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

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Abstract

Should governments prioritize subsidizing foreign technology adoption over domestic innovation, and how might this depend on different stages of development? Using historical technology transfer and patent data from South Korea, we find that greater productivity gaps between Korean and foreign firms correlate with larger productivity gains after adoption, accompanied by reduced fees paid to foreign technology sellers. Also, non-adopters increased patent citations to foreign sellers, indicating knowledge spillovers. Motivated by these findings, we build a two-country growth model of firm-level innovation and adoption. As firms narrow the gap, adoption costs rise due to strategic interactions between firms in the global market. Moreover, gains from adoption decrease as the advantages of backwardness diminish, reducing the effectiveness of adoption subsidies compared to innovation subsidies. We evaluate Korea's policy shift from adoption to innovation subsidies. The state-dependent nature of the policy has significant implications for welfare and catching up.

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1 Introduction

Policymakers in many developing countries often use subsidies to upgrade technologies and to stimulate economic growth. They typically consider two options: fostering innovation to develop own technologies or facilitating adoption of advanced foreign technologies. Government budget constraints require effective resource allocation between these two options. Therefore, to design effective technology policies, it is important to understand the relative benefits and costs of adoption versus innovation across different stages of development.

This paper studies how adoption and innovation contribute to aggregate growth depending on stages of economic development. To achieve this, we develop and estimate a two country endogenous growth model with firm-level adoption and innovation, where costs of adoption are endogenously determined by strategic interaction between technology sellers and buyers. Our main contribution is the novel quantification of the relative benefits and costs of adoption and innovation during the transition of an economy from a developing to a developed stage. The model is disciplined by a unique historical dataset on firm-to-firm technology transfers. We use this model to perform policy analysis.

Our setting is South Korea (Korea, hereafter) during the 70s to the 90s, which presents an ideal case study for two reasons. First, Korea is not only renowned for its remarkable long-term economic growth but also for its exceptional transition into one of the world's most innovative countries. Second, the Korean government proactively implemented subsidy policies to bridge the gap with the technological frontier during this transformative phase. Initially, these policies primarily subsidized adoption, but as Korea made strides in closing this gap, it shifted its emphasis towards domestic innovation.[1] Therefore, our research setting allows us to document how firms source their technological advancements as a country progresses from a developing to a developed stage and provides an opportunity to evaluate the impacts of stage-dependent technology policy.

Despite the widely-held belief in the importance of technology adoption in developing countries, little is quantitatively known about the benefits and costs of adoption due to the lack of detailed data on adoption and its pricing. We overcome this challenge by exploiting unique data on contract-level technology imports in Korea during the 1970s to the 1990s, which was digitized from the historical archive. These data include the universe of technology transfer contracts between Korean and foreign firms with detailed information on the price of technologies and firm-to-firm relationships, which has been less explored in the literature.

Using this data, we document two novel facts about technology adoption that motivate our model. First, when Korean firms' productivity lagged behind that of foreign firms, production gains from adoption were lower than those from innovation, but adoption fees were less expensive. Second, we provide empirical evidence on knowledge spillovers from adoption using patent citations and matching-based event study specifications. We document that non-adopting firms

[1]This policy is commonly adopted in rapidly growing developing countries. For example, Brazil shifted to an innovation-centered subsidy in 2021, and China, which initially promoted technology adoption through Foreign Direct Investment (FDI), transitioned to an innovation-driven development agenda in 2016 as part of the 13th five-year plan.

started to cite more patents from foreign firms that sold technology to Korean firms for the first time.

Motivated by these facts, we build a two-country growth model in which firms can improve productivity by adopting foreign technology or innovating themselves. We build on the step-by-step innovation model of Schumpeterian creative destruction, which allows strategic interaction among non-atomistic firms. There are two domestic and one foreign firms competing for global market shares. They make investments to improve their productivity through two options: innovation and adoption. Adoption differs from innovation in three ways. First, adoption features a stronger magnitude of the advantages of backwardness when compared to innovation. When productivity levels lag further behind, adoption can be a more effective means of boosting productivity than innovation. Second, adoption cannot results in a higher productivity level than that of a foreign firm. Finally, adopting firms must pay an adoption fee to a foreign firm, which is endogenously determined by determined by Nash bargaining between two firms involved.

When foreign firms sell technology, they can benefit from adoption fees paid by domestic firms, but adoption also reduces their future profits due to heightened competition with domestic firms in the global market, as adoption narrows the productivity gap between foreign and domestic firms. This competition effect becomes more pronounced as productivity gaps narrow, prompting foreign firms to charge higher adoption fees to compensate for this anticipated future loss. The combination of stronger advantages of backwardness and the competition effect related to adoption allows the model to generate features consistent with our first empirical fact.

Adoption and innovation generate knowledge spillovers across domestic firms, aligning with our second fact. With a positive probability, a home follower can learn a home leader's technology and improve on it through either innovation or adoption. This intertemporal spillover creates room for government subsidies to improve welfare. The extent of this intertemporal spillover depends on the productivity gains resulting from adoption and innovation. Due to the differential magnitude of advantages of backwardness and the fact that adoption does not yield a higher productivity level than that of a foreign firm, the spillovers from adoption are initially greater than those from innovation, especially when there are significant initial gaps. However, this effect diminishes as the gaps narrow, implying that the effectiveness of adoption or innovation subsidies varies based on the gaps.

We calibrate our model to the firm-level data. We solve for the transition of the model from the initial state, where Korean firms have lower productivity than foreign firms on average, to the 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. Specifically, we match the average adoption fee over sales and the regression coefficients found in our motivating facts. The estimated model successfully replicates Korea's catching-up period and aligns with untargeted moments, including our first observation regarding the increasing adoption fee as a function of the productivity gap.

Using the estimated model, we conduct three quantitative exercises. First, we decompose growth between adoption and innovation by examining counterfactual scenarios in which we isolate either adoption or innovation. Our findings reveal that in 1973, adoption contributed to 73% of TFP growth, but this number decreased to 6% by 2022. As productivity converged with that of foreign firms, the relative productivity gains from adoption decreased, leading firms to increase innovation rates while decreasing adoption rates.

Second, we evaluate the state-dependent technology policy implemented by the Korean government since 1973. The Korean government initially supported adoption through tax credits, gradually reducing the adoption subsidy rate while increasing the innovation subsidy rate after launching the R&D subsidy program in 1982. We compare the actual policy with three counterfactual scenarios: shutting down both subsidies, subsidizing only adoption, and subsidizing only innovation. In this comparison, the actual state-dependent policy increases consumption-equivalent welfare by 4.84% compared to the case with no subsidies. This policy has more substantial welfare effects than subsidizing only adoption (3.69%) or only innovation (3.28%).

Third, we explore the effects of a foreign policy that prohibits the transfer of advanced technology to Korea. This counterfactual is motivated by the ongoing debate regarding the US government's ban of transferring high-tech sector technologies to China. The foreign government has an incentive to restrict technology exports due to the externality wherein foreign incumbents do not internalize the future loss from potential entrants and might over-export technologies beyond their socially optimal level. In this counterfactual, we find that Korea's welfare decreases by 11.77%, while foreign welfare increases by 8.54%.

Finally, we quantitatively explore the optimal subsidies. We consider a class of subsidies in which the government can subsidize either adoption or innovation each year, and choose timing to switch from adoption to innovation subsidies with the aim of maximizing welfare. The optimal policy, in this case, begins with an adoption subsidy set at 55% and transitions to an innovation subsidy at 51% in 1985, when Korea's GDP reached 55% of Japan's. This policy leads to a 6.42% increase in welfare, surpassing the improvement achieved by the actual policy.

Related Literature Our paper contributes to several strands of 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; 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). While previous papers have primarily focused on innovation policies in developed countries, our paper shifts its focus to adoption policies in developing countries. We emphasize the welfare implications of state-dependent policies that transition from adoption to innovation subsidies. The most closely related paper is Acemoglu et al. (2006) who theoretically characterize the optimal timing to switch from adoption subsidies to innovation subsidies. Unlike this paper, we quantitatively study the welfare impact of the actual policy implemented and explore the optimal timing to switch using micro-level adoption and innovation data.

Second, this paper contributes to the literature on international knowledge diffusion (e.g.

Grossman and Helpman, 1991; Eaton and Kortum, 1999, 2001; Alvarez et al., 2017; Buera and Oberfield, 2020; Hsieh et al., 2019; Rachapalli, 2021; Santacreu, 2015; Sampson, 2019; Santacreu, 2022; Lind and Ramondo, 2022; Cai et al., 2022). We contribute to this literature by developing a new model with rich strategic interaction between foreign and domestic firms, and by quantifying the role of technology adoption using comprehensive adoption and innovation microdata. While most papers abstract away from foreign firms' incentives to sell technology, our model highlights that adoption requires mutual agreement between technology buyers and sellers, which allow us to explain the observed patterns in the data.

Third, our model is related to the literature on models of growth through step-by-step innovations (e.g., Aghion et al., 2001; Acemoglu and Akcigit, 2012; Akcigit et al., 2020, 2021; Akcigit and Ates, 2019; Olmstead-Rumsey, 2022; Liu et al., 2022). However, unlike conventional models that assume exogenous learning of other firms' technologies, we study endogenous technology adoption decisions while capturing rich strategic interactions between technology sellers and buyers.

Lastly, this paper is related to the macroeconomic literature that studies South Korea's growth miracle (e.g. Lucas, 1993; Young, 1995; Ventura, 1997; Connolly and Yi, 2015; Choi and Levchenko, 2021; Kim et al., 2021; Choi et al., 2023). Unlike previous studies, we focus on South Korea's long-term technology policy shift from adoption to innovation subsidies during the 70s to the 90s. The most closely related paper is our other paper, Choi and Shim (2023), which studies the role of technology adoption in industrialization, focusing on sector-specific and temporary industrial policy in the 1970s when Korean firms were far from the frontier. In contrast, this paper focuses on the catch-up growth period, during which strategic interactions between Korean and foreign firms became more important as Korean firms narrowed productivity gaps with their foreign competitors. To capture these strategic interactions between firms, we use novel information on adoption fees and exploit the firm-to-firm structure of the data.

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

2 Data

We construct our main dataset by combining technology adoption, patent, and balance sheet datasets. The data covers manufacturing firms and the sample period is 1970–1993. Further details regarding the data construction can be found in Appendix A.

Technology adoption We construct a firm-to-firm technology adoption dataset by digitizing technology transfer contracts from the National Archives of Korea and supplement them with

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%

data from Korea Industrial Technology Association (1995).[2] The data includes the universe of technology transfers between Korean and foreign firms for the period 1962–1993. There were 8,404 contracts made by 2,865 unique Korean firms. The key information is adoption fee, names of Korean buyers and foreign sellers, contract length, and years in which contracts were made.[3] One of the key information is adoption fee. Contracts specified either a fixed fee, royalty rate, or both. 1.38% of the contracts specified only royalty payments, 76.56% fixed fees, and 37.97% both. The average yearly royalty rate is 3.28%. The average fixed fee was 1.29 million dollars, which accounted for 1.97% of yearly sales. The average contract length was 5.13 years. 94% of the contracts were related to know-how, including providing technical and training service, sharing information, or transfers of blueprints. 50% and 26% of the contracts were made with Japanese and US firms, respectively (Appendix Table A.1). We exclude contracts between subsidiaries and headquarters within multinational firms from our sample, which accounted for only 3% of the total contracts. Table 1 shows the example of the available information from this data.

Patent To measure innovation of Korean firms, we mainly use patent data from the Korean Intellectual Property Office (KIPO) and cleaned the data following the procedure from Lee et al. (2020). KIPO starts in 1945 and includes the universe of patents registered in Korea by domestic and foreign firms. However, KIPO does not have citation information until the 1990s. Therefore, we use the data from the United States Patent and Trademark Office (USPTO) which covers the

[2] Korean firms were required to submit documents related to the contracts to the government when they import technology from a foreign country, which is the source of our data. Appendix Figure A.1 presents an example of the documents.

[3] Compared with data that we used in Choi and Shim (2023), we additionally collect information on adoption fee and foreign firm, and extend the sample period.

Table 2: Summary Statistics

	Ever-Adopted	Never-Adopted	Ever-Patented	Never-Patented
Emp.	1,172	291	952	308
Asset	181	18	188	16
Sales	200	30	205	25
Sales per emp.	0.18	0.16	0.18	0.15
Patenting (yearly dummy)	0.07	0.01	0.07	N/A
Adopting (yearly dummy)	0.17	N/A	0.11	0.03
# of unique firms	1,208	5,585	1,556	5,237
# of obs.	19,198	34,030	21,843	31,385

Notes. This table reports the summary statistics. We calculate average values for 1970-1993. Adopting firm is defined as a firm that has at least one adoption contract. All nominal values are converted to 2015 US million dollars.

universe of US patent citations since 1975. We use a crosswalk between the Korean patent office firm ID and USPTO ID constructed by Lee et al. (2020).

Also, we use USPTO data to measure innovation of foreign firms. Among the 8,404 contracts, 4,657 observations are matched with USPTO ID of foreign firms. We have 2,073 unique USPTO ID attached to foreign firms.

Balance sheet Our firm-balance sheet data has information on sales, fixed assets, employment, and sectors. We use two data sources to construct firm-level balance sheet data for Korean firms. First, we obtain firm balance information for the period 1970-1982 from digitizing the Annual Reports of Korean Companies published by the Korea Productivity Center. These reports cover firms with more than 50 employees. For the period 1982-1993, we obtain balance sheet information from KIS-VALUE which covers firms with assets of more than 3 billion Korean Won (2.65 million dollars in 2015). All nominal values are converted to 2015 US dollar values.

We use Compustat North America and Global data for foreign firms' balance sheet, which covers the publicly listed firms. To merge Compustat with USPTO, we use the global corporate patent dataset (Bena et al., 2017) who construct matching between Compustat IDs (gvkey) and patent IDs. If two assignees have the same gvkey, we merge them and consider as one firm.

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

3 Motivating Facts

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

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

Productivity growth after adoption and innovation We first document systematic relationships between productivity growth after adoption and innovation, and productivity gaps. We run the following regression model:

$$\log \frac{z_{i,t+5}}{z_{it}} = \beta \log \frac{z_{it}}{z_{ft}} + \mathbf{X}_{it}'\boldsymbol{\gamma} + \boldsymbol{\delta} + \epsilon_{it}, \tag{1}$$

where $\log z_{i,t+5}/z_{it}$ is growth rate of labor productivity after 5 years from either innovation or adoption of a Korean firm i and $\log z_{it}/z_{ft}$ is a productivity gap between a Korean firm i and a foreign firm f in the year of the adoption or innovation. If a firm has multiple contracts in a given year, we take the average of productivity gaps. Since innovating firm do not have corresponding foreign firm f, we pick the foreign technology seller with the maximum sales per employee in each sector and year. $\mathbf{X}_{it}$ are observable controls which include initial log sales per employee due to the mean reversion, and growth rate of fixed assets per employee over a 5-year period to account for capital growth in all specifications. We include additional fixed effects $\boldsymbol{\delta}$ depending on specifications. Standard errors are clustered at the firm levels.

We estimate Equation (1) for two estimation subsamples that consist of firms making adoption decisions and conducting own innovation in year t, respectively. Then, we compare the magnitude of the estimated $\hat{\beta}$ for these two subsamples.

Table 3 reports the results. In Panel A, we observe statistically significant negative relationships between log productivity gaps and the growth of labor productivity. On average, the coefficients in columns 1-4 imply that 1% higher productivity gap was negatively associated with 0.09 percentage point lower productivity growth after adoption. Firms were associated with higher labor productivity growth after adoption if they were more distant from foreign firms. In columns 5-8, we consider the DHS growth (Davis et al., 1998) and find similar results. In Panel B, we also find this negative relationship for innovating firms, but the magnitude was weaker than for adoption and the estimates were less precise. Figure 1 visually illustrates this relationship, corresponding to the specification in column (2). These findings suggest that productivity gaps have a more significant impact on adoption compared to innovation.

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

Dep.	△ log sales per emp.				DHS growth of sales per emp.			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A. Adoption							
Log Productivity Gap	-0.061***	-0.085***	-0.089***	-0.125***	-0.047***	-0.065***	-0.073***	-0.073***
	(0.015)	(0.017)	(0.018)	(0.026)	(0.013)	(0.013)	(0.015)	(0.020)
# Cl. (domestic firm)	425	392	242	386	425	392	242	386
N	1,438	1,327	1,255	1,271	1,438	1,327	1,255	1,271
	Panel B. Innovation							
Log Productivity Gap	-0.003	-0.027	-0.043***	-0.036*	0.000	-0.019	-0.036***	-0.024
	(0.011)	(0.017)	(0.014)	(0.021)	(0.010)	(0.014)	(0.011)	(0.019)
# Cl. (firm)	296	234	165	226	296	234	165	226
N	997	847	865	790	997	847	865	790
Year FE	✓	✓	✓		✓	✓	✓	
Sector FE		✓				✓		
Firm FE			✓				✓	
Sector×Year FE				✓				✓

Notes. Standard errors in parentheses are clustered at the domestic firm levels. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. This table reports the estiates from Equation (1). In panels A and B, the estimation samples are firms that had at least one technology transfer contract and that made at least one patent, respectively. Relative productivity is log ratio of sales per employee between the Korean firm (buyer) and the foreign firm (seller). For innovation, we use the maximum of log sales per employment of foreign firms within the same sector. All specifications include initial log sales per employment, growth rate fixed asset per employment for 5 years, and sector and year fixed effects.

Adoption fee To investigate the relationship between adoption fees and productivity gaps, we consider the following specification:

$$\mathcal{F}_{ift} = \beta \log \frac{z_{it}}{z_{ft}} + \boldsymbol{\delta} + \epsilon_{ift}, \tag{2}$$

where $\mathcal{F}_{ift}$ is the adoption fee that Korean firm i pays to foreign firm f in year t. We consider two measures of adoption fees: log fixed fee and the royalty rate. For samples that do not have information on foreign firms, we use maximum sales per employee within sector-year. We control for additional fixed effects $\boldsymbol{\delta}$ depending on specifications.

Table 4 reports the results. In column 1, we find that a 1% increase in the productivity gap is associated with a 0.18% increase in the fixed fee and a 0.11 percentage point increase in royalty rate. In columns 2-5, we include different sets of fixed effects. We include sector fixed effects in column 2; firm fixed-effects in column 3, which exploits within-firm time variation; sector-year fixed effects in column 4; and sector-year and foreign country-year fixed effects in column 5. We include the foreign country-year fixed effects to capture technological heterogeneity across countries. Across different specifications, we find robust positive correlations between the productivity gap and adoption fee.

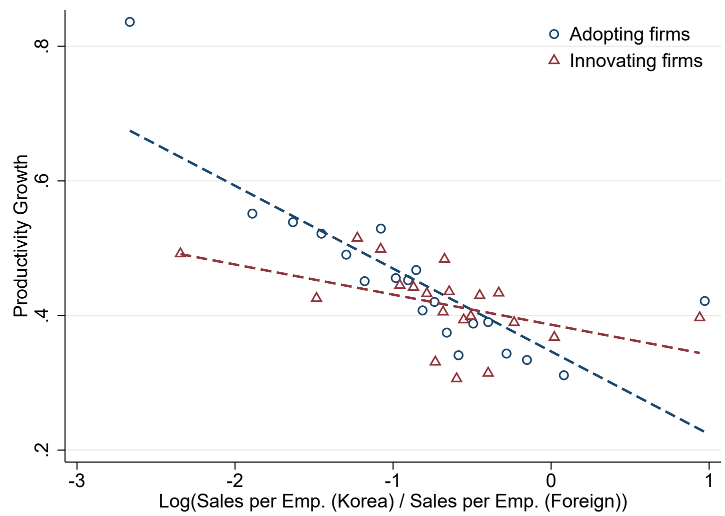


Figure 1: Productivity Growth over Initial Productivity Gap

Notes. This figure plots a binscatter plot with the growth of log sales per employment over a 5 year period on the Y-axis and the log productivity gap between Korean and foreign firms on the X-axis, corresponding to the specification of column 2 in Table 3. Blue circles represent firms that obtained patent, while red triangles represent firms that made adoption decisions.

3.2 Knowledge Spillovers from Adoption

We provide empirical evidence of knowledge spillovers from technology adoption. We use patent citations to measure knowledge spillovers following the innovation literature (e.g. Jaffe et al., 1993; Aghion et al., 2019). Consider two foreign firms, one of which has sold technology to a Korean firm while the other has not. If Korean firms that have never adopted any technologies from the foreign seller begin citing this foreign firm's patents more frequently after the technology sale, when compared to the foreign non-seller, we interpret these differential citation patterns following the contract as indicative of knowledge spillovers.

To address potential confounding factors, we employ a matching-based event study research design. We match two foreign firms: one that has sold technology (the treated group) and another that has never sold technology (the control group). Our matching involves two steps. We first exactly match on 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 log cumulative patent stock, log age, and log cumulative citations. The event year is defined as the year in which the matched foreign firm in the treated group sells technology to a Korean firm for the first time. We assign the same event year as a placebo year for the control group. We obtain 278 matches with 556 unique firms.

Table 4: Adoption Fee and Productivity Gap

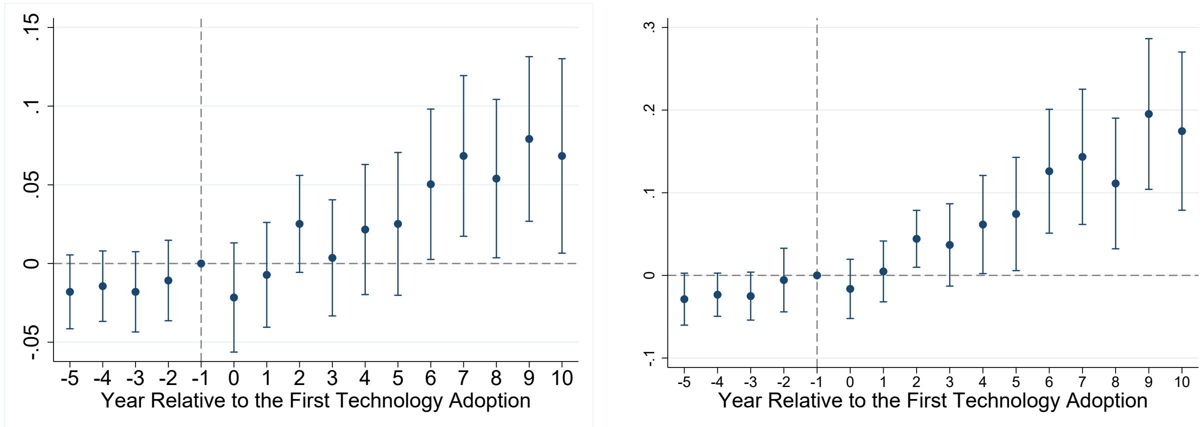
	(1)	(2)	(3)	(4)	(5)
	Panel A. Dep. Log Fixed Fee				
Log Productivity Gap	0.183***	0.133**	0.093	0.280***	0.292***
	(0.052)	(0.060)	(0.068)	(0.078)	(0.088)
# Cl. (domestic firm)	349	320	178	313	301
# Cl. (foreign firm)	1,288	1,180	1,144	1,171	1,076
N	1,790	1,644	1,619	1,630	1,516
	Panel B. Dep. Royalty Rate				
Log Productivity Gap	0.108*	0.160**	0.392*	0.202*	0.190*
	(0.059)	(0.079)	(0.203)	(0.118)	(0.114)
# Cl. (domestic firm)	315	292	152	288	267
# Cl. (foreign firm)	841	772	701	764	692
N	1,159	1,075	996	1,055	973
Year FE	✓	✓	✓		
Sector FE		✓			
Domestic Firm FE			✓		
Sector x Year FE				✓	✓
Foreign Country x Year FE					✓

Notes. Standard errors in parentheses are two-way clustered at the domestic and foreign firm levels. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. This table shows the result of equation (2) in which we regress the adoption fee on the relative productivity. In panels A and B, the dependent variables are $\ln(\text{Fixed fee})$ and royalty rate denoted in percentage terms, respectively. The productivity gap is the log ratio of sales per employee between the Korean firm (buyer) and the foreign firm (seller).

Using the matched sample, we consider the following specification:

$$y_{ft} = \sum_{\tau=-5}^{10} \beta_\tau (D^\tau_{mt} \times \mathbb{1}[\text{Treated}_{it}]) + \delta_{fm} + \delta_{mt} + \epsilon_{fmt}, \tag{3}$$

where f denotes foreign firm, m match, and t year. We consider two dependent variables: a dummy indicating whether any Korean firms that have never adopted any foreign technologies during the sample period cite patents from foreign firm $f$in year t $\mathbb{1}[\text{Citation}_{fmt} > 0]$, and the inverse hyperbolic sine transformation of foreign firm f's citations by these never-adopting firms $\text{Ihs}(\text{Citation}_{fmt})$. 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 foreign firm and match fixed effects, and δ_{fm}, match-year fixed effects δ_{mt}. ϵ_{it} is an error term. β_τ captures the difference between the treated and control firms in τ year from the event year. We two-way cluster standard errors at the foreign firm and match levels. The sample period of the analysis is 1975–2003, as USPTO citation data starts in 1975, and



A. $\mathbb{1}[\text{Citation}_{fmt} > 0]$ B. $\text{Ihs}(\text{Citation}_{fmt})$

Figure 2: Knowledge Spillovers from Technology Adoption

Notes. This figure plots the estimates of β_τ in Equation (3). In Panels A and B, dependent variables are a dummy of positive citations from never-adopting firms and the inverse hyperbolic sine transformation of total citations received by never-adopting firms, respectively. The vertical line is a 95% confidence interval. X-axis is the year relative to the first technology adoption by a Korean firm. β_{-1} is normalized to zero. The standard error is two-way clustered at the match and foreign firm levels. There are 278 and 556 number of clusters, respectively. $N = 8,896$

we study until post ten years from the adoption year, of which the last year is 1993.

Figure 2 presents the estimated β_τ. In Panels A and B, dependent variables are $\mathbb{1}[\text{Citation}_{fmt} > 0]$ and $\text{Ihs}(\text{Citation}_{fmt})$, respectively. After 10 years, the probability of being cited by never-adopting Korean firms increased by around 7%, compared to the control group. We observe a similar pattern for $\text{Ihs}(\text{Citation}_{fmt})$ which captures both intensive and extensive margins of citations. This suggests that Korean firms build on the adopted technology of other Korean firms, consistent with a positive externality associated with adoption. There were no pre-trends before the first technology adoption, supporting that the results were not driven by different trends between the two groups.

Identifying assumption The identifying assumption for the causal interpretation of β_τ requires that conditional on the controls and the fixed effects, the treated and the 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.

We present several pieces of empirical evidence supporting this assumption. First, we check the observables of balance. We find no statistically significant difference between the two groups in terms of observables (Appendix Table B.1). Second, we plot the raw average number of citations of the treated and the control groups (Appendix Figure B.1). The figure illustrates that two groups' citation flows had similar trends before the events but started to diverge only after the events, which is consistent with the no pre-trend results.

It is noteworthy to mention that we employ a stacked-by-event design (Cengiz et al., 2019; Deshpande and Li, 2019), and our event study coefficients are identified through the comparison between units switching into the treated group and units that got never-treated. Therefore, our design addresses the potential issues related to the presence of heterogeneous treatment effects, as discussed in the recent diff-in-diff literature (e.g. Goodman-Bacon, 2021; Sun and Abraham, 2021; Borusyak et al., 2023).

Placebo To further validate for our identifying assumption, we conduct a placebo exercise to examine whether our results are driven by unobserved shocks affecting the contracts of foreign firms and their number of citations received. For example, if Sony's new technology were unexpectedly superior, Korean firms might have become more likely to adopt from Sony, and citations to Sony could have increased after the adoption year. As a placebo test, we replicate the same regression using the number of citations received from firms in all the other countries except Korea. Appendix Figure B.2 shows no clear differences between treated and control groups, which lends support to our identifying assumption.

3.3 Discussion

These two empirical facts guide our model. We develop a dynamic general equilibrium model with firms' adoption and innovation decisions. The mechanisms of the advantages of backwardness and strategic competition between Korean and foreign firms are integral to ensuring that the model aligns with the first fact. These advantages imply that adoption yields greater productivity gains than innovation when Korean firms lag behind in technology, but diminish as the technological gap narrows. Simultaneously, forward-looking foreign firms charge higher adoption fees due to heightened competition. Therefore, relative benefits and costs of adoption vary across gaps. Furthermore, the model addresses the second fact by integrating knowledge spillovers resulting from technology adoption to non-adopting domestic firms. To rectify market failure arising from these positive externalities, the model justifies the need for subsidies to promote technology adoption.

4 Model

4.1 Setup

Time is continuous. There are two countries, home and foreign, and a continuum of a variety of goods $j \in [0, 1]$. Goods are tradable across countries with an iceberg cost of $\tau_x \geq 1$, which means firms need to ship τ_x units of goods for one unit of the good to export to another country. In home, 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, there is a representative firm f in each sector j. In foreign, instead of the follower, there is a potential entrant $\tilde{f}$ that can enter and replace the incumbent by innovating. Households in each country own all domestic firms and there is no trade in assets, which rules out international borrowing and lending.

4.2 Household

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

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

where C_{Hs} is final consumption at time s in country H and $\rho > 0$ is the discount factor. The budget constraint of the household is $r_{Ht}A_{Ht} + L_H w_{Ht} = P_{Ht}C_{Ht} + T_{Ht} + \dot{A}_{Ht}$, where r_{Ht} is interest rate, L_H is the labor endowment, w_{Ht} is wage, P_{Ht} is the price index of final consumption, T_{Ht} is the lump-sum tax that finances innovation and adoption subsidies, and A_{Ht} is the household's assets. $\dot{A}_{Ht}$ is the time derivative of A_{Ht}. A representative household's maximization gives the following Euler equation

$$\frac{\dot{C}_{Ht}}{C_{Ht}} = \rho - \left(r_{Ht} - \frac{\dot{P}_{Ht}}{P_{Ht}} \right). \tag{4}$$

Final consumption is given by

$$C_{Ht} = \exp\left(\int_0^1 \ln \left[\left(\psi_H^{\frac{1}{\sigma}} y_{hjt}^{\frac{\sigma-1}{\sigma}} + \psi_H^{\frac{1}{\sigma}} y_{\tilde{h}jt}^{\frac{\sigma-1}{\sigma}} + \psi_F^{\frac{1}{\sigma}} (y_{fjt}^*)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \right] \mathrm{d}j \right), \tag{5}$$

where y_{hjt} are firm h's quantities demanded in Home. y_{fjt}^* are foreign firm's export quantities demanded in home. The superscript asterisk denotes the goods that are exported. ψ_H and ψ_F are demand shifters for home and foreign goods. The final consumption aggregates all sector j with Cobb-Douglas function, and aggregates three goods in each sector j with a constant elasticity of substitution, σ. We assume $1 < \sigma < \infty$, meaning the goods within a sector are imperfect substitutes for each other. The price index of final consumption P_{Ht} in home country is given by

$$P_{Ht} = \exp\left(\int_0^1 \ln \left[\psi_H^{\frac{1}{\sigma}} p_{hjt}^{1-\sigma} + \psi_H^{\frac{1}{\sigma}} p_{\tilde{h}jt}^{1-\sigma} + \psi_F^{\frac{1}{\sigma}} (p_{fjt}^*)^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \mathrm{d}j \right), \tag{6}$$

where p_{ijt} and p_{fjt}^* are prices of goods charged by home firm $i \in \{h, \tilde{h}\}$ and foreign firm f in home, respectively.

4.3 Firms

Production Labor is the only factor of production and production function of the firm i is

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

where z_{ijt} represent productivity and l_{ijt} labor inputs. Because outputs are demanded in both countries, firms are subject to the following resource constraints: $\mathcal{Y}_{ijt} = y_{ijt} + \tau_x y_{ijt}^*$.

Market structure and pricing We assume that firms compete in prices á la Bertrand.[4] Firms internalize the fact that their pricing decisions affect their demand schedule. With the CES aggregator, home and foreign firms' demand schedule in Home is given as

$$y_{ijt} = \frac{\psi_H p_{ijt}^{-\sigma}}{\sum_{i' \in \{h,\tilde{h}\}} \psi_H p_{i'jt}^{1-\sigma} + \psi_F (p_{fjt}^*)^{1-\sigma}} P_{Ht} C_{Ht}, \qquad y_{fjt}^* = \frac{\psi_F (p_{fjt}^*)^{-\sigma}}{\sum_{i \in \{h,\tilde{h}\}} \psi_H p_{ijt}^{1-\sigma} + \psi_F (p_{fjt}^*)^{1-\sigma}} P_{Ht} C_{Ht}$$

for $i \in \{h, \tilde{h}\}$. Under the Bertrand competition, firms' charge variable markups and the optimal prices charged by firms are expressed as

$$p_{ijt} = \frac{1 - \frac{\sigma-1}{\sigma} s_{ijt}}{\frac{\sigma-1}{\sigma}(1 - s_{ijt})} \frac{w_{Ht}}{z_{ijt}}, \qquad p_{fjt}^* = \frac{1 - \frac{\sigma-1}{\sigma} s_{fjt}^*}{\frac{\sigma-1}{\sigma}(1 - s_{fjt}^*)} \frac{\tau_x w_{Ft}}{z_{fjt}},$$

where $s_{ijt} \equiv \frac{p_{ijt} y_{ijt}}{\sum_{i' \in \{h,\tilde{h},f\}} p_{i'jt} y_{i'jt}}$ are home market shares. Home operating profits are

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

Total operating profits in both markets are the sum of operating profits in home and foreign markets: $\Pi_{ijt} = \pi_{ijt} + \pi_{ijt}^*$.

Innovation, adoption, and step size All three firms can innovate and adopt technology from firms in another country to improve their productivity by $\lambda^{n_{ijt}}$. We let n_{ijt} denote the number of steps of improvement of firm i in sector j at time t, and λ is a unit step size in the economy. Therefore, we can express productivity as $\lambda^{N_{ijt}}$, where N_{ijt} denotes the cumulative number of steps that the firms have taken until time t, defined as $N_{ijt} \equiv \int_0^t n_{ijs} \mathrm{d}s$. Then, the productivity gap m_{ijt}^F between home firm i and foreign firm f in time t, measured in steps, can be written as

$$\frac{z_{ijt}}{z_{fjt}} = \frac{\lambda^{N_{ijt}}}{\lambda^{N_{fjt}}} = \lambda^{m_{ijt}^F}, \quad m_{ijt}^F \in \mathbb{Z}, \quad i \in \{h, \tilde{h}\}.$$

We express the gap between two domestic firms:

$$\frac{z_{ijt}}{z_{-i,jt}} = \frac{\lambda^{N_{ijt}}}{\lambda^{N_{-i,jt}}} = \lambda^{m_{ijt}^D}, \quad m_{ijt}^D \in \mathbb{Z}, \quad i \in \{h, \tilde{h}\}.$$

For a foreign firm, we define its gap relative to two domestic firms:

$$\frac{z_{fjt}}{z_{ijt}} = \frac{\lambda^{N_{fjt}}}{\lambda^{N_{ijt}}} = \lambda^{m_{fjt}^i}, \quad m_{fjt}^i \in \mathbb{Z} \quad i \in \{h, \tilde{h}\}$$

[4] As in Atkeson and Burstein (2008), we assume no interaction between home and foreign markets and do not allow dynamic collusion. In the equilibrium, there is no arbitrage opportunity since the price ratio between home and foreign goods is always less than the iceberg cost.

$m^F_{ijt} > 0$ and $m^D_{ijt} > 0$ imply that home firm i has higher productivity than a foreign firm and its domestic competitor, respectively. We assume that there is a sufficiently large and exogenously given limit in these productivity gaps, denoted as $\bar{m}$; that is, $\mathbf{m}_{ijt} \equiv \{m^F_{ijt}, m^D_{ijt}\} \in \{-\bar{m}, \ldots, \bar{m}\}^2$ and $\mathbf{m}_{fjt} \equiv \{m^h_{fjt}, m^{\tilde{h}}_{fjt}\} \in \{-\bar{m}, \ldots, \bar{m}\}^2$. Note that once we determine the value of $\mathbf{m}_{hjt}$, we can derive $\mathbf{m}_{\tilde{h}jt}$ and $\mathbf{m}_{fjt}$ simultaneously, and vice versa. As will become clear, given 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 subscript j and t when sector-specific values are denoted by productivity gaps.

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

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

We assume $\gamma_r > 1$, so the innovation cost function is convex. α_{cr} governs the scale of the innovation cost in country c. Similar to innovation, firms choose an adoption rate a_{ijt} at a cost of labor, given by

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

The adoption cost is in units of labor, which can be interpreted as researchers who investigate, learn, and implement a foreign technology. However, unlike innovation, an adopter pays a one-time adoption fee to foreign firms $\mathcal{F}_{ijt}$ in addition to adoption R&D costs in Equation (8). If either of firms does not agree on the contract's term, adoption does not happen and both have no change in their values. Adoption fee is determined through Nash bargaining between adopters and foreign sellers, which we discuss in detail below. To focus on foreign technology adoption, we assume domestic followers do not adopt technologies from leaders.[5]

Innovation rate x_{ijt} or adoption rate a_{ijt} implies that, with probability x_{ijt} or a_{ijt}, a firm improves its productivity by

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

where n_{ijt} is a stochastic variable that determines the number of steps of improvement. Innovation and adoption have different step-size distributions of n_{ijt}.

To maintain model simplicity and tractability, we parametrize the adoption and innovation step size distributions following the approach of Akcigit et al. (2021). First, we define the probability mass distribution $h_k(n', \bar{n})$, which is defined for positive integers n'. The distribution depends

[5]This assumption not only simplifies the model and its computation, but also is consistent with the fact that only small fractions of total adoption expenses were used for domestic transfers. For example, the estimated adoption expenses between domestic firms were only 6.3% of the total expenses (Lee, 2022). Also, in the model equilibrium with the calibrated values of the parameters, even if we allow adoption between the home firms, there is no room for them to trade technology between domestic firms, because the same wage and trade costs make the total surplus from the adoption contract negative.

on $\bar{n}$ which denotes the maximum value n' can take with a positive probability. For $k \in \{r, a\}$,

$$h_k(n', \bar{n}) = \begin{cases} c_k(\bar{n})(n' + \bar{m})^{-\eta_k}, & \text{if} \quad 1 \leq n' \leq \bar{n} \\ 0 & \text{if} \quad \bar{n} + 1 \leq n'. \end{cases} \tag{9}$$

Here, $c_k(\bar{n}) \equiv \sum_{n'=1}^{\bar{n}} (n'+\bar{m})^{-\eta_k}$ for given $\bar{n}$ is a normalizing constant ensuring that $\sum_{n'=1}^{\bar{n}} h_k(n', \bar{n}) = 1$.

Next, we define $f(n; m_i^F)$, which represents the step size distribution for innovation when a firm has a certain productivity gap m_i^F relative to foreign firms:

$$f(n; m_i^F) = \begin{cases} h_r(n + m^F, \bar{m} - m_{it}^F + 1) + \mathbb{A}_r(m_i^F) & \text{if} \quad n = 1 \\ h_r(n + m_i^F, \bar{m} - m_i^F + 1) & \text{if} \quad 2 \leq n \leq \bar{m} - m_i^F + 1 \\ 0 & \text{if} \quad \bar{m} - m_i^F + 2 \leq n. \end{cases}$$

In this equation, $\mathbb{A}_r(m_i^F)$ is defined as $\mathbb{A}_r(m_i^F) \equiv \sum_{n'=1}^{m_i^F + \bar{m}} h_r(n' + m_i^F, \bar{m} - m_i^F + 1)$, and $\bar{m} - m_i^F + 1$ is the maximum value that n can take with a positive probability, determined by the exogenously given limit of productivity gaps $\bar{m}$. Note that when a firm is at the most advanced position $\bar{m}$, the firm can only improve one step, and when a firm is at the most laggard position $-\bar{m}$, $f(n; -\bar{m}) = h_r(n, 2\bar{m} + 1)$. Note that these probability mass distributions are defined for each m_i^F, but they depend on a single parameter η_r due to their additive nature.

Similarly, for adoption, we define $g(n; m_i^F)$ as follows, where $m^F \in \{-\bar{m}, \ldots, 0\}$:

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

In this equation, $\mathbb{A}_a(m_i^F) \equiv \sum_{n'=1}^{\bar{m}+m_i^F} h_a(n' + m_i^F, -m_i^F)$. One important distinction between adoption and innovation is that $g(n; m_i^F)$ is defined only for cases where $m_i^F < 0$, indicating that home firm can only adopt technologies from foreign firms when they have lower productivity. Furthermore, the maximum step n can take with a positive probability is $-m_i^F$, reflecting the fact that home firm cannot surpass a foreign competitor from adoption alone. Therefore, if home firms already have higher productivity than foreign firms ($m_i^F > 0$), they will not engage in technology adoption. It's also noteworthy that adopters do not necessarily catch up with foreign firms after a single adoption.[6]

[6]This is a more flexible assumption compared to other models that incorporate technology adoption. If we set $g(1; m_i^F) = 1$, our model aligns with the case described in König et al. (2020), where adoption (imitation) results in only a single step of improvement, irrespective of the current productivity gap. If we assume $g(-m_i^F; m_i^F) = 1$, our model corresponds to the scenarios presented in Perla and Tonetti (2014) and Benhabib et al. (2021), where firms reach the same level of productivity as another firm after a single adoption. Additionally, if we were to set $g(0; m_i^F) = 1$, it would imply that the adoption fee is consistently higher when the initial productivity gap is smaller, which contradicts

For a foreign firm, the step size distributions can be similarly expressed as $f(n_{ft}; \min_{i\in\{h,\tilde{h}\}} \{m^i_{ft}\})$ and $g(n_{ft}; \min_{i\in\{h,\tilde{h}\}} \{m^i_{ft}\})$, where its step size distributions depend on its gaps with a home leader.

Because $\mathbb{A}_k(m^F_i)$ is added at $n = 1$, with higher m^F_i, firms become less likely to make drastic innovation and adoption and a probability of improving multiple steps becomes lower whereas a probability of improving one step becomes higher; i.e., the expected step size decreases with m^F_i, which captures the idea of the advantage of backwardness (Gerschenkron, 1962). The magnitude of these advantages is governed by the parameter η_k. With lower η_k, the magnitude becomes larger. For example, when $\eta_k \to \infty$, the model becomes a standard step-by-step model with only one step improvement and has no advantages of backwardness (e.g. Aghion et al., 2001). Panel A of Figure 3 illustrates the expected step size $\mathbb{E}[n; m^F_i]$ over m^F_i. The expected step size decreases with lower η_r, especially when the value of m^F_i is smaller.

Note that because $f(n; m^F_i)$ and $g(n; m^F_i)$ are governed by different parameters η_r and η_a, the magnitude of the advantages of backwardness from adoption and innovation can differ. Later, we calibrate η_r and η_a based on the first empirical fact in Section 3 and find $\eta_a < \eta_r$, which suggests adoption features stronger advantages of backwardness. In Panel B of Figure 3, we compare the conditional expected step sizes between adoption and innovation over m^F_i when $\eta_a < \eta_r$. Because $\eta_a < \eta_r$, even though the adoption step size distribution is truncated at $m^F = 0$, adoption features stronger advantages of backwardness.

To summarize, the three key differences between innovation and adoption are as follows. First, adoption cannot increase a firm's productivity beyond that of a foreign firm. Second, step size distributions of adoption and innovation can vary in terms of the magnitude of the advantages of backwardness associated with productivity gaps. Lastly, adopters have to pay adoption fees to foreign sellers in addition to the R&D costs.

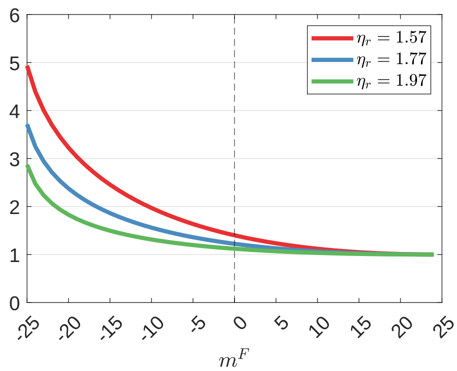
Knowledge spillovers We allow for two types of exogenous knowledge spillovers. The first is the spillovers between home leaders and followers, motivated by the empirical finding in Section 3.2. We assume that a home follower can receive knowledge spillovers from a home leader. With a probability δ, the home follower can build on the home leader's technology when innovating or adopting.[7]

The second type is the exogenous productivity spillovers across countries. With probability ϕ, all firms across countries gain access to frontier technology without costs. ϕ accounts for unobserved spillovers that occur outside of official adoption contracts, such as through activities like espionage or reverse engineering. Also, when $\phi > 0$, it ensures the existence of a non-degenerate stationary distribution of the productivity gap, a common feature among step-by-step innovation models (e.g., Aghion et al., 2001).[8]

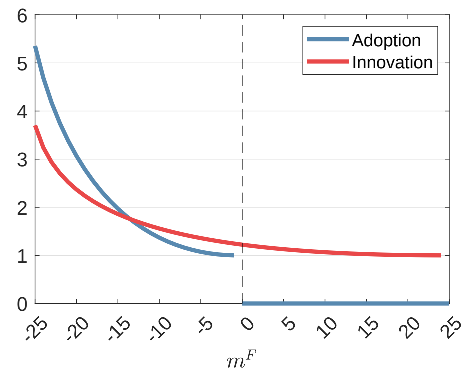
the pattern observed in the data. Therefore, our more flexible specification of the adoption step size distribution better matches the observed empirical patterns.

[7]If $\delta = 1$, the follower can always build on the incumbent's technology, the common assumption in the quality ladder model literature (e.g., Aghion and Howitt, 1992; Akcigit et al., 2021).

[8]$\phi > 0$ guarantees the presence of a non-degenerate stationary distribution. If $\phi = 0$ and $\eta_r, \eta_a \to \infty$, the leader's



A. Innovation, different values of η_r



B. Adoption vs. Innovation

Figure 3: Expected Step Size over the Initial Productivity Gap with Foreign Firms

Notes. Panel A compares the expected size from innovation over different values of η_r. Panel B compares the expected step size from innovation and adoption on the Y-axis and the initial productivity gap with the foreign firm on the X-axis over the different values. A negative m_F denotes a domestic firm has lower productivity than a foreign firm. We set η_a and η_r to 1.20 and 1.77, respectively, which are estimated values based on the firm-level data in Section 5.

Potential entrants In country F, there is a potential entrant $\tilde{f}$ that can innovate on the top of the incumbent's technology.[9] When an entrant innovates in country F, it replaces the incumbent and the incumbent exits. For simplicity, we do not allow potential entrants to adopt the technology. The innovation cost of the entrant is the same as the innovation cost of the incumbent (Equation (7)). With probability $\tilde{x}_{ijt}$ the potential entrant improves on top of the incumbent's productivity with the same innovation step size distribution $f(n_{ft}; \min_{i \in \{h,\tilde{h}\}} \{m^i_{ft}\})$.

Government policy The home government subsidizes κ_{Hrt} fraction of home firms' adoption costs and subsidizes κ_{Hrt} fraction of the innovation costs. The costs of both subsidies are financed by the lump-sum tax from the household.

4.4 Equilibrium

In this section, we define a Markov perfect equilibrium in which strategies of the firms depend only on the payoff relevant state variable $\mathbf{m}$.

Value function We define the state variable for a home firm i as $\mathbf{m}_i \equiv \{m^F_i, m^D_i\}$, $i \in \{h, \tilde{h}\}$ and for foreign firm f as $\mathbf{m}_f \equiv \{m^h_f, m^{\tilde{h}}_f\}$, where m^i_f represents the productivity gap between

productivity would be always higher than the follower as there are not enough reflective forces. This will result in the stationary distribution where every firm in one country has the maximum gap while every firm in another country has the minimum gap.

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

foreign firm f and domestic firm i.[10] The step size distributions for domestic firms given $\mathbf{m}_i$ can be expressed as follows:

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

The first and second terms of the right hand side reflect the cases in which a firm is a leader and a follower, respectively, as indicated by the indicator functions $\mathbb{1}[m_i^D > 0]$ and $\mathbb{1}[m_i^D \leq 0]$, which determines whether firm i is a leader or a follower (including the neck-and-neck case). In the second term, due to the domestic spillovers, the step size distribution becomes a mixture of $f(n;m_i^F)$ and $f(n+m_i^D;m_i^F-m_i^D)$, which is the distribution shifted by $-m_i^D$ from $f(n;m_i^F-m_i^D)$.

The value function of domestic firm $i \in \{h,\tilde{h}\}$ can be expressed as follows:

$$\begin{aligned}
&r_{Ht}V_{it}(\mathbf{m}_i) - \dot{V}_{it}(\mathbf{m}_i)\\
&= \max_{x_{it}(\mathbf{m}_i),a_{it}(\mathbf{m}_i)} \Bigg\{ \underbrace{\Pi_{Ht}(\mathbf{m}_i)}_{\text{Profit}} - \underbrace{(1-\kappa_{Hrt})\alpha_{Hr}\frac{x_{it}(\mathbf{m}_i)^{\gamma_r}}{\gamma_r}w_{Ht}}_{\text{Innovation R\&D cost}} - \underbrace{(1-\kappa_{Hat})\alpha_{Ha}\frac{a_{it}(\mathbf{m}_i)^{\gamma_a}}{\gamma_a}w_{Ht}}_{\text{Adoption R\&D cost}}\\
&+ x_{it}(\mathbf{m}_i)\sum_n \tilde{f}(n;\mathbf{m}_i)\underbrace{\big[V_{it}(m_i^F+n, m_i^D+n) - V_{it}(\mathbf{m}_i)\big]}_{\text{Gain from innovation}}\\
&+ a_{it}(\mathbf{m}_i)\Big[\sum_n \tilde{g}(n;\mathbf{m}_i)\underbrace{\big[V_{it}(m_i^F+n, m_i^D+n) - V_{it}(\mathbf{m}_i)\big]}_{\text{Gain from adoption}} - \underbrace{(1-\kappa_{Hrt})\mathcal{F}_{it}(\mathbf{m}_i)}_{\text{Adoption fee payment}}\Big]\\
&+ x_{-it}(\mathbf{m}_{-i})\sum_n \tilde{f}(n;\mathbf{m}_{-i})\underbrace{\big[V_{it}(m_i^F, m_i^D-n) - V_{it}(\mathbf{m}_i)\big]}_{\text{Loss from home competitor innovation}}\\
&+ a_{-it}(\mathbf{m}_{-i})\sum_n \tilde{g}(n;\mathbf{m}_{-i})\underbrace{\big[V_{it}(m_i^F, m_i^D-n) - V_{it}(\mathbf{m}_i)\big]}_{\text{Loss from home competitor adoption}}\\
&+ \big(x_{ft}(\mathbf{m}_f) + \tilde{x}_{ft}(\mathbf{m}_f)\big)\sum_n f(n;\min_{i\in\{h,\tilde{h}\}}\{m_{ft}^i\})\underbrace{\big[V_{it}(m_i^F-n, m_i^D) - V_{it}(\mathbf{m}_i)\big]}_{\text{Loss from foreign innovation}}\\
&+ a_{ft}(\mathbf{m}_f)\Big[\sum_n g(n;\min_{i\in\{h,\tilde{h}\}}\{m_{ft}^i\})\underbrace{\big[V_{it}(m_i^F-n, m_i^D) - V_{it}(\mathbf{m}_i)\big]}_{\text{Loss from foreign adoption}} + \underbrace{\mathbb{1}[m_i^D \geq 0]\times\mathcal{F}_{ft}(\mathbf{m}_f)}_{\text{Adoption fee receipt}}\Big]\\
&+ \phi\underbrace{\big[V_{it}(0,0) - V_{it}(\mathbf{m}_i)\big]}_{\text{Exogenous spillover}}\Bigg\}.
\end{aligned} \tag{10}$$

Firm i chooses the optimal innovation rate $x_{it}(\mathbf{m}_i)$ and the adoption rate $a_{it}(\mathbf{m}_i)$ to maximize its discounted sum of profits. The second line includes operating profits and innovation and adoption costs net of the subsidy rates. The next two lines capture the value increases from innovation and

[10] For example, if productivities of h, $\tilde{h}$, and f are λ^3, λ^2, and λ^1, respectively, then the state variables for firms h, $\tilde{h}$, and f are $\{2, 1\}$, $\{1, -1\}$, and $\{-2, -1\}$, respectively.

adoption, where the step size n follows the distributions $\tilde{f}(n;\mathbf{m}_i)$ and $\tilde{g}(n;\mathbf{m}_i)$, respectively. The adoption fee $\mathcal{F}_{it}(\mathbf{m}_i)$ is an endogenous variable that we discuss later. The next two lines represent the value decrease from innovation and adoption by the domestic competitor, where $x_{-it}(\mathbf{m}_{-i})$ and $a_{-it}(\mathbf{m}_{-i})$ denote the innovation and adoption rates of the domestic competitor, respectively. As the domestic competitor improves productivity as n steps, it decreases the value of firm i by reducing m_i^D. The following two lines denote the value decrease from foreign firms' (incumbent and entrant) innovation and adoption. A n-step improvement in a foreign firm's productivity decreases firm i's value by reducing m_i^F. The last line has the exogenous spillover, which is governed by the parameter ϕ. The value functions of foreign incumbents and entrants are expressed in Appendix C.1.

Knowledge spillovers between domestic firms generate intertemporal spillovers from both innovation and adoption; that is, a leader's innovation or adoption increases a domestic follower's future productivity. However, because these knowledge spillovers hurt a leader's future profits, and a leader takes that into account, a higher δ reduces a leader's innovation and adoption rates.

The magnitude of the domestic spillovers is proportional to the expected productivity gains times δ. Because the expected productivity gains from adoption and innovation depend on the gaps, the intertemporal spillovers from adoption and innovation also depend on these gaps. For example, if productivity gains from adoption are larger than those from innovation due to the advantages of backwardness, the spillovers from adoption are also larger than those from innovation.

Optimal innovation and adoption rate From the value function equations and the first order conditions, the optimal innovation rate of home firm $i \in \{h, \tilde{h}\}$ can be expressed as

$$x_{ijt} = x_{it}(\mathbf{m}_i) = \left(\frac{\sum_n \tilde{f}(n;\mathbf{m}_i) \left[V_{it}(m_i^F + n, m_i^D + n) - V_{it}(\mathbf{m}_i) \right]}{(1-\kappa_{Hrt})\alpha_{Hr} w_{Ht}} \right)^{\frac{1}{\gamma_r - 1}} . \tag{11}$$

Likewise, the optimal adoption rate of home firm $i \in \{h, \tilde{h}\}$ is as follows: for $m_i^F > 0$,

$$a_{ijt} = a_{it}(\mathbf{m}_i) = \left(\frac{\sum_n \tilde{g}(n;\mathbf{m}_i)[V_{it}(m_i^F + n, m_i^D + n) - V_{it}(\mathbf{m}_i)] - (1-\kappa_{Hat})\mathcal{F}_{it}(\mathbf{m}_i)}{(1-\kappa_{Hat})\alpha_{Ha} w_{Ht}} \right)^{\frac{1}{\gamma_a - 1}} . \tag{12}$$

The optimal innovation and adoption rates of foreign firms are derived in in Appendix C.3.

Adoption fee The adoption fee is jointly determined with the value functions of domestic and foreign firms based on Nash bargaining. It is a one-time payment that internalizes all adopter's future gains and seller's loss. Bargaining only happens between adopters and sellers, and we assume they cannot make the contract contingent on future behavior.[11] Also, we do not allow

[11]For example, we do not allow the foreign firm to prohibit the adopter from exporting to the foreign country, which is very rare in the data in which only 1.3% of the contracts restrict the adopter's future exports.

foreign firms to promise not to sell the technology to another domestic firm. This assumption can be micro-founded if we assume that the foreign firm cannot commit to its future behavior. Lastly, we do not allow one foreign firm to bargain with two domestic firms simultaneously.

The adoption fee is determined by Nash bargaining as follows:

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

where $0 \leq \xi \leq 1$ is the bargaining power of adopters. $\sum_n \tilde{g}(n;\mathbf{m}_i)V_{it}(m_{Fh}+n, m_{Dh}+n)$ is the expected new value of firm i after the adoption. The net value from adoption is the new value minus the price $\mathcal{F}_{it}(\mathbf{m}_i)$, and the home leader's outside option is the current value $V_{it}(\mathbf{m}_i)$. Likewise, the expected loss of sellers is $\sum_n \tilde{g}(n;\mathbf{m}_i)\big[V_{ft}(m_f^i - n, m_f^{(-i)})$ because of competition in both home and foreign markets, but they receive an adoption fee $\mathcal{F}_{it}(\mathbf{m}_i)$. Their outside option is the current value $V_{ft}(\mathbf{m}_f)$. Solving the above equation, we obtain that

$$\begin{aligned}\mathcal{F}_{it}(\mathbf{m}_i) = (1-\xi)\Big(&\sum_n \tilde{g}(n;\mathbf{m}_i)\big[V_{it}(m_i^F+n, m_i^D+n) - V_{it}(\mathbf{m}_i)\big] \\ &- \xi\Big(\sum_n \tilde{g}(n;\mathbf{m}_i)\big[V_{ft}(m_f^i - n, m_f^{(-i)}) - V_{ft}(\mathbf{m}_f)\big].\end{aligned} \tag{13}$$

The adoption fee paid by foreign firm to domestic leaders is expressed in Appendix C.2.

Adoption fees are higher if foreign firm lose more or if domestic firms gain more, which depends on two forces: the advantage of backwardness and the competition effect. The advantage of backwardness makes the price higher when the productivity gap is large. The productivity gain from adoption is larger when the initial productivity gap is larger. This means domestic firms gains more from adoption, and foreign firms loses more, which increases the adoption fee. On the other hand, the competition effect makes the price lower when the productivity gap is large. The increased profit from productivity improvement is small when the initial gap is large. Figure 4 shows an example of the profit function over the technology gap from a foreign firm, fixing other gaps. The slope of the profit function is small when the absolute value of m_i^F is large. The slope of the profit function increases as the absolute value of m_i^F converges to zero. This is because as the relative productivity matters more when two firms have similar productivity. Therefore, the $\mathcal{F}_{it}(\mathbf{m}_i)$ can either increase or decrease with m_i^F in our model. Our empirical results in Section 3.1 suggest that the competition effect is stronger than the advantage of backwardness.

Note that if the total surplus from the contract is negative, then the adoption contract does not happen. Several circumstances increase the total surplus, making room for technology trade. First, when the wage in the home country is lower, the foreign firm's technology can make more output in the home country and generate a positive total surplus. Second, when the trade cost is high, the two markets are more segmented, and it is more profitable to produce in the home

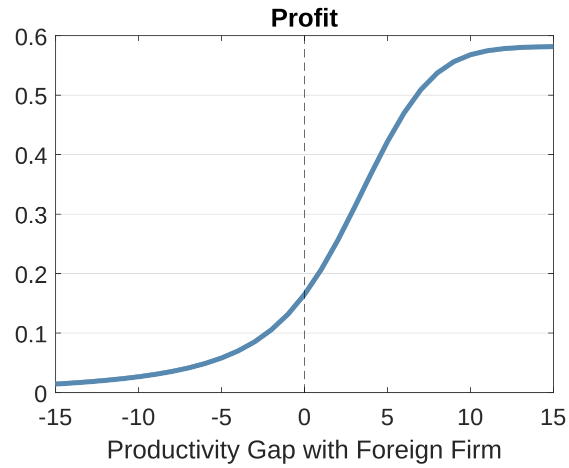


Figure 4: Profit Function over Productivity Gap with Foreign Firms

Notes. This figure plots the profits of a home firm on the Y-axis and productivity gap with a foreign firm on the X-axis in the model. We assume a constant gap between domestic firms, set at zero. We apply the following parameter values: $\sigma = 8, \tau_x = 1.2, \lambda = 1.1$.

country and sell to the household in the home country. Thus, selling technology can increase the total revenue, which increases the surplus from the adoption contract.[12] Third, firms in different countries produce imperfect substitutes. Therefore, when the elasticity of substitution is smaller, producing all varieties with good technology is valuable. Lastly, when the foreign firm sells technology, the potential entrant loses its future profit, but the foreign firm does not internalize this loss.

Distribution of the productivity gap We present the law of motions that summarizes the endogenous evolution of the gap distribution. We define $\mathbb{T}_i(n; \mathbf{m}_i)$ and $\mathbb{T}_f(n; \mathbf{m}_f)$ as the probability that home firm $i \in \{h, \tilde{h}\}$ and foreign firm f improves productivity n steps conditional on $\mathbf{m}_i$ and $\mathbf{m}_f$, respectively, as follows:

$$\mathbb{T}_i(n; \mathbf{m}_i) = \tilde{f}(n; \mathbf{m}_i)x_{it}(\mathbf{m}_i) + \tilde{g}(n; \mathbf{m}_i)a_{it}(\mathbf{m}_i),$$
$$\mathbb{T}_f(n; \mathbf{m}_f) = f(n_{ft}; \min_{i \in \{h,\tilde{h}\}} \{m^i_{ft}\})(x_{ft}(\mathbf{m}_f) + \tilde{x}_{ft}(\mathbf{m}_f)) + g(n_{ft}; \min_{i \in \{h,\tilde{h}\}} \{m^i_{ft}\})a_{ft}(\mathbf{m}_f).$$

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

Let $\mu_{\mathbf{m}t}$ denote shares of sectors with $\mathbf{m}_h = \mathbf{m}$ at time t. Law of motion for $\mu_t(\mathbf{m})$ is

$$
\begin{aligned}
\dot{\mu}_t(\mathbf{m}) = & \underbrace{\sum_{n=1}^{m_h^F+\bar{m}} \mathbb{T}_h(n; m_h^F - n, m_h^D - n)\mu_t(m_h^F - n, m_h^D - n)}_{\text{Innovation/adoption by firm } h} \\
& + \underbrace{\sum_{n=1}^{m_{\tilde{h}}^D+\bar{m}} \mathbb{T}_{\tilde{h}}(n; m_{\tilde{h}}^F, m_{\tilde{h}}^D - n)\mu_t(m_h^F, m_h^D + n)}_{\text{Innovation/adoption by firm } \tilde{h}} \\
& + \sum_{n=1}^{m_f^h+\bar{m}} \underbrace{\mathbb{T}_f(n; m_{ft}^h - n, m_{ft}^{\tilde{h}} - n)\mu_t(m_h^F + n, m_h^D)}_{\text{Innovation/adoption by firm } f} + \underbrace{\phi \mathbb{1}[\mathbf{m}_h = \mathbf{0}]}_{\text{Exogenous spillover}} \\
& - \underbrace{\left(x_{ht}(\mathbf{m}_h) + a_{ht}(\mathbf{m}_h) + x_{\tilde{h}t}(\mathbf{m}_{\tilde{h}}) + a_{\tilde{h}t}(\mathbf{m}_{\tilde{h}}) + x_{ft}(\mathbf{m}_f) + \tilde{x}_{ft}(\mathbf{m}_f) + \phi\right)\mu_t(\mathbf{m})}_{\text{subtracted mass}},
\end{aligned}
\tag{14}
$$

where the first line of the right hand side captures the added mass from firm h's innovation and adoption; the second line from innovation and adoption of firm $\tilde{h}$; and the third line from foreign incumbents and entrants and from the exogenous cross-country spillovers. The last line captures the subtracted mass from innovation and adoption, the exogenous cross-country spillovers. Along the balanced growth path, $\dot{\mu}_t(\mathbf{m}) = 0$ for all $\mathbf{m}$.

Market clearing Asset markets clear in each period: $A_{ct} = \int_0^1 \sum_{i'(c)} V_{i'jt} \mathrm{d}j$, where the right-hand side is the sum of the value of all firms in country c. $\mathcal{I}_c$ is set of firm i in country c. Goods markets clear according to

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

Labor market clearing implies that

$$
L_{ct} = \int_0^1 \sum_{i \in \mathcal{I}_c} \left(l_{ijt} + \alpha_{ca} \frac{a_{ijt}^{\gamma_a}}{\gamma_a} + \alpha_{cr} \frac{x_{ijt}^{\gamma_r}}{\gamma_r} \right) \mathrm{d}j.
$$

The left-hand side is the supply of labor, which is fixed over time, and the right-hand side is the demand for labor. The first term is labor demand from production, the second is from innovation, and the third term is from adoption. The government holds a balanced budget in each period:

$$
T_{Ht} = (1 + \theta) \int_0^1 \sum_{i \in \mathcal{I}_c} \left(\kappa_{Hat} a_{ijt} \mathcal{F}_{ijt} + \kappa_{Hat} \alpha_{Ha} \frac{a_{ijt}^{\gamma_a}}{\gamma_a} w_{Ht} + \kappa_{Hrt} \alpha_{Hr} \frac{x_{ijt}^{\gamma_r}}{\gamma_r} w_{Ht} \right) \mathrm{d}j \,,
$$

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

$T_{Ft} = 0$.

Trade is balanced between two countries in every period:

$$\int_0^1 \Big[p^*_{fjt}y^*_{fjt} + \sum_{i\in\{h,\tilde{h}\}} a_{ijt}\mathcal{F}_{ijt}\Big]\mathrm{d}j = \int_0^1 \Big[\sum_{i\in\{h,\tilde{h}\}} p^*_{ijt}y^*_{ijt} + a_{fjt}\mathcal{F}_{Fjt}\Big]\mathrm{d}j,$$

where the left and the right hand sides are the sum of imports and adoption fee expenses, and the sum of exports and adoption fee revenues, respectively.

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

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

- (Static equilibrium) A representative households maximize the sum of discounted utility subject to the budget constraint; Firms maximize profits; and 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 (11) and (12)); $\mathcal{F}_{ijt}$ solves Nash Bargaining between the buyer and seller (Equation (13)); and Given $\{\mu_{\mathbf{m}0}\}$, $\{\mu_{\mathbf{m}t}\}_{t\in[0,\infty)}$ is consistent with x_{ijt} and a_{ijt} by Equation (14).

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 $w_{ct}, V_{ijt}, \mathcal{F}_{ijt}, T_{ct}, C_{ct}$, and A_{ct} grow at a rate g, and r_{ct} and $\mu_{\mathbf{m}t}$ being constant over time.

4.5 Taking Stock

Gains and Costs from Adoption over Productivity Gaps The key feature of the model is that gains and costs from adoption and innovation depend on the productivity gap. The expected productivity gains from adoption and innovation are higher when there is a more significant productivity gap due to the advantages of backwardness. These advantages are governed by the parameters η_a and η_r, respectively. Our calibration, based on the firm-level data and the first fact documented in Section 3 (detailed in the next section), confirms that adoption indeed has stronger advantages of backwardness than innovation.

The costs of adoption also depend on the productivity gap because the price of technology is endogenously determined by Nash bargaining. The sign of the relationship between costs of adoption and productivity gaps is ambiguous. If the advantage of backwardness outweigh the competition effect in the global market, costs become lower as the productivity gap narrows. Conversely, if the competition effect predominates, the price increases, which is the pattern we find from our data. Later, we show that our calibrated model reproduces this pattern consistent with this fact.

Market Failures Several market failures in this model prevent the competitive equilibrium from being efficient. The first is positive externalities due to knowledge spillovers within and across countries, which lead to underinvestment in innovation and adoption. Second, innovation and adoption have business-stealing effects. Incentives for innovation and adoption include improving productivity and stealing the market share of other firms, whereas from the perspective of the social planner, only aggregate productivity and output matter. Firms may improve technology only marginally while overinvesting in resources on adoption or innovation. Note that when the elasticity of substitution is larger, these business stealing effects become stronger. Lastly, the oligopolistic power of firms leads them to produce less than the socially optimal level.

5 Taking the Model to the Data

In this section, we describe calibration procedure of our model. We estimate the model by matching model moments with the data counterparts through indirect inference. Our estimated model can match both targeted and untargeted moments well.

5.1 Estimation

Parametrization Before estimating the model, we impose more structure. We set the maximum technology gap between foreign incumbents and home incumbents, as well as between home incumbents and followers, to 25 and 5, respectively, for computational simplicity. We obtained these numbers by incrementally increasing the maximum gap until it no longer significantly affects the key results.

We assume that the initial productivity gap from between Korean and foreign firms follows a normal distribution with a mean of d and a standard deviation of 1, $\mathcal{N}(d, 1)$, across sectors $j \in [0, 1]$. When $d < 0$, it indicates that Korean firms' productivity levels lag behind those of foreign firms, with a greater magnitude implying a more significant lag.

Finally, we assume that foreign adoption and innovation costs are proportional to those of home firms, denoted by α_F. Specifically, $\alpha_{Fr} = \alpha_F \times \alpha_{Hr}$ and $\alpha_{Fa} = \alpha_F \times \alpha_{Ha}$.

Estimation strategy We estimate 22 parameters in three steps. 4 parameters are determined directly from the data. 8 parameters are externally calibrated. We jointly estimate the remaining 10 parameters by simulated method of moments (SMM). Given a guess of parameters, we solve the transition of the model with the initial conditions until it converges to the balanced growth path. Along the transition, we compute model moments based on the guess, and then update the guess to minimize the distance between the moments from the model and the data counterparts. We provide the computational algorithm for solving the transition in Appendix D.2.

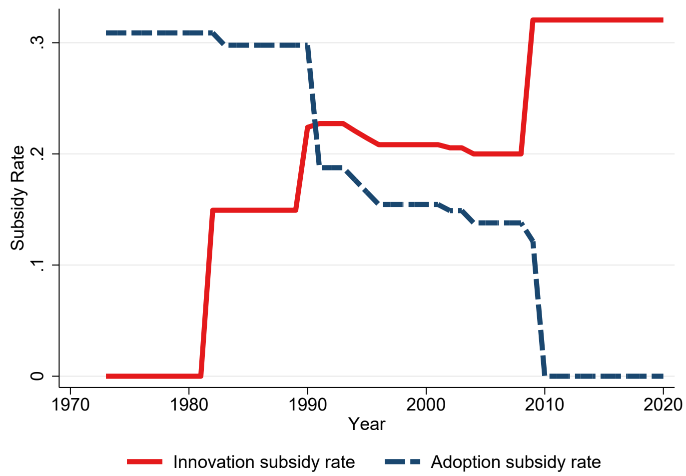


Figure 5: Innovation and Adoption Subsidy Rate in Korea

Notes. This figure plots the calculated adoption subsidy rate in the dashed navy line and the innovation (R&D) subsidy rate in the solid red line in Korea over time.

5.1.1 Parameters that Directly Match the Data

The four parameters $\{L_H, L_F, \kappa_{Hat}, \kappa_{Hrt}\}$ are obtained directly from the data. We set the home country's labor supply $L_H = 1$ as a normalization and $L_F = 2$ to match Japan's relative population size. We calculate the subsidy rates κ_{Hat} and κ_{Hrt} from the tax credit data and incorporate them into the model while assuming perfect foresight of the agents. For country F, we set $\kappa_{Fat} = 0$ and $\kappa_{Frt} = 0$. Figure 5 displays the calculated innovation and adoption subsidy rates over time.

The Korean government has provided tax credits for adoption expenses since 1973. For the first five years of the adoption contract, firms received a full tax credit covering the fixed fee and royalty payments, and for the subsequent three years, they received half of the tax credit. However, in 1981, the policy changed, and firms were eligible for tax credits for only five years. By 1991, the policy further restricted the tax credit to cover only advanced technology adoptions. In the dataset, we observe that 42% of adoption contracts have received the tax credit since 1991, and we interpret this as firms benefiting from a 42% tax credit on adoption costs. Notably, in 2010, the government discontinued providing tax credits for adoption costs. To compute the adoption subsidy rate over time, we employ the corporate tax and formula outlined in Bloom et al. (2002).

The government also subsidized innovation through R&D tax credits. This initiative commenced in 1981 with a tax credit rate of 10%. Subsequently, in 1990, the tax credit rate was raised to 15%, and in 2009, it was further increased to 25%. We once again calculate the rate using the formula detailed in Bloom et al. (2002), with the tax credit rates sourced from Choe and Lee (2012).

5.1.2 External Calibration

The 8 parameters $\{\rho, \psi_H, \psi_F, \gamma_r, \gamma_a, \sigma, \tau_x, \theta\}$, are externally calibrated. We use a discount rate of $\rho = 0.03$, a commonly used value in the literature. To achieve symmetry between the two countries, we impose $\psi_H = 0.25$, $\psi_F = 0.5$, as the home country has two incumbents while the foreign country has only one. The curvature parameters for R&D and adoption costs, γ_r and γ_a, are both set to 2 to match the elasticity of successful innovation with respect to R&D, as indicated in Blundell et al. (2002).[13] Because we lack precise estimates for adoption costs, we assume the same curvature parameter for both adoption and innovation. We choose $\sigma = 7$ to align with the average value found in Broda and Weinstein (2006) for SITC 5-digit level categories. The iceberg trade cost parameter τ_x ist set to 1.5, following the estimates of trade costs between the US and Canada in Anderson and Van Wincoop (2004). We use $\theta = 1$ as a baseline value following Feldstein (1999), which implies that the government needs to collect 2 units of tax revenue to finance one unit of expenditure.

5.1.3 Simulated Method of Moments

The remaining 10 parameters $\mathbf{\Theta} = \{\lambda, \alpha_r, \alpha_a, \alpha_F, \eta_a, \eta_r, \xi, \delta, d, \phi\}$ are estimated to target 10 empirical moments. We choose Θ to minimize the distance between empirical moments M_i^D and moments from model $M_i(\mathbf{\Theta})$ as follows,

$$\min_{\mathbf{\Theta}} \sum_{i=1}^{10} \left(\frac{M_i^D - M_i(\mathbf{\Theta})}{\frac{1}{2}(M_i^D + M_i(\mathbf{\Theta}))} \right)^2 . \tag{15}$$

We document ten empirical moments and then discuss the relevant parameters that we identify based on these moments.

Ratio of adoption fee to yearly sales We calculate the total adoption fee as the sum of royal rate times sales and fixed fees. Using this calculated total adoption fee, we obtain ratio of the total adoption fee to yearly sales in adoption contracts averages at 22.4%. Additionally, we calculate the adoption fee over annualized sales within the model and compare both moments. This comparison helps determine ξ, which governs the bargaining power of adopters.

Productivity gain from adoption and innovation over the initial gap We run the regression in Equation (1) using the model-simulated data, and compare the coefficients from Table 3. We simulate 1,000,000 firms. The key parameters identified by these moments are η_r and η_a, which govern the magnitude of the advantages of backwardness of adoption and innovation (Figure 3).

Patent citation increase after adoption We calibrate δ, a parameter that governs knowledge spillovers between domestic firms, to match the average increase of the probability of being cited

[13] For further discussion, see Akcigit et al. (2021).

when compared with the control group within 5 years from the first technology adoption (Figure 2). The average effect is 0.026, which is obtained by running simpler diff-in-diff regression model.[14] To map the model to the data object, we develop a simple model of patent citation. In this model, a home follower can receive knowledge spillovers from adopted technologies but must cite a foreign firm's patents when innovating based on knowledge diffused from adopted technologies. The increased citation from a domestic follower to the foreign firm is represented as $x \times \delta$, where x is the innovation rate, and δ is the probability of experiencing knowledge spillovers. We calibrate δ to match the average effect of 0.026.

Long-run growth rate We calibrate λ, representing the unit productivity growth resulting from innovation and adoption, to match Japan's growth rate has been 1.6% since 2010. The long-term GDP growth rate is related to the level of λ, and we consider Japan's long-run growth rate along the balanced growth path.

R&D and adoption expenditure as a share of manufacturing value added We calibrate α_a and α_r to match R&D and adoption expenditure as a share of manufacturing value added between 1985–1990.[15] The R&D and adoption expenditure shares are 2.97% and 1.48%, respectively. These moments are informative on the scale parameters of innovation and adoption costs, α_r and α_a. From Equations (11) and (12), we can calculate the innovation and adoption expenditure, which decreases with α_r and α_a, respectively.

GDP per capita ratio between Korea and Japan in 1973 and 2020 In 1973, the initial GDP per capita ratio between Korea and Japan was 0.21, which is informative on the parameter d related to the average initial productivity gap between the two countries. By 2020, this GDP ratio had risen to 0.981, informing us about the exogenous spillover parameter ϕ, because higher ϕ implies faster convergence and a smaller GDP ratio in 2020.

Productivity gap in the long run Because in our model, 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. To ensure symmetry in productivity levels along the balanced growth path, we adjust α_F and target a zero long-run productivity gap–a higher α_F results in higher innovation and adoption costs in Japan and lower long-run productivity.

Table 5: Estimation Results

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

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

5.2 Estimation Results

Tables 5 reports the estimation results. Our estimate for λ is 1.047, which implies one step improvement increases labor productivity by 4.7%. $\eta_r > \eta_a$ implies that the advantages of backwardness are larger for adoption than innovation, as the panel B of Figure 3 shows. This is consistent with our empirical finding in Figure 1. We find that $\alpha_a < \alpha_r$, signifying lower labor requirements for adoption. The bargaining power parameter for the adopting firm, ξ, is 0.464, which implies that the adopter receives about 46% of the total surplus generated from adoption. The probability of receiving knowledge spillovers, δ, is 0.231. The initial productivity gap d stands at -23.672, indicating Japanese firms were initially 2.97 times more productive than Korean firms. Relative innovation and adoption costs of Japan is estimated to be $\alpha_F = 5.702$, revealing Japan's higher adoption and innovation costs. The probability of exogenous spillover, ϕ, is estimated at 0.025.

Tables 6 reports the estimation results and the target moments from the data and the model.

[14] We calculate this average effect by running the following regression model: $\mathbb{1}[\text{Citation}_{fmt}] = \beta \mathbb{1}[\text{Treated}_{fmt}] \times \mathbb{1}[\text{Adopt}_{mt}] + \delta_{mt} + \delta_{fm} + \epsilon_{fmt}$. The estimated β is 0.026. Appendix Table B.2 reports the results.

[15] We use the value in 1985–1990 due to the data availability. R&D expenses in manufacturing are from Ministry of Science and Technology (1990), adoption expenses from Korea Industrial Technology Association (1995), and manufacturing value-added from the Input-Output tables provided by the Bank of Korea.

Table 6: Target Moments in Model and Data

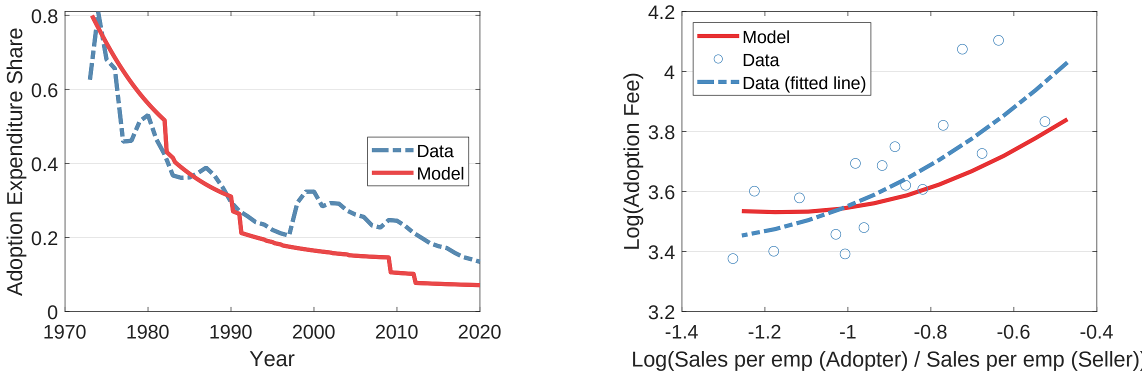
Moment	Model	Data
Adoption fee / annual sale	0.221	0.224
β^a : productivity growth and initial gap (adoption)	-0.116	-0.120
β^i : productivity growth and initial gap (innovation)	-0.044	-0.046
β^s : Δ Patent citation after adoption	0.026	0.028
Long-run growth rate	0.017	0.016
Adoption / value added in manufacturing	0.016	0.015
R&D / value added in manufacturing	0.032	0.030
GDP ratio in 1973	0.210	0.210
GDP ratio in 2020	0.983	0.981
Long-run productivity gap	0.001	0.000

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

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

5.3 Validation

To validate the model, we present two untargeted moments. In Panel A of Figure 6, we illustrate the evolution of shares of adoption expenditure relative to the sum of adoption expenditures and R&D expenditures over time in both the model and the data. Although we only target the average value of the ratios between adoption and R&D, and value-added during 1985–1990, we can match the declining trend in the adoption expenditure share. It is worth noting that this decreasing trend in the adoption expenditure share is not solely a result of the policy and 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 come closer to foreign firms in terms of technology advancement. In the right panel, we present log adoption fees plotted against the log ratio of sales per employment between domestic and foreign firms, based on both model outcomes and empirical data. This untargeted moment reflects the model's dynamics. wherein foreign firms charge higher adoption fees due to heightened competition as productivity gaps between Korean and foreign firms narrow.



A. Adoption Expenditure Share

B. Adoption Fee over Gap

Figure 6: 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 shown by the dashed blue line. Panel B displays the log of the adoption fee over the log ratio of sales per employment between domestic and foreign firms in the model (solid red line), accompanied by the data represented by dashed blue lines and circles.

6 Quantitative Results

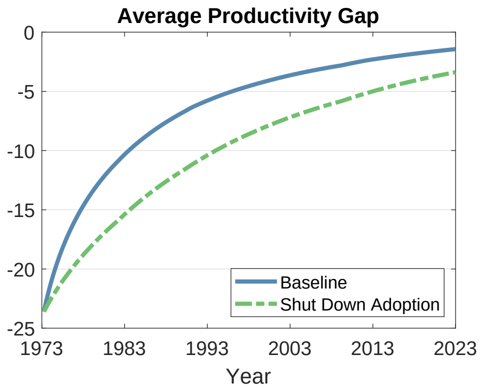
6.1 Contribution of Adoption and Innovation to Growth over Time

We study contribution of adoption to TFP growth by shutting down the adoption channel by increasing the adoption costs to infinity. The left panel of Figure 7 shows the average productivity gap over time in the baseline economy and in the counterfactual economy in which we shut down the adoption channel while we keep the innovation subsidy as in the data. Convergence is much slower without adoption, especially in the early years, because of the stronger advantages of backwardness from adoption when compared to those of innovation. The right panel compares the evolution of log GDP over time in the baseline and counterfactual economies. Korea experiences a substantial loss of GDP without the adoption channel, the GDP growth rate being much lower in the early periods. In particular, GDP in 2023 and welfare in the infinite horizon would have been 13.3% and 11.77% lower, respectively.

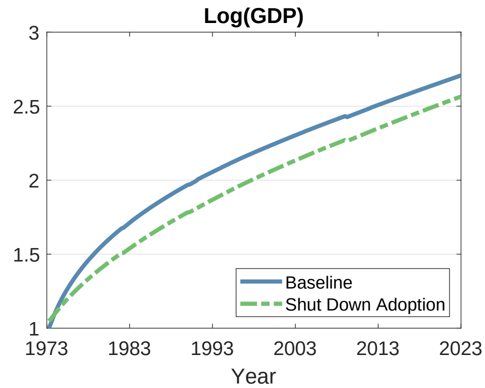
Next, we decompose TFP growth between adoption and innovation over time. We define TFP in country H as the weighted average labor productivity:

$$\text{TFP}_{Ht} = \frac{\left(\int_0^1 \left(l_{hjt} z_{hjt} + l_{\tilde{h}jt} z_{\tilde{h}jt}\right) \mathrm{d}j\right)}{\int_0^1 \left(l_{hjt} + l_{\tilde{h}jt}\right) \mathrm{d}j}. \tag{16}$$

We then calculate contribution of adoption to TFP growth by shutting down innovation and exogenous spillover ϕ while keeping the adoption channel. Likewise, we compute the TFP growth



A. Average Productivity Gap



B. Log GDP

Figure 7: Baseline and Counterfactual without Adoption

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

rates from innovation. Figure 8 plots the TFP Growth from adoption as a share of the sum of TFP growth from adoption and innovation. Adoption share is 73% in 1973, whereas it becomes 6% in 2022. In other words, the main driver of growth is technology adoption from foreign countries in the early stage of development, and it shifts to innovation as the country becomes more developed.

In this section, we start by discussing the policy implications of our model. Then, we evaluate the technology policies implemented in Korea since 1973, which started with an adoption subsidy and switched to an innovation subsidy as in Figure 5. Next, we study the optimal timing of the switch from adoption to innovation subsidy while fixing the subsidy rate at the maximum rate of the actual policy. Finally, we jointly study the optimal subsidy rate and timing to switch.

6.2 Policy Evaluation

Actual policy implemented by the Korean government We evaluate the actual policy in Korea, which has shifted its focus on adoption to innovation as the productivity of Korean firms converged with foreign firms. We include both actual adoption and innovation subsidies over the year from the data (Figure 5). We compare the actual policy with three counterfactuals. First, we shut down both subsidies, which we consider an undistorted case. Second, the government subsidizes only adoption at 31%, the initial value in the actual policy. Lastly, the government subsidizes only innovation at 32%, the final value in the actual policy.[16]

[16]In Aooebdux Figure D.3, we compare the baseline case with the cases when we shut down either adoption or innovation subsidies to decompose the contribution of actual adoption and innovation subsidies.

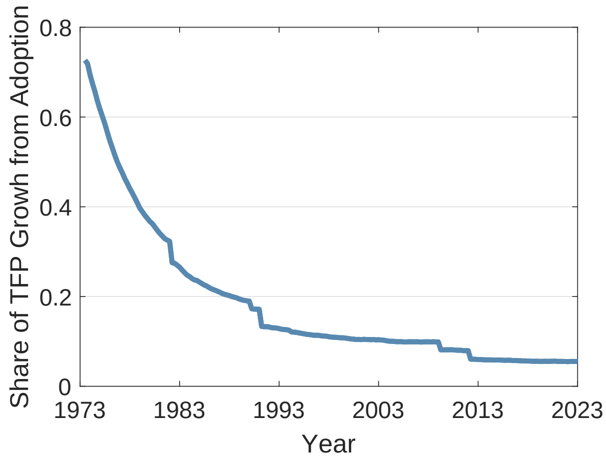
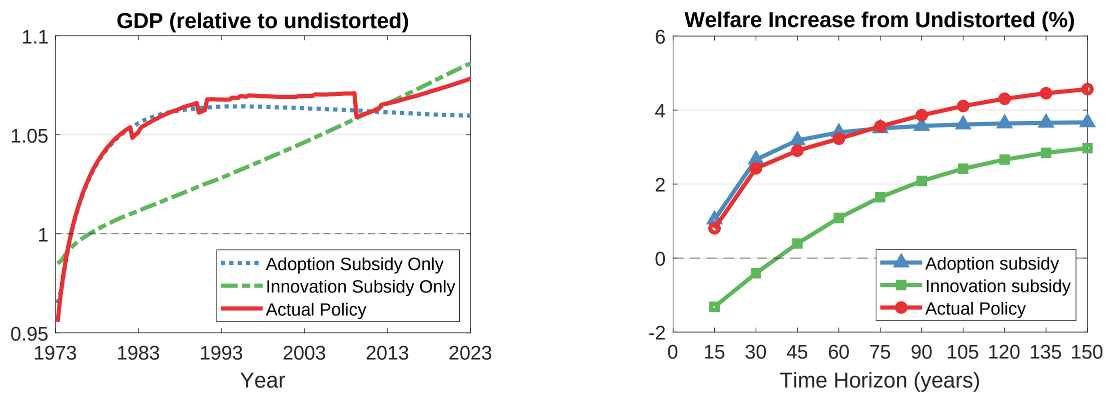


Figure 8: Share of Growth from Adoption over Time

Notes. This figure plots the TFP growth share of adoption over time. To be specific, we calculate the counterfactual TFP growth rate while keeping either adoption or innovation. We then calculate the TFP growth from adoption and divide by the sum of growth from innovation and growth from adoption. We keep other aggregate variables such as wages. TFP is defined in Equation (16). It has kinks when the adoption or innovation subsidy changes.



A. Relative GDP

B. Welfare Increase (%)

Figure 9: Results of the Counterfactual Analysis

Notes. This figure evaluates the actual policy by comparing it with counterfactuals. Panel A plots GDP in three scenarios divided by GDP in the undistorted case. The dotted blue line subsidizes only adoption at 31%, the dashed green line subsidizes only innovation at 32%, and the solid red line follows the actual policy in Figure 5. Panel B plots the welfare increase compared to the undistorted case over different time horizons. For instance, time horizon 15 means that we calculate the discounted sum of utility from year 0 to 15. The welfare increase is calculated in consumption-equivalent units using equation (17).

The left panel of Figure 9 shows GDP relative to the undistorted case with no subsidies over time. The adoption subsidy generates a higher growth rate in the early stage, and GDP becomes larger than undistorted case without subsidies. However, relative GDP eventually flattens and even decreases slightly, 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 adoption subsidy case. However, it yields a higher growth rate at later stages of development. This is because subsidizing innovation in the early years can be distortive, allocating resources to innovation instead of adoption, even though adoption has a larger positive externality. Lastly, the actual policy yields GDP similar to the adoption subsidy case and also yields a higher growth rate at later stages of development.

The right panel of Figure 9 shows the welfare implication of the policies over the different time horizons. Specifically, we calculate the discounted sum of the utility of different time horizons. Then, we calculate the percentage increase from the undistorted case with no subsidies in terms of consumption units. The consumption-equivalent change Ψ is given such that

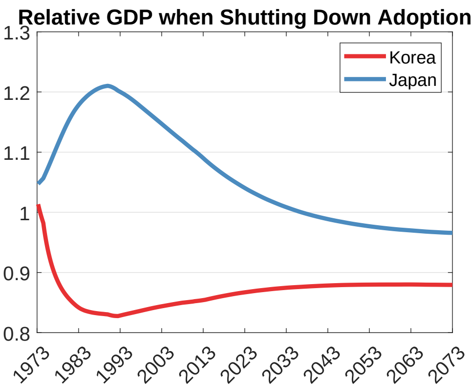
$$\int_{t=0}^{T} \exp(-\rho t) \log(C_{Ht}) dt = \int_{t=0}^{T} \exp(-\rho t) \log(\hat{C}_{Ht}(1+\Psi)) dt \,, \tag{17}$$

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

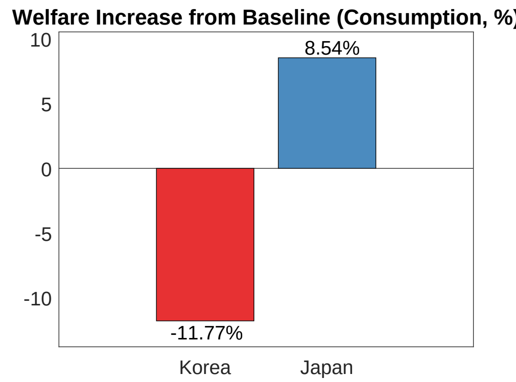
In the infinite horizon, the actual policy increases the consumption-equivalent welfare by 4.84%, which raises welfare more than subsidizing only adoption (3.69%) or subsidizing only innovation (3.28%). This result suggests that the actual policy implemented in Korea was qualitatively close to the optimal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

Foreign policy We consider hypothetical scenario in which the Japanese government prevents technology exports to South Korea. Note that Japanese incumbents always earn benefits from selling technology; if not, they will not sell technology. However, firms might sell more technology than the socially optimal level of Japan because they do not internalize the future loss for the potential entrants of Japan. When the previous incumbent sells technologies, the potential entrants will earn smaller profits and the Korean firms will have relatively higher productivity from adoption. Therefore, there can be an incentive for the Japanese government to prevent exporting technology. In this exercise, we set the innovation subsidy rates to be the same to those in the baseline.

Figure 10 reports the results. The left panel indicates that in the short-run, Japan had higher GDP when banning exports of technologies when compared to the baseline. However, in the long run, it has lower GDP as the long-run growth rate becomes lower. The right panel indicates that



A. Relative GDP



B. Welfare increase (%)

Figure 10: 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. Panel A plots the GDP of Korea and Japan relative to the baseline. Panel B plots welfare effects of these two countries.

the welfare in Korea would decrease by 11.77% when Japan prohibit technology export. On the other hand, the welfare in Japan would increase by 8.54%.

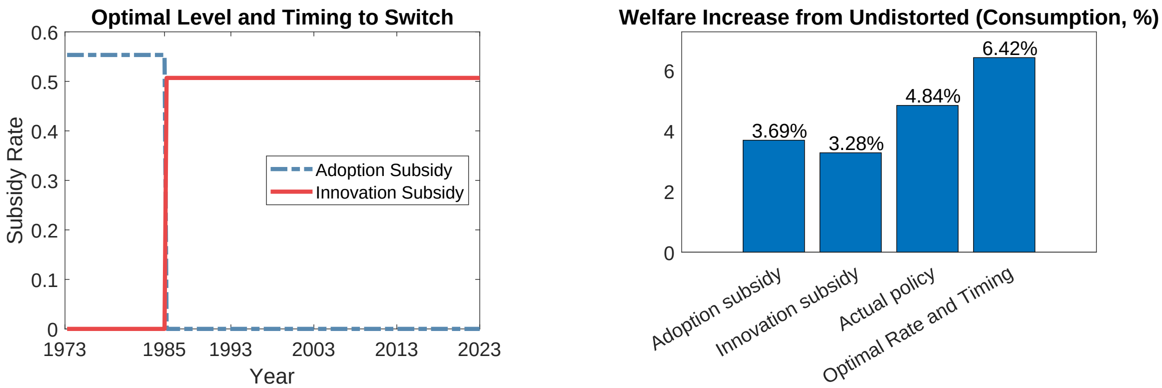
Robustness We conduct a battery of robustness checks on different values of parameters. We consider different values of discount rates, iceberg trade costs, and elasticity of substitution in Appendix Figures D.4, D.5, and D.6, respectively. The results are qualitatively similar to the main results.

6.3 Optimal Policy

We study the optimal government policy. The government chooses three parameters—the adoption subsidy rate, the innovation subsidy rate, and the timing to switch from the adoption to the innovation subsidy—to maximize welfare in the infinite time horizon. We computationally calculate these parameters.

The left panel of Figure 11 reports the optimal subsidies over time. The optimal policy within this class of policies is to start the adoption subsidy at 55% and switch to an innovation subsidy in 1985 of 51%, which is much higher than the actual subsidy rates. The right panel compares welfare gains from other policies. The optimal subsidy increases consumption-equivalent welfare by 6.42%, whose magnitude is larger than the actual and the other counterfactual policies.

To make this result applicable to other developing countries, we calculate the relative GDP per capita of Korea compared with Japan in the year of the switch. GDP per capita in Korea was 55% of Japan in 1985, which suggests that it would be better to switch from an adoption to an innovation subsidy when developing countries reach roughly half the GDP per capita of the



A. Optimal Subsidy Rates

B. Welfare increase (%)

Figure 11: Optimal Subsidy Rates and Welfare Increase

Notes. This figure plots the optimal subsidies and welfare results. Panel A plots the optimal adoption (dashed blue line) and innovation subsidy rate (solid red line). We allow the government to choose an adoption rate, innovation rate, and year to change from the adoption to innovation subsidy. The optimal policy is to start the adoption subsidy at 55% and switch to the innovation subsidy in 1985, at 51%. In 1985, the GDP per capita in Korea was 55% of that of Japan. Panel B plots the consumption-equivalent welfare increase from the undistorted case over different policies.

frontier countries. This rough number depends on the calibrated values of the cost parameters of adoption and innovation, which may reflect human capital endowment and quality of institutions of countries.

7 Conclusion

In this paper, we examine the role of 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, wherein 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 strategic interaction between them. A novel firm-to-firm technology transfer data from South Korea disciplines this crucial part of the model. Using the quantified model, we find that the state-dependent nature has important implications for welfare and catch-up growth.

Our study emphasizes that developing countries should pursue strategies distinct from those of developed countries to enhance their technology. Given South Korea's rapid transformation from a low-income to a high-income, innovative country, our quantitative analysis provides novel insights for policy makers 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 technology policy that benefits both countries? How do technology policies interact with trade policies? These questions represent promising avenues for future research.

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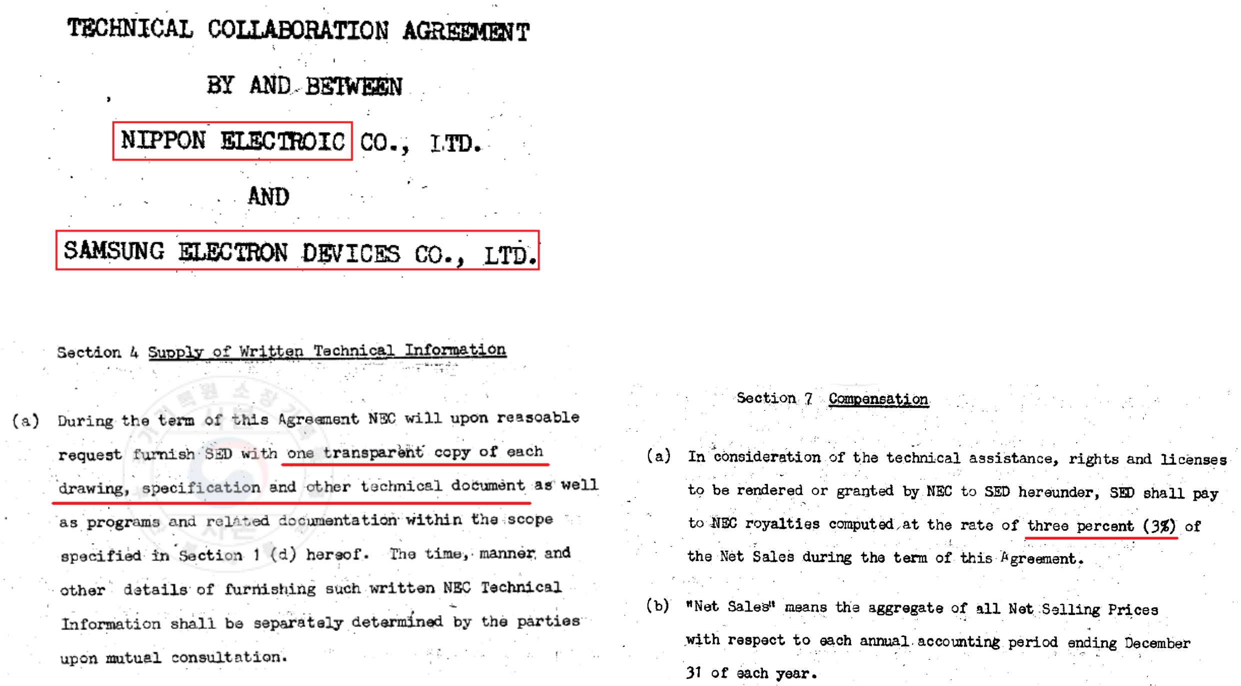
A Data

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.

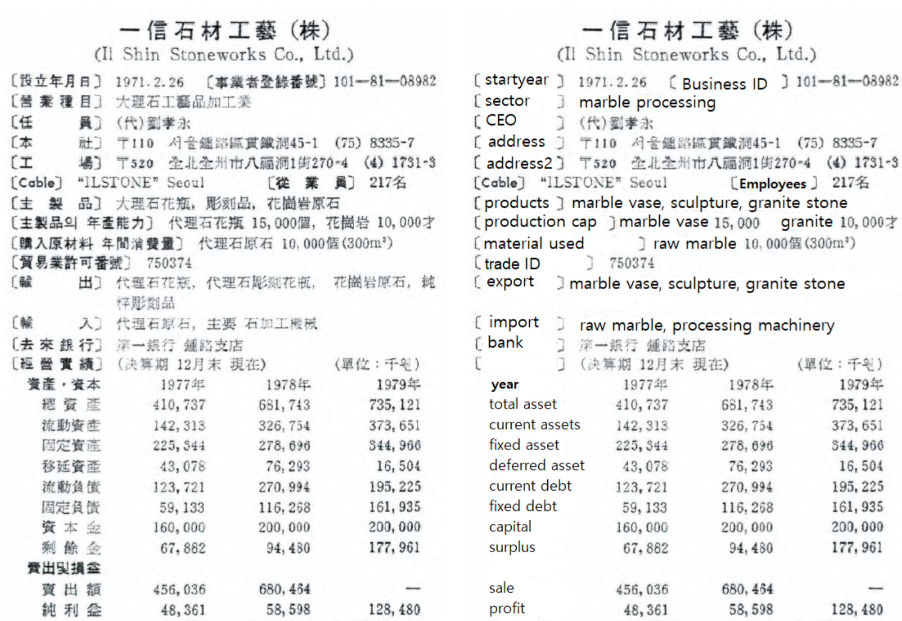
In 1962–1993, Korean firms were strictly required to report all transactions involving foreign currencies under the Foreign Capital Inducement Act. To be specific, they reported details of technology imports to the Economic Planning Board. Therefore, the universe of technology transfer contracts between Korean and foreign firms are stored in the national archives in Korea. We collect and digitize these technology transfers.

Korea Industrial Technology Association (1995) classifies contracts into five categories - sharing information, technical guidance, patent licensing, trademark licensing, etc. We consider the first two as know-how transfers and the third and fourth as licensing. Know-how transfer includes sharing blueprints, design specifications, production details, and training the Korean employees. 53% of contracts involve only know-how transfer, 41% involve both know-how and licensing, and 4% involve only licensing.

Table A.1: 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 8,322.



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

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

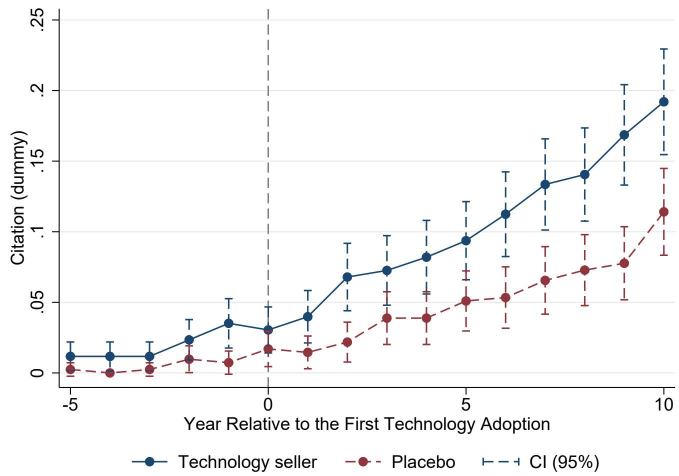


Figure B.1: Raw Average of Patent Citations Between Two Groups

Notes. The figure plots the average number of the citations from Korean never-adopters to the foreign firms that sold technology (solid navy line), and to the foriegn firms that did not (dashed red line). Vertical line is 95% confidence interval. X-axis is the year relative to the first technology adoption by a Korean firm. The coefficient one year before the adoption (-1) is normalized to zero. There are 278 and 556 number of clusters, respectively. $N = 8,896$

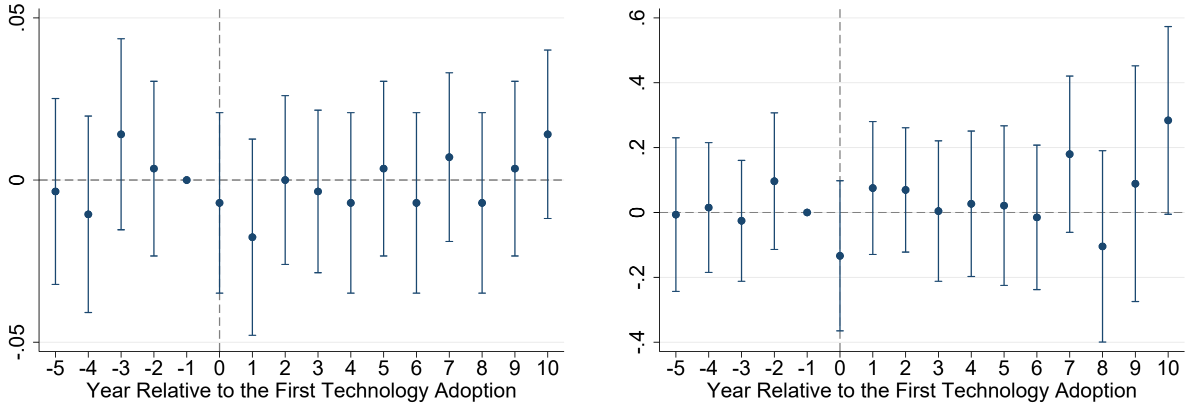
data sometimes assign multiple assignee ID to one firm.

B Empirical Analysis: Additional Tables and Graphs

Table B.1: Covariate Balance.

	Treated	Control	P-value
log cum. patent stock	4.03	4.44	0.02
	(2.20)	(2.34)	
log cum. citations	1.09	1.17	0.12
	(0.84)	(0.87)	
log age	1.21	1.38	0.16
	(1.82)	(2.00)	
N	372	377	

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



A. $\mathbb{1}[\text{Citation}_{fmt} > 0]$ B. $\text{Ihs}(\text{Citation}_{fmt})$

Figure B.2: Placebo. Knowledge Spillovers from Technology Adoption

Notes. This figure plots the estimates of β_τ in Equation (3). In Panels A and B, dependent variables are a dummy of positive citations from firms outside of Korea and the inverse hyperbolic sine transformation of total citations received by never-adopting firms, respectively. The vertical line is a 95% confidence interval. X-axis is the year relative to the first technology adoption by a Korean firm. β_{-1} is normalized to zero. The standard error is two-way clustered at the match and foreign firm levels. There are 278 and 556 number of clusters, respectively. $N = 8,896$

Table B.2: Knowledge Spillovers from Technology Adoption. Diff-in-Diff Estimator

Dep.	$\mathbb{1}[\text{Citation}_{fmt}]$
Post Adoption	0.0255***
	(0.009)
N	6,424
Match×Firm FE	yes
Match×Year FE	yes

Notes. This table displays the estimates of β^s. We restrict the sample from 5 years before and post five years from the first technology adoption. Standard errors are clustered at the foreign firm level.

C 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_{ftt}(\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 cost}} - (1-\kappa_{Fat}) \underbrace{\alpha_{Fa} \frac{a_{ft}(\mathbf{m}_f)^{\gamma_a}}{\gamma_a} w_{Ft}}_{\text{adoption cost}} \\
&+ x_{ft}(\mathbf{m}_f) \sum_n f(n; \min_{i \in \{h, \tilde{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 \{h, \tilde{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}
$$

Value function of potential entrant $\tilde{f}$ in country F is

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

C.2 Adoption Fee

The adoption fee when foreign firm f adopts from the domestic leader i is

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

C.3 Optimal Policy Function

When the domestic leader is firm i, the optimal innovation and adoption rate of foreign incumbent is

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

The optimal innovation rate of 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.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 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 $x \cdot \delta$, where x is the 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, $x \cdot \delta$ is to be matched with the average increase of 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 $\mu_t(\mathbf{m})$, 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 country $P_{Ht} = 1$. Therefore, it is useful to divide Equation (10) with $P_{Ht}C_{Ht}$ and define $v_{it} = \frac{V_{it}}{C_{Ht}}$ as normalized value function, $\omega_{Ht} = \frac{w_{Ht}}{C_{Ht}}$, as normalized wage, $\tilde{p}_{H\mathbf{m}t} = \frac{p_{H\mathbf{m}t}}{C_{Ht}}$, and $\tilde{\mathcal{F}}_{ijt} = \frac{\mathcal{F}_{ijt}}{C_{Ht}}$. Also, define consumption share in each country as $\psi_{Ht} = \frac{C_{Ht}}{C_{Ht}+P_{Ft}C_{Ft}}$ and represent profit function as below.

$$\begin{aligned} \Pi_{it}(\mathbf{m}_i) &= \tilde{\pi}_{it}(\mathbf{m}_i) \times C_{Ht} + \tilde{\pi}^*_{it}(\mathbf{m}_i) \times P_{Ft}C_{Ft} \\ \frac{\Pi_{it}(\mathbf{m}_i)}{C_{Ht}} &= \tilde{\pi}_{it}(\mathbf{m}_i) + \tilde{\pi}^*_{it}(\mathbf{m}_i) \times \frac{1-\psi_{Ht}}{\psi_{Ht}}, \end{aligned} \tag{18}$$

where $\pi_{it}(\mathbf{m}_i)$, and $\pi^*_{it}(\mathbf{m}_i)$ are the profit divided by total consumption in home and foreign markets. Then, we normalize value function of firm $i \in \{h, \tilde{h}\}$ as below.

$$\begin{aligned}
&(r_{Ht} - g_t)v_{it}(\mathbf{m}_i) \\
&= \max_{x_{it}(\mathbf{m}_i), a_{it}(\mathbf{m}_i)} \pi_{Ht}(\mathbf{m}_i) + \pi^*_{Ht}(\mathbf{m}_i) \times \frac{1-\psi_{Ht}}{\psi_{Ht}} \\
&- (1-\kappa_{Hrt})\alpha_{Hr}\frac{(x_{it}(\mathbf{m}_i))^{\gamma_r}}{\gamma_r}\omega_{it} - (1-\kappa_{Hrt})\alpha_{Ha}\frac{(a_{it}(\mathbf{m}_i))^{\gamma_a}}{\gamma_a}\omega_{Ht} \\
&+ x_{it}(\mathbf{m}_i)\sum_n \tilde{f}(n;\mathbf{m}_i)\big[v_{it}(m_i^F+n, m_i^D+n) - v_{it}(\mathbf{m}_i)\big] \\
&+ a_{it}(\mathbf{m}_i)\Big[\sum_n \tilde{g}(n;\mathbf{m}_i)\big[v_{it}(m_i^F+n, m_i^D+n) - v_{it}(\mathbf{m}_i)\big] - (1-\kappa_{Hrt})\tilde{\mathcal{F}}_{it}(\mathbf{m}_i)\Big] \\
&+ x_{-it}(\mathbf{m}_{-i})\sum_n \tilde{f}(n;\mathbf{m}_{-i})\big[v_{it}(m_i^F, m_i^D-n) - v_{it}(\mathbf{m}_i)\big] \\
&+ a_{-it}(\mathbf{m}_{-i})\sum_n \tilde{g}(n;\mathbf{m}_{-i})\big[v_{it}(m_i^F, m_i^D-n) - v_{it}(\mathbf{m}_i)\big] \\
&+ \big(x_{Ft}(\mathbf{m}_f) + \tilde{x}_{Ft}(\mathbf{m}_f)\big)\sum_n f(n; \min_{i\in\{h,\tilde{h}\}}\{m^i_{ft}\})\big[v_{it}(m_i^F-n, m_i^D) - v_{it}(\mathbf{m}_i)\big] \\
&+ a_{Ft}(\mathbf{m}_f)\Big[\sum_n g(n; \min_{i\in\{h,\tilde{h}\}}\{m^i_{ft}\})\big[v_{it}(m_i^F-n, m_i^D) - v_{it}(\mathbf{m}_i)\big] + \mathbb{1}[m_i^D \geq 0] \times \tilde{\mathcal{F}}_{ft}(\mathbf{m}_f)\Big] \\
&+ \phi\big[v_{it}(0,0) - v_{it}(\mathbf{m}_i)\big]\Bigg\}.
\end{aligned} \tag{19}$$

Note that from the household Euler Equation (4), we know $r_{Ht} - g_t = \rho$ in any t. We solve the balanced growth path in two layers. First, we make a guess of $\{\omega_H, \omega_F, \psi_H\}$. Then, we make a guess of value function for each $\mathbf{m}$, and iterate until it converges using the Equation (19). After the normalized value functions converges, we check the labor market clearing conditions for each country, and check the trade balance conditions. We update these three variables until 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 $\mathbb{X}_t^0 = \{\omega_{Ht}, \omega_{Ft}, \psi_{Ht}\}_{t=0}^{t=T}$
4. Given the guess, we solve value function, innovation, and adoption rate backward from the period T to period 0.
5. Given the innovation and adoption decisions, we solve the distribution of productivity gap $\{\mu_t(\mathbf{m})\}_{t=0}^{t=T}$ forward from period 0 to period T. $\mu_{H\mathbf{m}0}$ is given as the initial condition. We also solve implied $\tilde{\mathbb{X}}_t^1 = \{\omega_{Ht}, \omega_{Ft}, \psi_{Ht}\}_{t=0}^{t=T}$ using $\{\mu_t(\mathbf{m})\}_{t=0}^{t=T}$.
6. Get the distance $\|\mathbb{X}_t^0 - \mathbb{X}_t^1\|$ between the guess and implied value. We use Euclidean norm.
7. Update the guess as below until $\|\mathbb{X}_t^0 - \mathbb{X}_t^1\| < \epsilon$

$$\mathbb{X}_t^{i+1} = (1-\Delta)\mathbb{X}_t^i + \Delta\tilde{\mathbb{X}}_t^{i+1}\,, \tag{20}$$

   where $0 < \Delta < 1$ is dampening parameter
8. Once we find the equilibrium $\mathbb{X}$, we simulate 1,000,000 firms using the distribution $\mu_{H\mathbf{m}t}$, and calculate C_{Ht}.

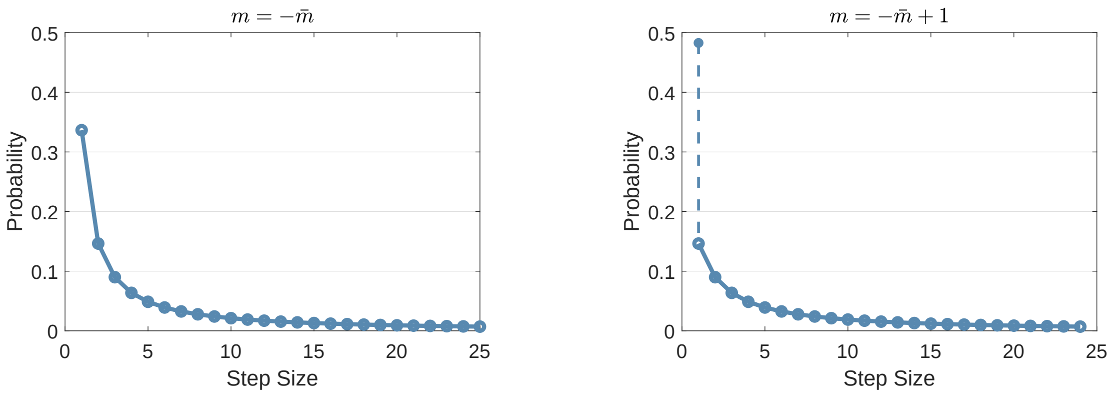


Figure D.1: Probability Mass Function of Step Size

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

D.3 Additional Figures

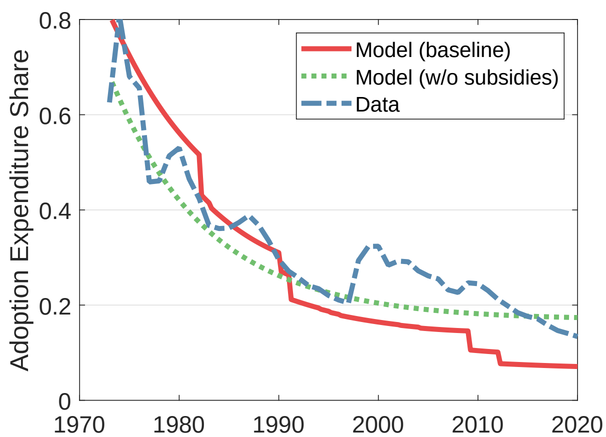
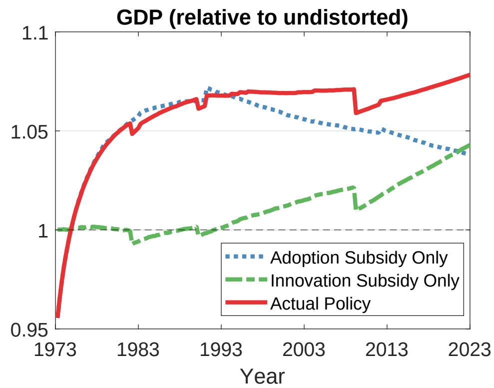
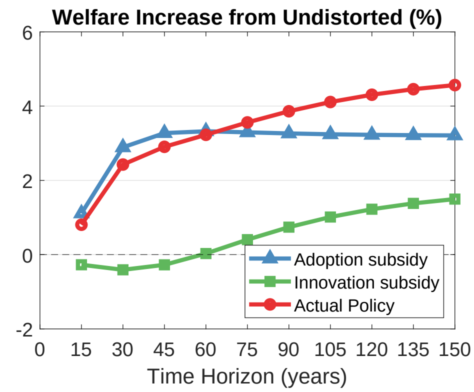


Figure D.2: Adoption Expenditure Share in the Model and the Data

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.





A. Relative GDP

B. Welfare increase (%)

Figure D.3: Results of the Counterfactual Analysis

Notes. This figure evaluates the actual policy by comparing it with counterfactuals. Panel A plots GDP in three scenarios divided by GDP in the undistorted case. The dotted blue line when we shut down the innovation subsidy, the dashed green line when we shut down the adoption subsidy, and the solid red line follows the actual policy in Figure 5. Panel B plots the welfare increase compared to the undistorted case over different time horizons. For instance, time horizon 15 means that we calculate the discounted sum of utility from year 0 to 15. The welfare increase is calculated in consumption-equivalent units (equation (17)).

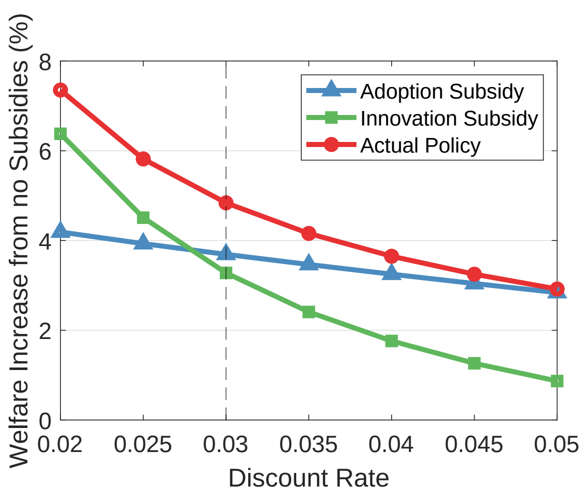
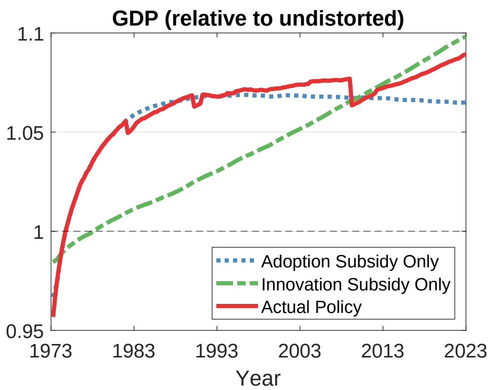
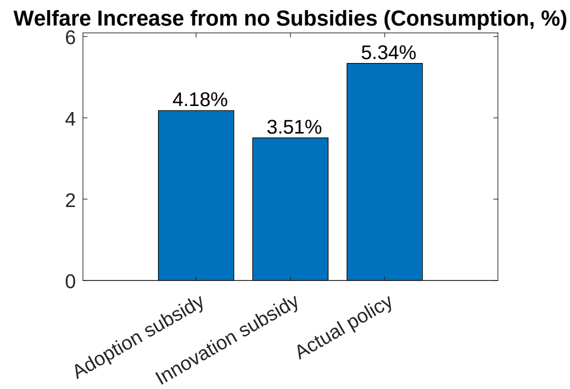


Figure D.4: Welfare Increase from Undistorted Case over Discount Rate

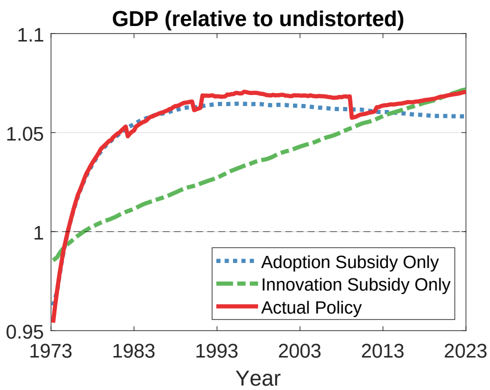
Notes. This figure plots the welfare increase compared to the undistorted case in infinite time horizon over different discount rate ρ. The baseline value is $\rho = 0.03$. Welfare increase is calculated in consumption-equivalent unit (equation (17)). The blue triangle is when subsidizing only adoption at 31%, the green square is when subsidizing only innovation at 32%, and the red circle is when imposing the actual policy in Figure 5.



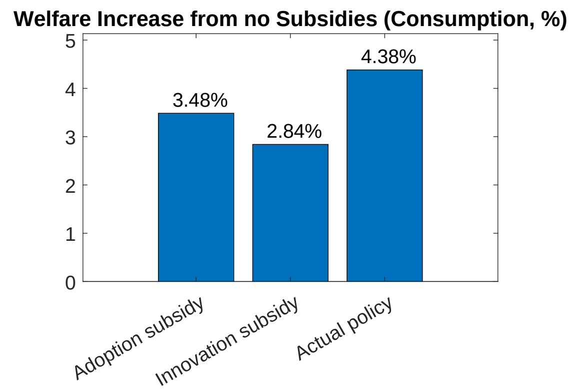
A. Relative GDP ($\tau_x = 1.25$)



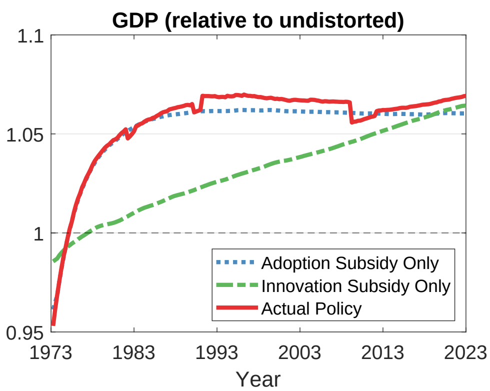
B. Welfare increase (%, $\tau_x = 1.25$)



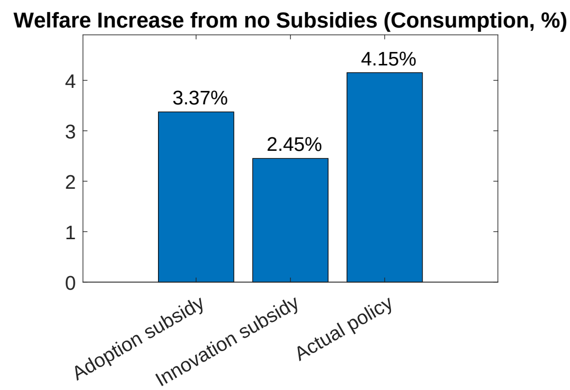
C. Relative GDP ($\tau_x = 1.75$)



D. Welfare increase (%, $\tau_x = 1.75$)



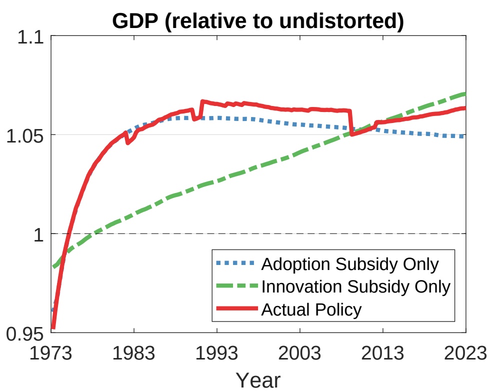
E. Relative GDP ($\tau_x = 2.0$)



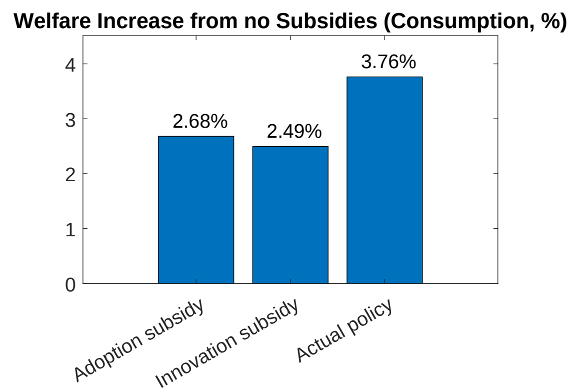
F. Welfare increase (%, $\tau_x = 2.0$)

Figure D.5: Results of the Counterfactual Analysis with Iceberg Trade Cost

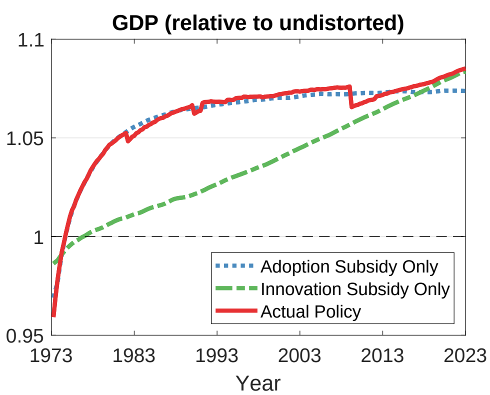
Notes. This figure evaluates the actual policy by comparing it with counterfactuals. Panels A and B plot the case with $\tau_x = 1.25$, Panels C and D plot the case with $\tau_x = 1.75$ and Panels E and F plot the case when $\tau_x = 2.0$. Panels A,C, and E plot GDP in three scenarios divided by GDP in the undistorted case. The dotted blue line subsidizes only adoption at 31%, the dashed green line subsidizes only innovation at 32%, and the solid red line follows the actual policy in Figure 5. Panels B,D, and F plot the welfare increase compared to the undistorted case in the infinite time horizon. The welfare increase is calculated in consumption-equivalent units using equation (17).



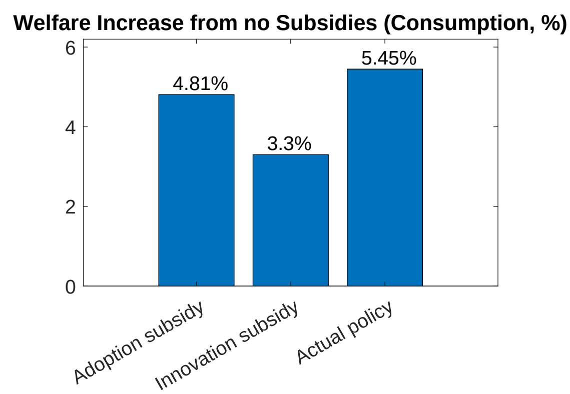
A. Relative GDP ($\sigma = 4$)



B. Welfare increase (%, $\sigma = 4$)



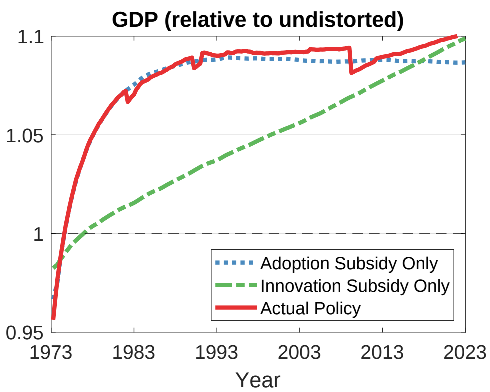
C. Relative GDP ($\sigma = 12$)



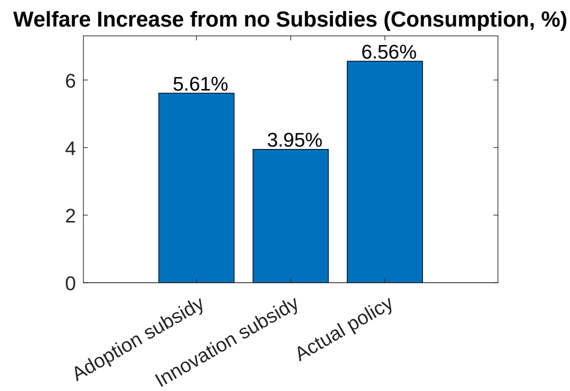
D. Welfare increase (%, $\sigma = 12$)

Figure D.6: Results of the Counterfactual Analysis with Elasticity of Substitution

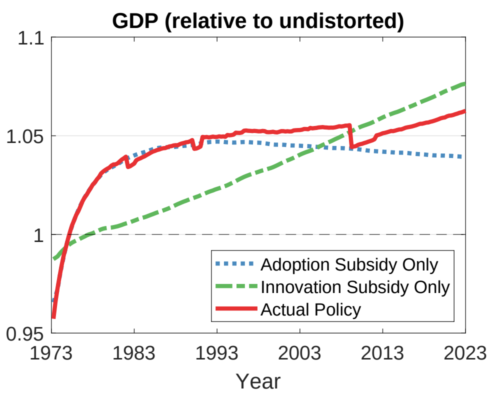
Notes. This figure evaluates the actual policy by comparing it with counterfactuals. Panels A and B plot the case with $\sigma = 4$ and Panels C and D plot the case with $\sigma = 12$. Panels A and C plot GDP in three scenarios divided by GDP in the undistorted case. The dotted blue line subsidizes only adoption at 31%, the dashed green line subsidizes only innovation at 32%, and the solid red line follows the actual policy in Figure 5. Panels B and D plot the welfare increase compared to the undistorted case in the infinite time horizon.



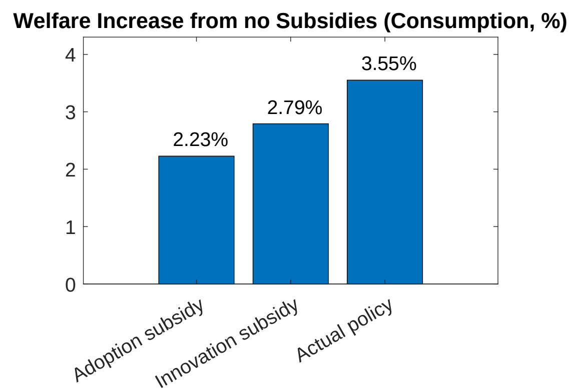
A. Relative GDP ($\xi = 0.25$)



B. Welfare increase (%, $\xi = 0.25$)



C. Relative GDP ($\xi = 0.75$)



D. Welfare increase (%, $\xi = 0.75$)

Figure D.7: Results of the Counterfactual Analysis with Bargaining Power Parameter

Notes. This figure evaluates the actual policy by comparing it with counterfactuals. Panels A and B plot the case with $\xi = 0.25$ and Panels C and D plot the case with $\xi = 0.75$. Panels A and C plot GDP in three scenarios divided by GDP in the undistorted case. The dotted blue line subsidizes only adoption at 31%, the dashed green line subsidizes only innovation at 32%, and the solid red line follows the actual policy in Figure 5. Panels B and D plot the welfare increase compared to the undistorted case in the infinite time horizon. The welfare increase is calculated in consumption-equivalent units using equation (17).