which implies one step improvement increases productivity by 5.6%. We find that $\alpha_a < \alpha_r$, which implies lower labor requirements for adoption. τ, the iceberg trade cost parameter, is estimated to be 1.568. The bargaining power parameter for the adopting firm ξ is 0.556, which suggests that adopters have slightly larger bargaining power with sellers. The probability of receiving knowledge spillovers δ is 0.252. Initial productivity gap d is -17.551, which indicates that Japanese firms were initially 2.6 times more productive than Korean firms. The estimate for Japan's relative innovation and adoption costs α_F is 6.168. The probability of exogenous spillover ϕ is estimated at 0.037, which falls within the lower range of estimates in the literature.[24]

Table 7 reports estimation results and target moments from the data and the model. The model

[24] Akcigit and Ates (2023) provide estimates from 0.034 to 0.084 in a closed economy. Cavenaile et al. (2023) estimates at 0.016, and Sui (2023) between 0.01 and 0.09 in open economy settings.

Table 7: Target Moments in the Model and the Data

Moment	Model	Data
Adoption fee / annual sale	0.224	0.224
β^a : productivity growth and initial gap (adoption)	-0.065	-0.065
β^s : Δ Patent citation after adoption	0.019	0.019
Long-run growth rate	0.021	0.021
Adoption / value-added in manufacturing	0.015	0.015
R&D / value-added in manufacturing	0.030	0.030
Export / value-added in manufacturing	0.392	0.392
GDP ratio in 1973	0.210	0.210
GDP ratio in 2020	0.981	0.980
Long-run productivity ratio	1.000	1.006

Notes. This table reports targeted moments of the model and data counterparts.

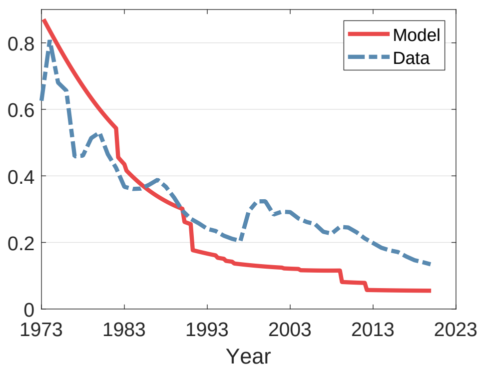
closely matches micro and macro moments in the data. In particular, the model can replicate Korea's catching up with Japan during the sample period.

5.4 Validation

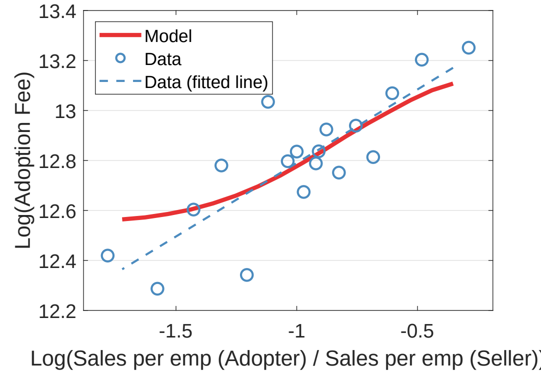
To validate the model, we present two untargeted moments. Panel A of Figure 5 illustrates the evolution of shares of total adoption fees relative to the sum of total adoption fees and innovation R&D expenditures computed from the model and data (Panel B of Figure 1). Our model can match the declining trend in adoption fee shares. It is worth noting that this decreasing trend is not solely a result of the policy; the model inherently generates this trend even without subsidies (Appendix Figure D.2). This untargeted moment is related to the fact that firms tend to prioritize innovation over adopting foreign technologies as they narrow the gaps. In Panel B, we present log adoption fees plotted against the log ratio of sales per employee between Home and Foreign firms, in which adoption fees become higher as Korean firms narrow productivity gaps, consistent with the first fact regarding the relationship between adoption fees and productivity gaps (Table 4). This untargeted moment highlights the importance of competition effects in determining adoption fees.

6 Quantitative Results

In this section, we first decompose aggregate TFP growth between adoption and innovation. Then, we evaluate the state-dependent technology policy implemented in Korea in 1973, which started with an adoption subsidy and switched to an innovation subsidy, as depicted in Panel A of Figure 1. We also examine the impact of a hypothetical foreign policy—specifically, Japan's restrictions on technology transfers to Korea. Finally, we examine optimal adoption and innovation subsi-



A. Adoption Expenditure Share



B. Adoption Fee over Gap

Figure 5: Untargeted Moments

Notes. This figure illustrates untargeted moments from both the data and the model. In Panel A, the model's adoption fee expenditure / (adoption fee + innovation cost) is represented by the solid red line, while the data is denoted by the dashed blue line. Panel B displays the log of the adoption fee over the log ratio of sales per employee between Home and Foreign firms in the model (solid red line), accompanied by data represented by dashed blue lines and circles.

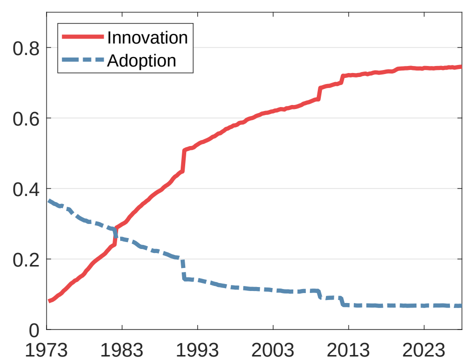


Figure 6: Share of TFP Growth from Adoption and Innovation over Time

Notes. This figure plots the TFP growth share of adoption (dashed blue line) and innovation (solid red line) over time, using equation (14). The remaining share is from exogenous spillover.

dies—while keeping the ratio of government spending to GDP remains consistent with actual policy implementation—and how the optimal policy interacts with trade policies.

6.1 Contribution of Adoption and Innovation to TFP Growth over Time

Our analysis begins by decomposing contributions from adoption and innovation to aggregate TFP growth over time. We define aggregate TFP as the aggregate output per production labor as below:

$$Z_{Ht} = \frac{Y_{Ht}}{L^p_{Ht}},$$

where L^p_{Ht} is the labor used for production.[25] $d\log Z_{Ht}$ can be first-order approximated as

$$d\log Z_{Ht} \approx \sum_{\mathbf{m}_h} \mu_t(\mathbf{m}_h) \sum_{i\in\mathcal{I}_H} \omega_{it}(\mathbf{m}_i) \log\lambda \times \Bigg(\underbrace{x_{it}(\mathbf{m}_i)\sum_n \tilde{f}(n;\mathbf{m}_i)n}_{\text{Innovation}} + \underbrace{a_{it}(\mathbf{m}_i)\sum_n \tilde{g}(n;\mathbf{m}_i)n}_{\text{Adoption}} + \underbrace{\phi_0 \max\{-m_i^F, -m_i^D, 0\}}_{\text{Exogenous Spillover}} \Bigg) \tag{14}$$

where

$$\omega_{it}(\mathbf{m}_i) = \frac{\frac{S_{Ht}s_t(\mathbf{m}_i)}{\mathcal{M}_t(\mathbf{m}_i)} + \frac{(1-S_{Ht})s^*_t(\mathbf{m}_i)}{\mathcal{M}^*_t(\mathbf{m}_i)}}{\sum_{\mathbf{m}_h}\mu_t(\mathbf{m}_h)\sum_{i\in\mathcal{I}_H}\frac{S_{Ht}s_t(\mathbf{m}_i)}{\mathcal{M}_t(\mathbf{m}_i)} + \frac{(1-S_{Ht})s^*_t(\mathbf{m}_i)}{\mathcal{M}^*_t(\mathbf{m}_i)}},$$

and S_{Ht} is Home's relative market size: $S_{Ht} = P_{Ht}Y_{Ht}/(P_{Ht}Y_{Ht} + P_{Ft}Y_{Ft})$. The weights $\omega_{it}(\mathbf{m}_i)$ are functions of Home firms' markups and their market shares, which are functions of productivity gap $\mathbf{m}_i$. Firms with larger size, adjusted by markups, get higher weights. Each term in the last bracket indicates the contributions from innovation, adoption, and exogenous spillover. Derivation of the approximation can be found in Appendix D.3.

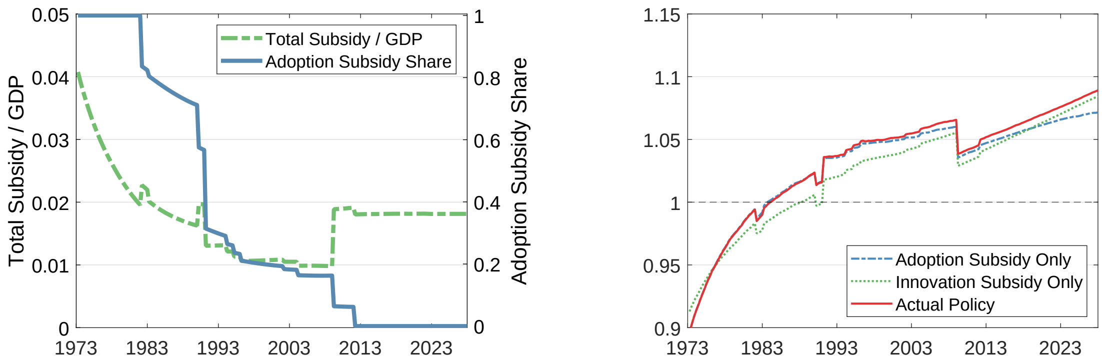
Figure 6 plots the aggregate TFP growth share from adoption and innovation over time, with the remaining share from exogenous spillover. In 1973, adoption accounted for 37% of TFP growth and dropped to 7% by 2023. Conversely, innovation's contribution rose from 8% in 1973 to 74% by 2023.[26] This implies that technology adoption from abroad is a more significant growth driver in the early stages of development, which shifts toward greater reliance on innovation as the country progresses.

6.2 Policy Evaluation

Actual policy We evaluate the actual stage-dependent policy in Korea. We include both actual adoption and innovation subsidies over the years from the data (Figure 1). We compare the actual policy with two counterfactual policies. First, we calculate welfare gains from the actual policy compared with a scenario in which we shut down both subsidies, which we consider an undistorted case. Next, we compute the welfare gains from the two alternative counterfactual policies, in which the government allocates all of the budget into either an adoption or innovation subsidy, while keeping the share of government spending over GDP consistent with the actual policy case. Because we are keeping the spending GDP share constant across all three policies, we evaluate the effectiveness of each policy holding the budget constant.

[25] Our definition of TFP is in line with the literature (e.g., Edmond et al., 2023).

[26] This is in line with the results of Santacreu (2015), who finds that innovation contributes to 35% of embodied growth in developing countries compared with 75% in developed countries, using cross-country data.



A. Subsidy / GDP and Adoption Subsidy Share

B. Relative Consumption

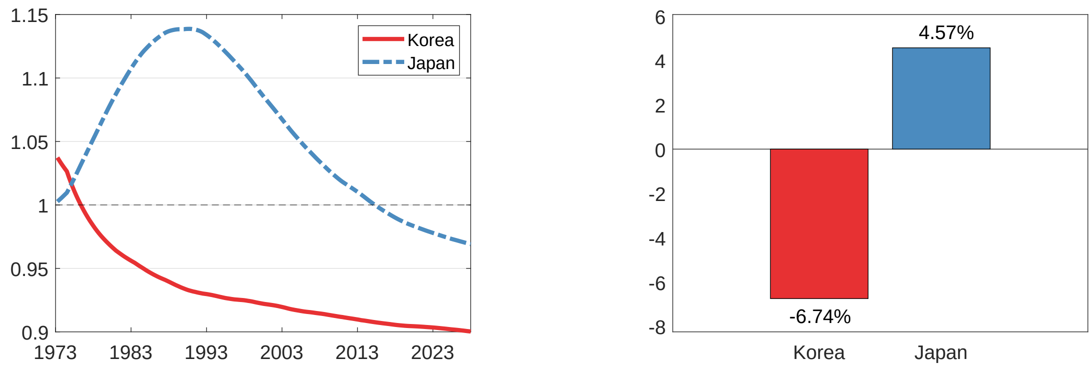
Figure 7: Government Subsidy Share and Results of the Counterfactual Analysis

Notes. Panel A displays the total subsidy expenditure as a share of GDP, along with the adoption subsidy share under the actual policy scenario. The adoption subsidy share is calculated as the ratio of adoption subsidy expenditure to the combined total of adoption and innovation subsidy expenditures. Panel B plots real consumption in the three scenarios divided by real consumption in the case with no subsidies. The dotted blue line subsidizes only adoption, the dashed green line subsidizes only innovation, and the solid red line follows the actual policy in Figure 1. In all counterfactual scenarios, the share of government spending relative to GDP remained constant.

The left panel of Figure 7 shows the total subsidy expenditure as a share of GDP and the breakdown between adoption and innovation subsidies. These results are calculated within the model, using subsidy rates derived from the data. Total subsidy expenditure accounts for 1.75% of GDP on average, with fluctuations as the relative expenditure between adoption and innovation changes and also the government shifts policies. The adoption subsidy share is defined as the ratio of adoption subsidy expenditure to the sum of both adoption and innovation subsidy expenditures. In 1973, this share was one, which reflects the exclusive presence of adoption subsidies. However, as government policy evolved, this share gradually converged to zero by 2011.

The right panel shows real consumption relative to the case with no subsidies over time under the three policies. Subsidizing only adoption generates a higher growth rate in the early stage, but after several years, consumption becomes larger than without subsidies. However, the growth rate of relative consumption decreases over time, implying that subsidizing only adoption does not generate a significantly higher long-run growth rate. On the other hand, subsidizing only innovation does not yield a higher growth rate at the beginning compared with the only-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, by allocating resources to innovation instead of adoption even though innovation has a smaller positive externality. Lastly, the actual policy yields consumption similar to the adoption-subsidy case in early stages and also yields higher growth rates in later stages.

To explore the welfare implications of the policies, we compute consumption-equivalent changes in welfare from the case without subsidies. The consumption-equivalent change Ψ is given such



A. Relative Consumption

B. Welfare increase (%)

Figure 8: 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 baseline case with adoption. When the Japanese government restricts adoption, the Korean government subsidizes only innovation while keeping the government expenditure relative to GDP constant with the baseline. Panel A plots the consumption of Korea and Japan relative to the baseline. Panel B plots welfare effects on both countries.

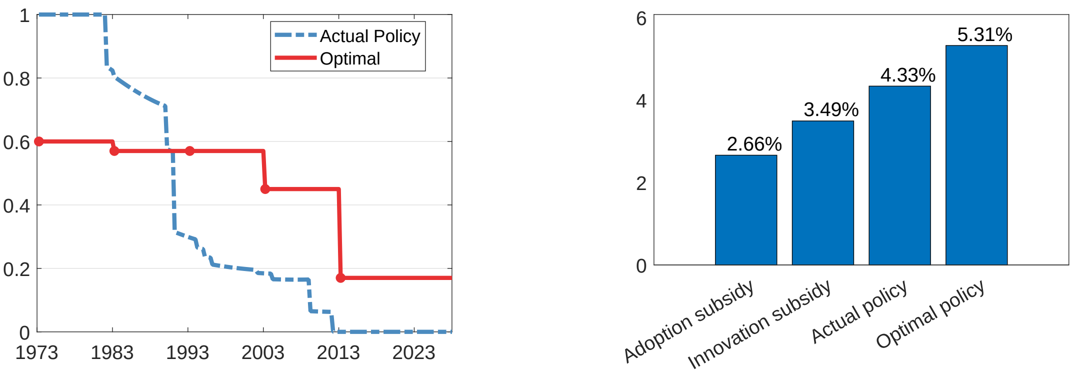
that

$$\int_{t=0}^{T} \exp(-\rho t) \log(C_{Ht}) dt = \int_{t=0}^{T} \exp(-\rho t) \log(\hat{C}_{Ht}(1+\Psi)) dt \,, \tag{15}$$

where $\hat{C}_{Ht}$ is consumption in the undistorted case. For example, $\Psi = 0.03$ means that the welfare within T year horizon is equivalent to the case when we uniformly increase consumption by 3% in the case without subsidies. In the infinite horizon, the actual policy increases consumption-equivalent welfare by 4.3%, which raises welfare more than subsidizing only adoption (2.7%) or subsidizing only innovation (3.5%). This result suggests that the actual policy implemented in Korea was quantitatively better than the time-invariant policies.

Foreign policy We consider a hypothetical scenario in which the Japanese government prevents technology exports to Korea. Japanese incumbents always earn benefits from selling technology; if not, they will not sell technology. However, they may sell more technology than Japan's socially optimal level because they do not internalize future losses of potential entrants in Japan. When the previous incumbent sells technologies, potential entrants will earn smaller profits because Korean firms will have relatively higher productivity from adoption. Therefore, there can be an incentive for the Japanese government to prevent transferring technology. In this exercise, we assume that the Korean government allocates the entire budget to innovation subsidies, keeping the budget-to-GDP ratio unchanged as in the previous exercise.

Figure 8 reports the results. The left panel shows that in the short run, consumption in Japan would be higher when banning exports of technologies compared with the baseline. However, in the long run, the consumption would become lower as the long-run growth rate decreases. This is because competition between Korean and Japanese firms becomes weaker, which decreases the



A. Adoption Subsidy Share

B. Welfare increase (%)

Figure 9: Optimal Policy and Welfare Increase

Notes. This figure plots optimal and actual subsidy shares and welfare results. Panel A plots the optimal adoption subsidy share (red) compared with the actual case (blue). The government is allowed to change the adoption subsidy share every ten years, while keeping government spending over GDP equal to the actual policy. Panel B plots the consumption-equivalent welfare increase from the undistorted case over different policies.

innovation incentive for Japanese firms; and as Korean firms become less productive, Japanese firms gain less from adoption in the long run. Overall, the welfare in Korea would decrease by 6.7% when Japan prohibits technology transfers. On the other hand, welfare in Japan would increase by 4.6%.

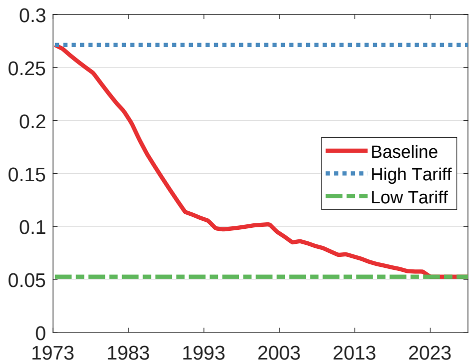
Robustness We conduct a battery of robustness checks for different values of discount rates, elasticity of substitution, and the deadweight cost of taxation parameter in Appendix Figures D.3, D.4, and D.5, respectively. Results are qualitatively similar to the main results, since the actual policy yields greater welfare improvements than the other counterfactual time-invariant policies.

6.3 Optimal Policy

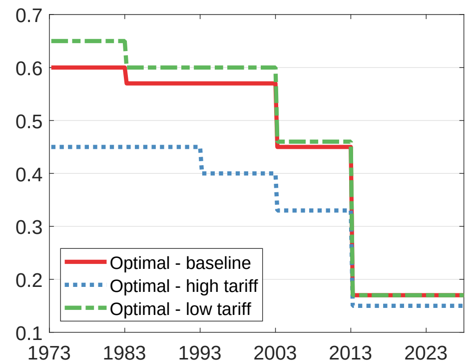
We study the optimal government policy, in which governments choose the adoption subsidy share to maximize welfare while maintaining the government budget over GDP equal to the baseline case. To mimic the government's practical constraint and reduce the computational burden, we allow the government to change the policy every 10 years for 50 years.

Panel A of Figure 9 reports the optimal subsidy share over time, compared with the actual policy. The optimal share decreases rapidly from 45% to 17% in 2013, which is later than the actual policy change in the data. The right panel compares welfare gains relative to the no-subsidy scenario from the optimal policies to those from other policies. The optimal subsidy increases consumption-equivalent welfare by 5.3%, whose magnitude is larger than the actual and the other counterfactual time-invariant policies.

Appendix Figure D.6 displays the optimal policy in which the subsidy share is a quadratic function of calendar years. The optimal quadratic policy also reduces the share of the adoption



A. Import Tariffs



B. Optimal Adoption Subsidy Share

Figure 10: Optimal Policy under Actual and Counterfactual Tariffs

Notes. Panel A plots the actual and the counterfactual tariffs. Panel B plots the optimal share of adoption subsidy in two cases. The government is allowed to change the adoption subsidy share every 10 years, while keeping the share of government spending over GDP equal to the actual policy.

subsidy at a comparable pace, with welfare increases being close to those of the linear policy.

Interaction with Trade Policy Import tariffs can affect the optimal policy by affecting Foreign firms' incentives to sell technologies. In our model, import tariffs lower adoption fees by weakening competition between Home and Foreign firms. In an extreme scenario in which the tariff is infinitely high, foreign firms do not incur any profit losses from selling technology, which leads to reduced equilibrium adoption fees. Hence, a protective trade policy can render adoption more affordable, and thereby increasing adoption rates closer to the socially optimal level. This reduces the effectiveness of adoption subsidies, and leads the optimal policy to allocate a larger portion of the budget to innovation subsidies. On the other hand, a liberal trade policy enhances the effectiveness of adoption subsidies.

To explore the interaction between trade and technology policies, we compute the optimal policy under two counterfactual scenarios with import tariffs initially set at 28% and 5%, respectively, and remaining constant over time. The left panel of Figure 10 depicts import tariffs in actual and counterfactual cases, and the right panel depicts the optimal policies under these scenarios. In the scenario with higher tariffs, the optimal policy allocates a smaller portion of its budget to adoption subsidies, whereas in the scenario with lower tariffs it allocates a larger portion relative to the baseline scenario.

7 Conclusion

In this paper, we examine the role of technology adoption and innovation in development and explore their policy implications across different stages of development. To do so, we build a novel two-country open economy endogenous growth model, in which firms can upgrade their technology through either innovation or the adoption of technologies from foreign firms. Our model incorporates the incentives of both technology buyers and sellers and their strategic interaction. Novel firm-to-firm technology transfer data from Korea disciplines this crucial aspect of the model. Using the quantified model, we find that the state-dependent nature of the policies has important implications for welfare and growth.

Our study suggests that it may be optimal for developing countries to pursue strategies distinct from those of developed countries to enhance their technology. Given Korea's rapid transformation from a low-income to a high-income and innovative country, our quantitative analysis provides novel insights for policymakers in developing countries when designing long-term growth policies. Our framework can serve as a foundation for addressing broader questions. For example, how can we design a technology policy that benefits both countries? What are the optimal combinations of trade and technology policies? These questions represent promising avenues for future research.

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ONLINE APPENDIX

(NOT FOR PUBLICATION)

A Data

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.

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.

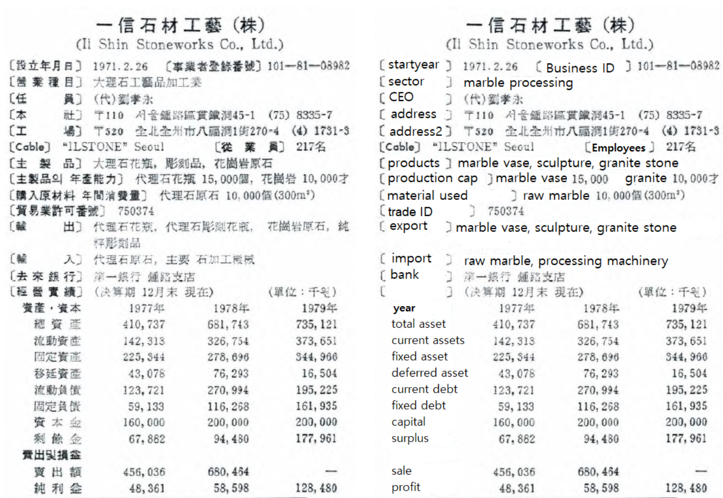
During the period 1962–1993, Korean firms were mandated under the Foreign Capital Inducement Act to report all foreign currency transactions. Specifically, details of technology imports were reported to the Economic Planning Board. Therefore, the universe of technology transfer contracts between Korean and foreign firms is stored in the national archives in Korea. We collect and digitize these technology transfers. Figure A.1 provides a sample contract, while Table A.1 displays the distribution of these contracts by country and sector.

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, 42% involve both know-how and licensing, and 4% involve only licensing.

Table A.1: Top 10 Industries and Source Countries among Technology Transfers

Country	Share (%)	Sector	Share (%)
Japan	49.88	Machinery	26.66
United States	26.29	Electronics	24.89
Germany (West)	5.56	Chemical manufacturing	16.09
France	4.07	Chemical fiber	4.97
United Kingdom	3.69	Metal	4.93
Italy	1.75	Food	3.08
Switzerland	1.60	Shipbuilding	2.70
Netherlands	1.36	Non-metallic products	2.66
Canada	0.94	Pharmaceutical	2.45
Sweden	0.70	Construction	1.81
Others	4.16	Others	9.76

Notes. The sample period is 1970–1993. The total number of observations is 8,346.


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및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.2: Snapshot of Annual Reports of Korean Companies

Korean firm balance sheet data For the period from 1970 to 1982, we use balance sheet information from the Annual Reports of Korean Companies, published by the Korea Productivity Center. Figure A.2 shows an example of raw data, which we digitize. This dataset is merged with KIS-VALUE dataset which provides information starting in 1980. We use firm-level sales, fixed assets, total assets, the number of employees, and industry. All nominal values in this dataset are converted to 2015 US dollar values for consistency. Table A.2 shows the industry classification in the data, which is based on ISIC Rev 3.1 codes. For firms with missing employment, fixed assets, or

Table A.2: Sector Classification

Aggregated Industry	Industry
Petrochemicals	Coke oven products (231), Refined petroleum products (232)
Chemicals, and rubber and plastic products	Basic chemicals (241), Other chemical products (242) Man-made fibres (243) except for pharmaceuticals and medicine chemicals (2423) Rubber products (251), Plastic products (252)
Pharmaceuticals	pharmaceuticals and medicine chemicals (2423)
Electronics	Office, accounting, & computing machinery (30) Electrical machinery and apparatus n.e.c. (31) Ratio, television and communication equipment and apparatus (32) Medical, precision, and optical instruments, watches and clocks (33)
Metals	Basic metals (27), Fabricated metals (28)
Machinery, and transportation equipment	Machinery and equipment n.e.c. (29) Motor vehicles, trailers and semi trailers (34) Manufacture of other transport equipment (35)
Food	Food products and beverages (15), Tobacco products (16)
Textiles, Apparel, and Leather	Textiles (17), Apparel (18) Leather, luggage, handbags, saddlery, harness, and footwear (19)
Manufacturing n.e.c.	Manufacturing n.e.c. (369)
Wood	Wood and of products, cork (20), Paper and paper products (21) Publishing and printing (22), Furniture (361)
Other nonmetallic mineral products	Glass and glass products (261), On-metallic mineral products n.e.c. (269)

Notes. The numbers inside parenthesis denote ISIC Rev 3.1 codes.

sales, we impute by using total assets.

Foreign firm balance sheet data Our foreign firm balance sheet data comes from Compustat. We use PPEGT to measure foreign firms' capital. We drop samples with missing values of employment, fixed assets, and sales. Table A.3 reports the summary statistics of foreign firms.

Merging the datasets The firm balance sheet and the technology adoption dataset are combined by matching them based on firm names. Next, this merged dataset is combined with data from the Korean patent office, utilizing both the Business ID of firms and firm names. KIS-VALUE dataset provides Business IDs, which facilitates the merge with the patent office data. For foreign firms, we utilize the names listed in the technology adoption dataset to merge with USPTO data. Finally, foreign firms are also matched with Compustat utilizing an existing match between Compustat and USPTO constructed by Bena et al. (2017).

B Motivating Facts

B.1 Production Function Estimation

We estimate the production function using the control function approach (Olley and Pakes, 1996; Ackerberg et al., 2015) and Compustat data. We calculate value-added by subtracting the wage bill from the cost of goods sold (COGS), where the wage index is obtained from the Social Secu-

Table A.3: Summary Statistics

	Ever-Sold	Never-Sold	All
Emp.	18,913	3,973	4,530
Fixed Asset	2,634	796	885
Sales	4,088	1,040	1,180
Sales per Emp.	0.40	0.44	0.44
# of Unique Firms	769	21,818	22,587
# of Obs.	7,997	184,208	192,205

Notes. This table presents the average values of firms in Compustat data between 1970 and 1993. Ever-sold refers to firms that engaged in at least one adoption contract with a Korean firm as a technology seller during the sample period. All nominal values are converted to 2015 US million dollars.

rity Administration. We measure investment using capital expenditure (CAPX) and capital using fixed assets (PPEGT), deflated by the price index for non-residential private fixed investment from NIPA. We estimate the production function within 2-digit ISIC Rev 3.1, with year fixed effects. To convert NAICS codes to ISIC Rev 3.1, we use NAICS-ISIC rev 3.1 crosswalks provided by the United Nations Statistics Division.

Using the estimated coefficients, we define revenue-based TFP for both the foreign and Korean firms as below.

$$\text{TFP}^{\text{rr}}_{ijt} = \log(\text{Value Added})_{ijt} - \alpha^k_j \log k_{ijt} - \alpha^L_j \log l_{ijt}$$

For Korean firms, we do not have information on value-added for most firms in the sample. Therefore, we multiply the industry-year level value-added share with the total firm-level revenue to impute the value-added. We calculate the industry-year level value-added shares using the IO tables.

B.2 Additional Figures and Tables

Table B.1: Robustness. DHS Growth. Productivity Gap and Productivity Growth after Adoption and Innovation

Dep.	DHS sales per emp.				DHS TFP^{rr}			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\log \text{Gap}_{it}$	-0.186***	-0.203***	-0.401***	-0.407***	-0.230***	-0.268***	-0.456***	-0.462***
	(0.008)	(0.008)	(0.012)	(0.011)	(0.008)	(0.010)	(0.012)	(0.012)
$\log \text{Gap}_{it} \times \mathbb{1}[\text{Adopt}_{it}]$	-0.064**	-0.064**	-0.046**	-0.065***	-0.050*	-0.063**	-0.044**	-0.058***
	(0.027)	(0.026)	(0.022)	(0.024)	(0.027)	(0.025)	(0.021)	(0.022)
$\log \text{Gap}_{it} \times \mathbb{1}[\text{Innovate}_{it}]$	0.025	0.031	-0.000	-0.013	0.041*	0.050**	0.018	0.002
	(0.024)	(0.023)	(0.019)	(0.020)	(0.025)	(0.025)	(0.021)	(0.022)
$\mathbb{1}[\text{Adopt}_{it}]$	0.128***	0.133***	0.168***	-0.089**	0.122***	0.116***	0.148***	-0.100***
	(0.032)	(0.032)	(0.029)	(0.039)	(0.029)	(0.029)	(0.026)	(0.038)
$\mathbb{1}[\text{Innovate}_{it}]$	0.029	0.036	0.060*	0.046	0.032	0.032	0.065**	0.051
	(0.040)	(0.040)	(0.034)	(0.035)	(0.037)	(0.037)	(0.031)	(0.032)
Adj. R^2	0.17	0.19	0.30	0.30	0.18	0.21	0.34	0.34
# Cl. (Korean firm)	2,217	2,217	2,217	2,217	2,217	2,217	2,217	2,217
N	12,824	12,824	12,812	12,812	12,824	12,824	12,812	12,812

Notes. Standard errors in parentheses are clustered at Korean firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. This table reports estimates from equation (2). In columns 1–4 and 5–8, dependent variables are DHS growth rates of sales per employee and TFP^{rr}, respectively (Davis et al., 1998). Columns 1–4 and 5–8 define the gap as the ratio of sales per employee and TFP^{rr} between Korean and foreign frontier firms, respectively. $\mathbb{1}[\text{Adopt}_{it}]$ and $\mathbb{1}[\text{Innovate}_{it}]$ are dummies that take values of 1 if Korean firm i engaged in at least one technology transfer contract or filed at least one patent, for the first time, respectively. Columns 1 and 5 include year fixed effects. Columns 2 and 6 include year and sector fixed effects. Columns 3 and 7 include sector-year fixed effects. Columns 4 and 8 include sector-year fixed effects and foreign country-year fixed effects, interacted with the adoption dummy. Columns 1–4 and 5–8 include log initial sales per employee and TFP^{rr}, respectively. All specifications include the 5-year growth rate of fixed assets.

Royalty Fee Table B.2 shows the results of Equation (3), where we use logged royalty fee and total fee as dependent variables. In the technology transfer contract, the royalty fee is defined as the royalty percentage times the corresponding revenue derived from using the technology transferred. Given that only total revenue is available in the dataset, we employ the total revenue of the subsequent years as a proxy for the specific revenue associated with the technology use. As the contracts' average duration is 5 years, we calculate the royalty fee based on the five-year average sales following the contract year. Consequently, the royalty fee is estimated by royalty rate $\times$ contract length $\times$ $\frac{1}{5}\sum_{s=1}^{s=5} \text{sales}_{t+s}$.

Table B.2: Adoption Fee and Productivity Gap using Different Measure of Adoption Fee

Gap	Sales per emp.				TFP^{rr}			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A. Dep. Royalty Fee							
$\log \text{Gap}_{it}$	0.274***	0.274***	0.840***	0.796***	0.432***	0.390***	1.110***	1.060***
	(0.059)	(0.052)	(0.134)	(0.126)	(0.085)	(0.080)	(0.186)	(0.182)
Adj R^2	0.30	0.52	0.59	0.61	0.33	0.53	0.63	0.64
# Cl. (Korean firm)	362	359	324	314	362	359	324	314
# Cl. (Foreign firm)	876	874	825	763	876	874	825	763
N	1,332	1,329	1,256	1,188	1,332	1,329	1,256	1,188
	Panel B. Dep. Total Fee							
$\log \text{Gap}_{it}$	0.259***	0.261***	0.782***	0.746***	0.418***	0.372***	1.024***	0.986***
	(0.059)	(0.051)	(0.129)	(0.122)	(0.082)	(0.077)	(0.179)	(0.176)
Adj R^2	0.30	0.51	0.59	0.61	0.32	0.52	0.62	0.64
# Cl. (Korean firm)	362	359	325	316	362	359	325	316
# Cl. (Foreign firm)	872	870	821	760	872	870	821	760
N	1,326	1,323	1,251	1,184	1,326	1,323	1,251	1,184
Year FE	✓	✓			✓	✓		
Sector FE		✓				✓		
Sector-year FE			✓	✓			✓	✓
Foreign country-year FE				✓				✓

Notes. Standard errors in parentheses are two-way clustered at the domestic and foreign firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. This table shows the result of Equation (3), in which we regress the adoption fee on the productivity gap. In panels A and B, the dependent variables are logged royalty fee and total fee, respectively. The royalty fee is estimated by royalty rate $\times$ contract length $\times$ $\frac{1}{5}\sum_{s=1}^{s=5} \text{sales}_{t+s}$, and the total fee is the sum of the fixed fee and royalty fee. Columns 1 and 5 include year fixed effects. Columns 2 and 6 include year and sector fixed effects. Columns 3 and 7 include sector-year fixed effects. Columns 4 and 8 include sector-year fixed effects and foreign country-year fixed effects, interacted with the adoption dummy. In columns 1–4 and 5–8, the gap is measured based on the ratio of sales per employee and revenue-based TFP between the Korean firm (buyer) and the foreign firm (seller), respectively.

Table B.3: Covariate Balance

	Mean		t-stat	p-value
	Technology seller	Control group		
	(1)	(2)	(3)	(4)
$\mathbb{1}[\text{\# cite}_{fmt} > 0]$	0.78	0.82	0.95	0.33
	(0.41)	(0.38)		
IHS(# cite$_{fmt}$)	2.58	2.85	1.74	0.19
	(2.09)	(2.18)		
$\mathbb{1}[\text{\# cite by never-adopting Korean firms}_{fmt} > 0]$	0.02	0.01	0.51	0.48
	(0.15)	(0.12)		
Ihs(# cite by never-adopting Korean firms$_{fmt}$)	0.03	0.02	0.34	0.56
	(0.17)	(0.15)		
$\mathbb{1}[\text{\# cite by non-Korean firms}_{fmt} > 0]$	0.77	0.80	0.51	0.48
	(0.42)	(0.40)		
IHS(# cite by non-Korean firms$_{fmt}$)	2.47	2.73	1.76	0.19
	(2.02)	(2.12)		
$\log$(# cumulative patents$_{fmt}$)	3.67	3.88	1.18	0.28
	(1.98)	(2.09)		
$\mathbb{1}[\text{\# new patents}_{fmt} > 0]$	0.57	0.62	1.40	0.24
	(0.50)	(0.49)		
IHS(# new patents$_{fmt}$)	1.59	1.81	1.35	0.25
	(1.81)	(1.94)		
N	213	213		

Notes. Both variables are the cumulative numbers in the year of first (placebo) technology adoption. The P-value is for the null hypothesis that the difference of the mean between technology sellers and the matched group is zero. $\mathbb{1}[\cdot]$ and Ihs denote an indicator function and inverse hyperbolic sine transformation, respectively. # cite$_{fmt}$ is the number of total citations received by foreign firm f of match m in a year t, excluding self citations. # cite by never-adopting Korean firms$_{fmt}$ is the number of citations received by never-adopting Korean firms. # cite by non-Korean firms$_{fmt}$ is the number of citations received by non-Korean firms. # cumulative patents$_{fmt}$ is the number of cumulative patent stock of firm f. # new patents$_{fmt}$ is the number of new patents made by firm f.

Table B.4: Balance Test

Dep.	$\mathbb{1}[\text{Seller}_{fmt}]$									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$\mathbb{1}$[# cite$_{fmt} > 0$]	0.06									0.30
	(0.06)									(0.26)
Ihs(# cite$_{fmt}$)		0.01								-0.10
		(0.01)								(0.16)
$\mathbb{1}$[# cite by never-adopting Korean firms$_{fmt} > 0$]			-0.13							-0.38
			(0.17)							(0.60)
Ihs(# cite by never-adopting Korean firms$_{fmt}$)				-0.09						0.16
				(0.15)						(0.49)
$\mathbb{1}$[# cite by non-Korean firms$_{fmt} > 0$]					0.04					-0.32
					(0.06)					(0.25)
Ihs(# cite by non-Korean firms$_{fmt}$)						0.02				0.14
						(0.01)				(0.15)
log(# cumulative patents$_{fmt}$)							0.01			-0.02
							(0.01)			(0.04)
$\mathbb{1}$[# new patents$_{fmt} > 0$]								0.06		0.04
								(0.05)		(0.08)
Ihs(# new patents$_{fmt}$)									0.02	-0.00
									(0.01)	(0.03)
p-val (F)	0.33	0.18	0.46	0.57	0.48	0.18	0.28	0.24	0.24	0.82
Adj. R^2	-0.00	0.00	-0.00	-0.00	-0.00	0.00	0.00	0.00	0.00	-0.01
N	426	426	426	426	426	426	426	426	426	426

Notes. Robust standard errors are in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. This table reports the balance test. Dependent variables are dummies indicating a technology seller status. $\mathbb{1}[\cdot]$ and Ihs denote for an indicator function and inverse hyperbolic sine transformation, respectively. # cite$_{fmt}$ is the number of total citations received by foreign firm f of match m in a year t, excluding self citations. # cite by never-adopting Korean firms$_{fmt}$ is the number of citations received by never-adopting Korean firms. # cite by non-Korean firms$_{fmt}$ is the number of citations received by non-Korean firms. # cumulative patents$_{fmt}$ is the number of cumulative patent stock of firm f. # new patents$_{fmt}$ is the number of new patents made by firm f.

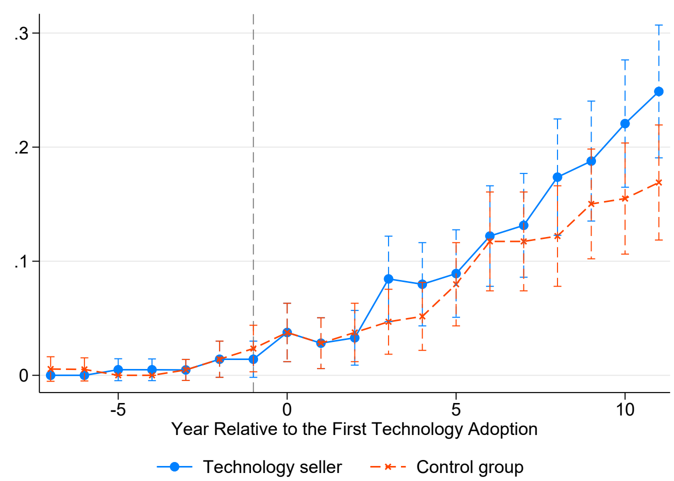


Figure B.1: Raw Average of Patent Citations Between Two Groups

Notes. The figure plots the average number of citations from Korean never-adopters to the foreign firms that sold technology (solid blue line), and to the foreign firms that did not (dashed red line). Vertical line is 95% confidence interval. X-axis is the year relative to the first technology adoption by a Korean firm. $N = 8,896$

Table B.5: Robustness. Alternative Numbers of Matches and Specifications. Knowledge Spillovers from Adoption.

Dep.	$\mathbb{1}[\text{Citation}^{\text{Kor}}_{fmt} > 0]$						
	Alternative numbers of matches				Long-difference specification		
	# match = 2		# match = 5				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\mathbb{1}[\text{Seller}_{fmt}] \times \text{Post}_{mt}$	0.02*	0.04***	0.03***	0.06***	0.08***	0.07**	0.15***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.03)	(0.03)	(0.03)
Firm-match FE	✓	✓	✓	✓			✓
Match-year FE	✓	✓	✓	✓			✓
Match FE					✓	✓	
Controls						✓	
Adj. R^2	0.40	0.47	0.36	0.42	0.40	0.42	0.16
# Cl. (Foreign firm)	597	597	1,120	1,120	412	412	412
# Cl. (Match)	213	213	213	213	213	213	213
N	8,083	11,905	16,081	23,683	426	426	790

Notes. Standard errors two-way clustered at foreign firm and match level are reported. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. This table reports results of the robustness checks on knowledge spillovers from adoption. Dependent variables are a dummy of positive citations from never-adopting Korean firms. Columns 1-4 and 5-7 report the estimates of β^{dd} of equation (5) and the long-difference specification: $\triangle\mathbb{1}[\text{Citation}_{fmt}] = \beta^{dd}\mathbb{1}[\text{Seller}_{fmt}] + \mathbf{X}_{fmtt} + \delta_m + \epsilon_{fmt}$. Columns 1–4 include firm-match and match-year fixed effects. Column 5 includes match fixed effects. Column 6 includes match fixed effects, the log of initial cumulative patent stock and the inverse hyperbolic sine transformation of citations received, excluding self citations, in the initial year. In column 7, we stack two long-differences, the difference between $\tau = -7$ and $\tau = -2$, and between $\tau = -1$ and $\tau = 11$, and control for firm-match fixed effects that absorb out linear random trends.

C Model

C.1 Value Function

Foreign incumbent Value function of the foreign incumbent f with gap $\mathbf{m}_f = (m_f^h, m_f^{\tilde{h}})$ is

$$
\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-\kappa_{Frt}) \underbrace{\alpha_{Fr} \frac{x_{ft}(\mathbf{m}_f)^{\gamma_r}}{\gamma_r} w_{Ft}}_{\text{innovation R\&D cost}} - (1-\kappa_{Fat}) \underbrace{\alpha_{Fa} \frac{a_{ft}(\mathbf{m}_f)^{\gamma_a}}{\gamma_a} w_{Ft}}_{\text{adoption labor cost}} \\
&+ x_{ft}(\mathbf{m}_f) \sum_n f(n; \min_{i \in \mathcal{I}_H} \{m_f^i\}) \underbrace{[V_{ft}(m_f^h + n, m_f^{\tilde{h}} + n) - V_{ft}(\mathbf{m}_f)]}_{\text{gain from innovation}} \\
&+ a_{ft}(\mathbf{m}_f) \Big[\sum_n g(n; \min_{i \in \mathcal{I}_H} \{m_f^i\}) \underbrace{[V_{ft}(m_f^h + n, m_f^{\tilde{h}} + n) - V_{ft}(\mathbf{m}_f)]}_{\text{gain from adoption}} - (1-\kappa_{Fat}) \underbrace{\mathcal{F}_{Ft}(\mathbf{m}_f)}_{\text{adoption fee}} \Big] \\
&+ x_{ht}(\mathbf{m}_h) \sum_n \tilde{f}(n; \mathbf{m}_h) \underbrace{[V_{ft}(m_f^h - n, m_f^{\tilde{h}}) - V_{ft}(\mathbf{m}_f)]}_{\text{loss from innovation by } h} \\
&+ a_{ht}(\mathbf{m}_h) \Big[\sum_n \tilde{g}(n; \mathbf{m}_h) \underbrace{[V_{ft}(m_f^h - n, m_f^{\tilde{h}}) - V_{ft}(\mathbf{m}_f)]}_{\text{loss from adoption by } \tilde{h}} + \underbrace{\mathcal{F}_{ht}(\mathbf{m}_h)}_{\text{adoption fee}} \Big] \\
&+ x_{\tilde{h}t}(\mathbf{m}_{\tilde{h}}) \sum_n \tilde{f}(n; \mathbf{m}_{\tilde{h}}) \underbrace{[V_{ft}(m_f^h, m_f^{\tilde{h}} - n) - V_{ft}(\mathbf{m}_f)]}_{\text{loss from innovation by } h} \\
&+ a_{\tilde{h}t}(\mathbf{m}_{\tilde{h}}) \Big[\sum_n \tilde{g}(n; \mathbf{m}_{\tilde{h}}) \underbrace{[V_{ft}(m_f^h, m_f^{\tilde{h}} - n) - V_{ft}(\mathbf{m}_f)]}_{\text{loss from adoption by } \tilde{h}} + \underbrace{\mathcal{F}_{\tilde{h}t}(\mathbf{m}_{\tilde{h}})}_{\text{adoption fee}} \Big] \\
&- \underbrace{\tilde{x}_{ft}(\mathbf{m}_f) V_{ft}(\mathbf{m}_f)}_{\text{replaced by entrant}} + \phi \underbrace{(V_{ft}(0,0) - V_{ft}(\mathbf{m}_f))}_{\text{exogenous spillover}}.
\end{aligned}
$$

Foreign entrant Value function of a Foreign potential entrant $\tilde{f}$ is

$$
\begin{aligned}
r_{Ft} \tilde{V}_{ft}(\mathbf{m}_f) - \dot{\tilde{V}}_{ft}(\mathbf{m}_f) = & \max_{\tilde{x}_{ft}(\mathbf{m}_f)} - (1-\kappa_{Frt}) \underbrace{\tilde{\alpha}_{Fr} \frac{(\tilde{x}_{ft}(\mathbf{m}_f))^{\gamma_r}}{\gamma_r} w_{Ft}}_{\text{innovation cost}} \\
& + \tilde{x}_{Ft}(\mathbf{m}_f) \sum_n f(n; \min_{i \in \mathcal{I}_H} \{m_f^i\}) V_{ft}(m_f^h + n, m_f^{\tilde{h}} + n).
\end{aligned}
$$

C.2 Optimal Policy Function

Foreign incumbent Let i denotes for Home leader. Then, the optimal innovation and adoption rate of a Foreign incumbent is

$$x_{ft}(\mathbf{m}_f) = \left(\frac{\sum_n f(n; m_f^i)[V_{ft}(m_f^h + n, m_f^{\tilde{h}} + n) - V_{ft}(\mathbf{m}_f)]}{(1 - \kappa_{Frt})\alpha_{Fr} w_{Ft}} \right)^{\frac{1}{\gamma_r - 1}}$$

$$a_{ft}(\mathbf{m}_f) = \left(\frac{\sum_n g(n; m_f^i)[V_{ft}(m_f^h + n, m_f^{\tilde{h}} + n) - V_{ft}(\mathbf{m}_f) - (1 - \kappa_{Fat})\mathcal{F}_{ft}(\mathbf{m}_f)]}{(1 - \kappa_{Fat})\alpha_{Fa} w_{Ft}} \right)^{\frac{1}{\gamma_a - 1}}.$$

Foreign entrant The optimal innovation rate of a Foreign entrant is

$$\tilde{x}_{ft}(\mathbf{m}_f) = \left(\frac{\sum_n f(n; m_f^i) V_{ft}(m_f^h + n, m_f^{\tilde{h}} + n)}{(1 - \kappa_{Frt})\alpha_{Fr} w_{Ft}} \right)^{\frac{1}{\gamma_r - 1}}.$$

C.3 Adoption Fee

The adoption fee when Foreign incumbent f adopts from a Home leader i is

$$\begin{aligned} \mathcal{F}_{ft}(\mathbf{m}_f) = & \underset{\mathcal{F}_{ft}(\mathbf{m}_f)}{\text{argmax}} (\sum_n g(n; m_f^i) V_{ft}(m_f^i + n, m_f^{-i} + n) - V_{ft}(\mathbf{m}_f) - (1 - \kappa_{Fat})\mathcal{F}_{ft}(\mathbf{m}_f))^{\xi} \\ & \times (\sum_n g(n; m_f^i) V_{it}(m_i^F - n, m_i^D) + \mathcal{F}_{ft}(\mathbf{m}_f) - V_{it}(\mathbf{m}_i))^{1-\xi}. \end{aligned}$$

From the first order conditions, we obtain

$$\begin{aligned} \mathcal{F}_{ft}(\mathbf{m}_f) = & \Big((1 - \xi)(\sum_n g(n; m_f^i) V_{ft}(m_f^i + n, m_f^{-i}) - V_{ft}(\mathbf{m}_f)) \\ & - \xi(\sum_n g(n; m_f^i) V_{it}(m_i^F - n, m_i^D) - V_{it}(\mathbf{m}_i)) \Big) / (1 - \xi \kappa_{Fat}). \end{aligned}$$

C.4 Simple Model of Patent Citation

In this subsection, we present an extended version of our model, incorporating a feature that mandates firms to cite pertinent patents when innovating new technology, a requirement consistent with the patent laws of most countries. Specifically, should sector j's firm h_j adopt technology from sector j foreign firm f_j, it must cite f_j's patent during any subsequent innovation that builds on this technology. Moreover, another domestic firm $\tilde{h}_j$ has to cite a patent of f_j if it receives knowledge spillover from the h_j and innovates a related technology. As firms are required to cite the related technology, citations are made only within the sector.

Suppose that firm f_j exported technology to firm h_j but sector k Foreign firm f_k did not. We then compare the probability of receiving patent citations from non-adopters of the corresponding sectors to two foreign firms. The probability of patent citation from non-adopter $\tilde{h}_j$ to f_j increases by $\bar{x} \cdot \delta$, where $\bar{x}$ is the average innovation rate and δ is the probability of knowledge spillover. Conversely, the citation probability from non-adopter $\tilde{h}_k$ to f_k does not change. Therefore, $\bar{x} \cdot \delta$ is to be matched with the average increase in the probability of receiving citations.

D Quantification

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 $\mu_t(\mathbf{m}_h)$, innovation rate $x_{it}(\mathbf{m}_i)$, adoption rate $a_{it}(\mathbf{m}_i)$, and the relative price P_{Ft} stay the same. Note that we normalize price index of Home $P_{Ht} = 1$. Therefore, it is useful to divide Equation (9) with $P_{Ht}Y_{Ht}$ and define $\tilde{V}_{it} = \frac{V_{it}}{Y_{Ht}}$, $\tilde{w}_{Ht} = \frac{w_{Ht}}{Y_{Ht}}$, and $\tilde{\mathcal{F}}_{ijt} = \frac{\mathcal{F}_{ijt}}{Y_{Ht}}$ as normalized value function, wage, and adoption fee, respectively. Also, define the aggregate output share in each country as $S_{Ht} = \frac{Y_{Ht}}{Y_{Ht}+P_{Ft}Y_{Ft}}$ and represent profit function as below.

$$\Pi_{it}(\mathbf{m}_i) = \tilde{\pi}_{it}(\mathbf{m}_i) \times Y_{Ht} + \tilde{\pi}^*_{it}(\mathbf{m}_i) \times P_{Ft}Y_{Ft}$$
$$\frac{\Pi_{it}(\mathbf{m}_i)}{Y_{Ht}} = \tilde{\pi}_{it}(\mathbf{m}_i) + \tilde{\pi}^*_{it}(\mathbf{m}_i) \times \frac{1 - S_{Ht}}{S_{Ht}},$$

where $\pi_{it}(\mathbf{m}_i)$, and $\pi^*_{it}(\mathbf{m}_i)$ are the profits divided by total consumption in Home and Foreign. Then, we normalize the value function of firm $i \in \mathcal{I}_H$ as below.

$$\begin{aligned}
&(r_{Ht} - g_t)\tilde{V}_{it}(\mathbf{m}_i) \\
&= \max_{x_{it}(\mathbf{m}_i), a_{it}(\mathbf{m}_i)} \pi_{Ht}(\mathbf{m}_i) + \pi^*_{Ht}(\mathbf{m}_i) \times \frac{1 - S_{Ht}}{S_{Ht}} \\
&- (1 - \kappa_{Hrt})\alpha_{Hr}\frac{(x_{it}(\mathbf{m}_i))^{\gamma_r}}{\gamma_r}\tilde{w}_{Ht} - (1 - \kappa_{Hrt})\alpha_{Ha}\frac{(a_{it}(\mathbf{m}_i))^{\gamma_a}}{\gamma_a}\tilde{w}_{Ht} \\
&+ x_{it}(\mathbf{m}_i)\sum_n \tilde{f}(n; \mathbf{m}_i)\big[\tilde{V}_{it}(m_i^F + n, m_i^D + n) - \tilde{V}_{it}(\mathbf{m}_i)\big] \\
&+ a_{it}(\mathbf{m}_i)\Big[\sum_n \tilde{g}(n; \mathbf{m}_i)\big[\tilde{V}_{it}(m_i^F + n, m_i^D + n) - \tilde{V}_{it}(\mathbf{m}_i)\big] - (1 - \kappa_{Hrt})\tilde{\mathcal{F}}_{it}(\mathbf{m}_i)\Big] \\
&+ x_{-it}(\mathbf{m}_{-i})\sum_n \tilde{f}(n; \mathbf{m}_{-i})\big[\tilde{V}_{it}(m_i^F, m_i^D - n) - \tilde{V}_{it}(\mathbf{m}_i)\big] \\
&+ a_{-it}(\mathbf{m}_{-i})\sum_n \tilde{g}(n; \mathbf{m}_{-i})\big[\tilde{V}_{it}(m_i^F, m_i^D - n) - \tilde{V}_{it}(\mathbf{m}_i)\big] \\
&+ \big(x_{Ft}(\mathbf{m}_f) + \tilde{x}_{Ft}(\mathbf{m}_f)\big)\sum_n f(n; \min_{i \in \mathcal{I}_H}\{m^i_{ft}\})\big[\tilde{V}_{it}(m_i^F - n, m_i^D) - \tilde{V}_{it}(\mathbf{m}_i)\big] \\
&+ a_{Ft}(\mathbf{m}_f)\Big[\sum_n g(n; \min_{i \in \mathcal{I}_H}\{m^i_{ft}\})\big[\tilde{V}_{it}(m_i^F - n, m_i^D) - \tilde{V}_{it}(\mathbf{m}_i)\big] + \mathbb{1}[m_i^D \geq 0] \times \tilde{\mathcal{F}}_{ft}(\mathbf{m}_f)\Big] \\
&+ \phi\big[\tilde{V}_{it}(0, 0) - \tilde{V}_{it}(\mathbf{m}_i)\big]\Bigg\}.
\end{aligned} \tag{16}$$

Note that from the household Euler Equation (6), 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 $\{\tilde{w}_H, \tilde{w}_F, S_H\}$. Then, we make a guess of the value function for each $\mathbf{m}$, and iterate until it converges using the Equation (16). After the normalized value functions converge, we check the labor market clearing conditions for each country and check the trade balance conditions. We update these three variables until the labor market clears in each country and trade is balanced.

D.2 Transitional 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 $\mathbb{X}_t^0 = \{\tilde{w}_{Ht}, \tilde{w}_{Ft}, S_{Ht}\}_{t=0}^{t=T}$.
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 $\{\mu_t(\mathbf{m}_h)\}_{t=0}^{t=T}$ forward from period 0 to period T. $\mu_{H\mathbf{m}0}$ is given as the initial condition. We also solve implied $\tilde{\mathbb{X}}_t^1 = \{\tilde{w}_{Ht}, \tilde{w}_{Ft}, S_{Ht}\}_{t=0}^{t=T}$ using $\{\mu_t(\mathbf{m}_h)\}_{t=0}^{t=T}$.
6. Get the distance $\|\mathbb{X}_t^0 - \mathbb{X}_t^1\|$ between the guess and implied value. We use the Euclidean norm.
7. Update the guess as below until $\|\mathbb{X}_t^0 - \mathbb{X}_t^1\| < \epsilon$

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

   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 Y_{Ht}.

D.3 TFP Decomposition

Plugging $L_{Ht}^p = \int_0^1 \sum_{i \in \mathcal{I}_H} l_{ijt}$ into the definition of the aggregate TFP,

$$Z_{Ht} = \frac{Y_{Ht}}{L_{Ht}^p} = \frac{Y_{Ht}}{\int_0^1 \sum_{i \in \mathcal{I}_H} \frac{y_{ijt} + \tau y_{ijt}^*}{z_{ijt}} dj} = \left(\int_0^1 \sum_{i \in \mathcal{I}_H} \frac{y_{ijt} + \tau y_{ijt}^*}{Y_{Ht}} \frac{1}{z_{ijt}} dj \right)^{-1} .$$

Then, we can approximate $d \log Z_{Ht}$ at the first order as

$$d \log Z_{Ht} \approx \int_0^1 \sum_{i \in \mathcal{I}_H} \frac{\partial \log Z_{Ht}}{\partial \log z_{ijt}} d \log z_{ijt} ,$$

where $\frac{\partial \log Z_{Ht}}{\partial \log z_{ijt}}$ can be represented as

$$\frac{\partial \log Z_{Ht}}{\partial \log z_{ijt}} = \frac{z_{ijt}}{Z_{Ht}} \frac{\partial Z_{Ht}}{\partial z_{ijt}} = \frac{z_{ijt}}{Z_{Ht}} \left(\int_0^1 \sum_{i \in \mathcal{I}_H} \frac{y_{ijt} + \tau y^*_{ijt}}{Y_{Ht}} \frac{1}{z_{ijt}} dj \right)^{-2} \frac{y_{ijt} + \tau y^*_{ijt}}{Y_{Ht}} \frac{1}{z^2_{ijt}}$$
$$= \frac{\frac{y_{ijt}+\tau y^*_{ijt}}{Y_{Ht}} \frac{1}{z_{ijt}}}{\left(\int_0^1 \sum_{i \in \mathcal{I}_H} \frac{y_{ijt}+\tau y^*_{ijt}}{Y_{Ht}} \frac{1}{z_{ijt}} dj \right)} = \omega_{ijt}.$$

The numerator of ω_{ijt} can be expressed as

$$\frac{y_{ijt} + \tau y^*_{ijt}}{Y_{Ht}} \frac{1}{z_{ijt}} = \frac{\frac{p_{ijt} y_{ijt}}{P_{Ht} Y_{Ht}}}{\frac{p_{ijt} z_{ijt}}{w_{Ht}} w_{Ht}} + \frac{\frac{p^*_{ijt} y^*_{ijt}}{P_{Ft} Y_{Ft}} \frac{P_{Ft} Y_{Ft}}{P_{Ht} Y_{Ht}}}{\frac{p^*_{ijt} z_{ijt}}{\tau w_{Ht}} w_{Ht}} = \frac{P_{Ht} Y_{Ht} + P_{Ft} Y_{Ft}}{P_{Ht} Y_{Ht}} \left(\frac{S_{Ht} s_{ijt}}{\mathcal{M}_{ijt} w_{Ht}} + \frac{(1 - S_{Ht}) s^*_{ijt}}{\mathcal{M}^*_{ijt} w_{Ht}} \right),$$

where the first equality comes from the normalization of $P_{Ht} = 1$.

Because markups and market shares can be represented as a function of productivity gap, ω_{ijt} is a function of productivity gap $\mathbf{m}_i$. Therefore, ω_{ijt} can be expressed as

$$\omega_{ijt} = \omega_{it}(\mathbf{m}_i) = \frac{\left(\frac{S_{Ht} s_t(\mathbf{m}_i)}{\mathcal{M}_t(\mathbf{m}_i)} + \frac{(1-S_{Ht}) s^*_t(\mathbf{m}_i)}{\mathcal{M}^*_t(\mathbf{m}_i)} \right)}{\left(\sum_{\mathbf{m}_h} \mu_t(\mathbf{m}_h) \sum_{i \in \mathcal{I}_H} \frac{S_{Ht} s_t(\mathbf{m}_i)}{\mathcal{M}_t(\mathbf{m}_i)} + \frac{(1-S_{Ht}) s^*_t(\mathbf{m}_i)}{\mathcal{M}^*_t(\mathbf{m}_i)} \right)},$$

where the common terms w_{Ht} and $(P_{Ht} Y_{Ht} + P_{Ft} Y_{Ft})/P_{Ht} Y_{Ht}$ are canceled out in the numerator and the denominator. Then, $d \log Z_{Ht}$ can be approximated as follows:

$$d \log Z_{Ht} \approx \int_0^1 \sum_{i \in \mathcal{I}_H} \omega_{ijt} d \log z_{ijt} = \sum_{\mathbf{m}_h} \int_{\mathbf{m}_{hjt} = \mathbf{m}_h} \left(\omega_{ht}(\mathbf{m}_h) d \log z_{hjt} + \omega_{\tilde{h}t}(\mathbf{m}_{\tilde{h}}) d \log z_{\tilde{h}jt} \right) dj.$$

As the innovation and adoption rate is a function of productivity gap, $\int_{\mathbf{m}_{hjt} = \mathbf{m}_h} d \log z_{ijt} dj$ is also a function of productivity gap $\mathbf{m}$. Moreover, it can be represented as a function of the innovation rate ($x_{it}(\mathbf{m}_i)$), adoption rate ($a_{it}(\mathbf{m}_i)$), and exogenous spillover (ϕ_0) as below:

$$\int_{\mathbf{m}_{hjt} = \mathbf{m}} d \log z_{ijt}(\mathbf{m}_i) dj = \mu_t(\mathbf{m}_h)$$
$$\times \left(\left[x_{it}(\mathbf{m}_i) \sum_n \tilde{f}(n; \mathbf{m}_i) n + a_{it}(\mathbf{m}_i) \sum_n \tilde{g}(n; \mathbf{m}_i) n + \phi_0 \max\{-m_i^F, -m_i^D, 0\} \right] \log \lambda + o(\Delta t) \right),$$

where the first term indicates the step size increase from innovation, the second from adoption, and the last one from exogenous spillover. $o(\Delta t)$ is the second order term, representing the probability of firms experiencing more than one event. $\lim_{\Delta t \to 0} o(\Delta t)/t = 0$ holds in continuous time.

Finally, TFP can be decomposed between innovation, adoption, and spillover as

$$
\begin{aligned}
d\log Z_{Ht} \approx & \sum_{\mathbf{m}_h} \mu_t(\mathbf{m}_h) \sum_{i \in \mathcal{I}_H} \omega_{it}(\mathbf{m}_i) \\
& \times \left[\underbrace{x_{it}(\mathbf{m}_i) \sum_n \tilde{f}(n; \mathbf{m}_i) n}_{\text{Innovation}} + \underbrace{a_{it}(\mathbf{m}_i) \sum_n \tilde{g}(n; \mathbf{m}_i) n}_{\text{Adoption}} + \underbrace{\phi_0 \max\{-m_i^F, -m_i^D, 0\}}_{\text{Exogenous Spillover}} \right] \log \lambda.
\end{aligned}
$$

D.4 Additional Figures

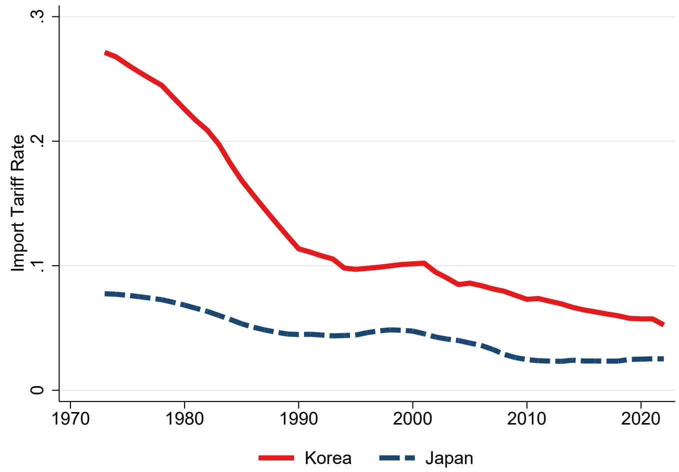


Figure D.1: Import Tariff

Notes. This figure displays the import-weighted tariff rate of both Korea and Japan. For the period between 1973 and 1988, Korea's import tariff rate data is sourced from the Korea Customs Service, and Japan's from the average import tariff of G7 countries calculated by Yi (2003). Post-1988, the tariff rates are obtained from the World Development Indicators.

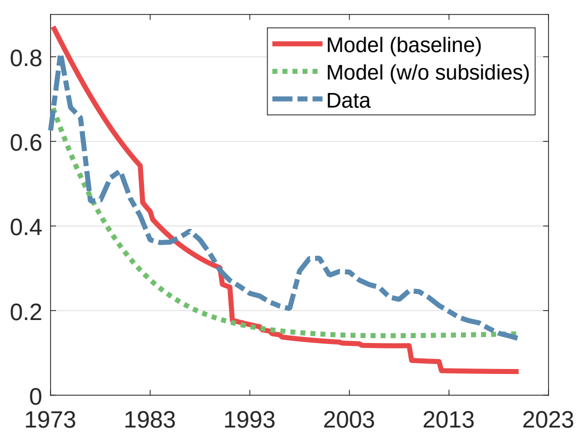


Figure D.2: Adoption Expenditure Share in the Model and the Data

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 with no subsidies, and the dashed blue line is data.

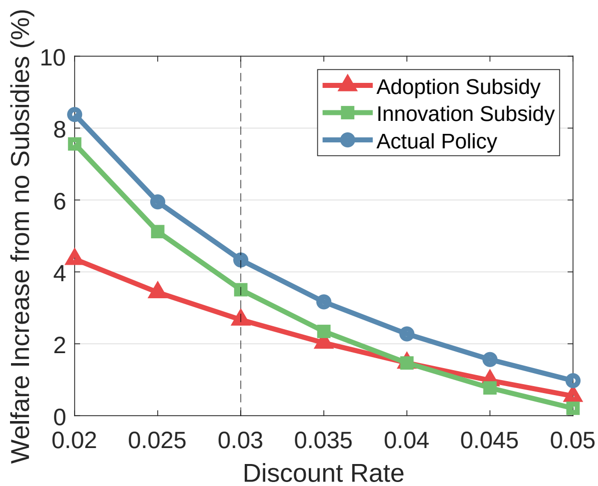
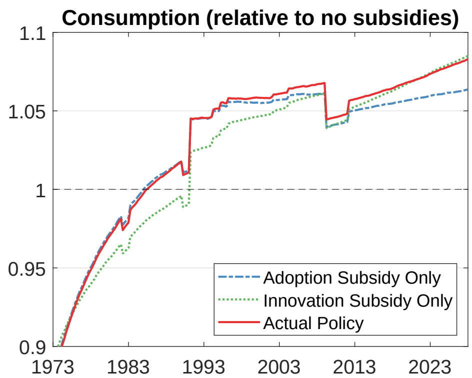
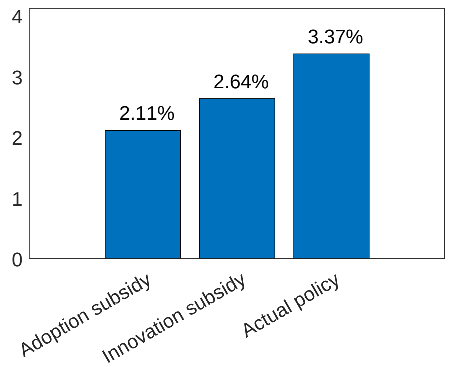


Figure D.3: Welfare Increase from Undistorted Case over Discount Rate

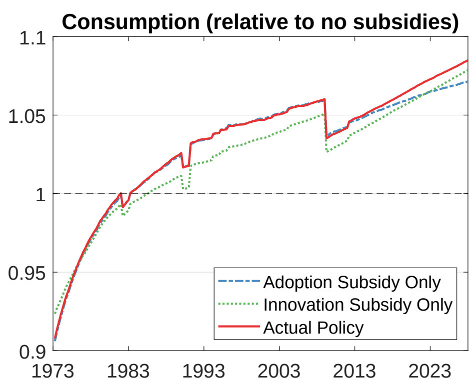
Notes. This figure plots the welfare increase compared to the undistorted case in an infinite time horizon over different discount rates ρ. The baseline value is $\rho = 0.03$. Welfare increase is calculated in a consumption-equivalent unit (equation (15)). The blue triangle is when subsidizes only adoption, the green square subsidizes only innovation, and the solid red line follows the actual policy in Figure 1. In all counterfactual scenarios, the share of government spending relative to GDP remained constant.



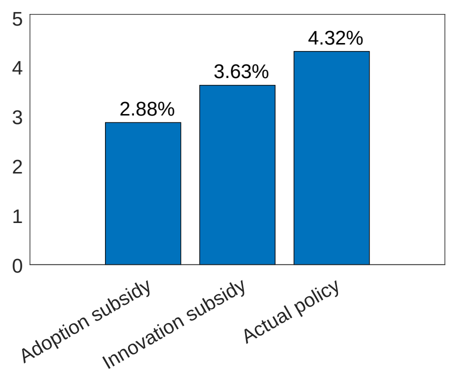
A. Relative GDP ($\sigma = 3$)



B. Welfare increase (%, $\sigma = 3$)



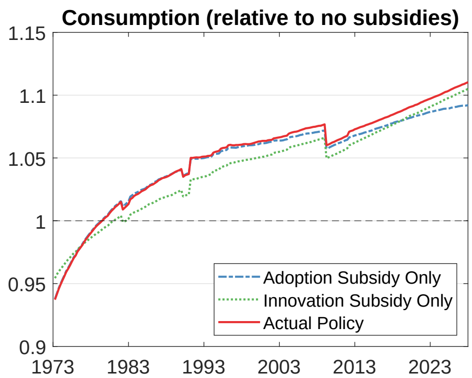
C. Relative GDP ($\sigma = 9$)



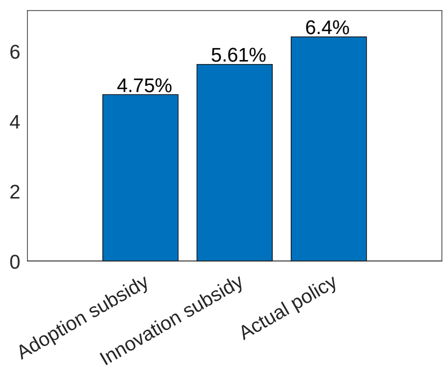
D. Welfare increase (%, $\sigma = 9$)

Figure D.4: Results of the Counterfactual Analysis with Elasticity of Substitution

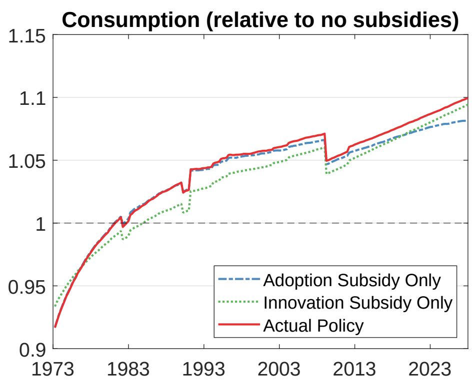
Notes. This figure evaluates the actual policy by comparing it with counterfactuals under alternative parameter values. Panels A and B plot the case with $\sigma = 3$, and Panels C and D plot the case with $\sigma = 9$. Panels A and C plot real consumption in the three scenarios divided by real consumption in the case with no subsidies. The dotted blue line subsidizes only adoption, the dashed green line subsidizes only innovation, and the solid red line follows the actual policy in Figure 1. In all counterfactual scenarios, the share of government spending relative to GDP remained constant. Panels B and D plot the welfare increase compared to the case without subsidies in the infinite time horizon. The welfare increase is calculated in consumption-equivalent units using equation (15).



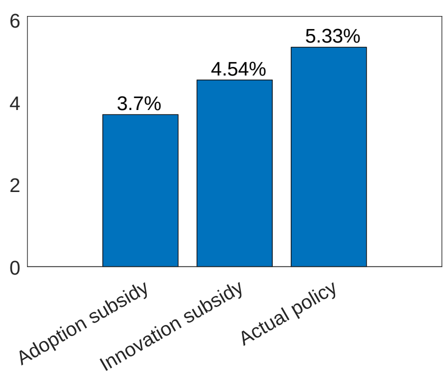
A. Relative GDP ($\theta = 0$)



B. Welfare increase (%, $\theta = 0$)



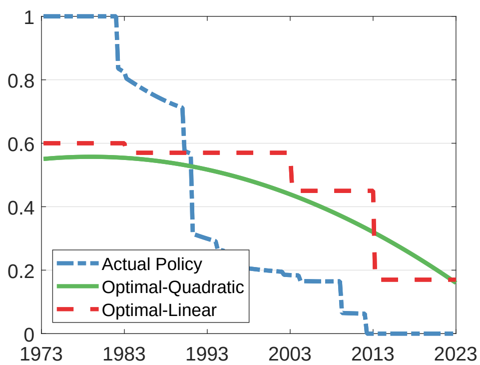
C. Relative GDP ($\theta = 0.5$)



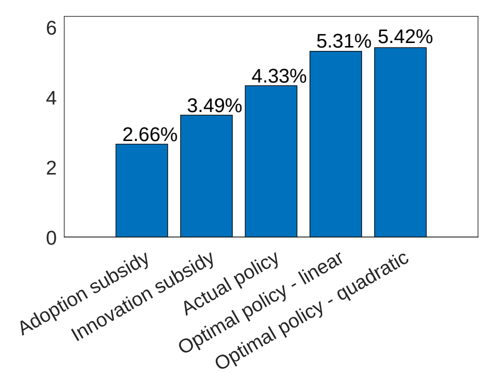
D. Welfare increase (%, $\theta = 0.5$)

Figure D.5: Results of the Counterfactual Analysis with Deadweight Cost of Taxation Parameter

Notes. This figure evaluates the actual policy by comparing it with counterfactuals under alternative parameter values. Panels A and B plot the case with $\theta = 0$, and Panels C and D plot the case with $\theta = 0.5$. Panels A and C plot real consumption in the three scenarios divided by real consumption in the case with no subsidies. The dotted blue line subsidizes only adoption, the dashed green line subsidizes only innovation, and the solid red line follows the actual policy in Figure 1. Notably, in all counterfactual scenarios, the share of government spending relative to GDP remained constant. Panels B and D plot the welfare increase compared to the case without subsidies in the infinite time horizon. The welfare increase is calculated in consumption-equivalent units using equation (15).



A. Adoption Subsidy Share



B. Welfare increase (%)

Figure D.6: Optimal Policy and Welfare Increase

Notes. This figure plots the optimal and actual subsidy shares and welfare results. Panel A plots the linear optimal policy (red), and quadratic optimal policy (green), compared with the actual case (blue). For linear policy, the government is allowed to change adoption subsidy share every 10 years, while keeping the government spending over GDP equal to the actual policy. For quadratic policy, subsidy share is a quadratic function of time as $\kappa_{Hat} = \alpha + \beta t + \gamma t^2$ and the government chooses $\{\alpha, \beta, \gamma\}$ to maximize the welfare. Panel B plots the consumption-equivalent welfare increase from the undistorted case over different policies.

PUBLICATIONS

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