Essays on Technology, Fiscal Policy, and Firm Behavior

by

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Dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy
in the Department of Economics
in the Graduate School of
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ABSTRACT

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Abstract

My dissertation seeks to enhance our understanding of how technology and fiscal policies shape firm behavior and implications for the aggregate economy and policy designs. In the first two chapters, I show empirically and quantitatively that information and communication technology (ICT) can widen firms' geographic span of control by reducing internal communication costs. Combining comprehensive establishment-level datasets with ownership linkages, geographic locations, and ICT adoption, I document that firms with more advanced technology have both higher within-firm communication and larger geographic coverage. Exploiting natural experimental variation from the Internet privatization in the early 1990s, I show that better access to ICT helped firms expand geographically. Using a model where firms endogenously adopt ICT, choose multiple production locations, and trade domestically, I estimate that the Internet privatization increased overall efficiency by 1.1%. Compared to a trade-only model, a model with multi-unit firms predicts that efficiency gains are larger and more geographically dispersed. Policy counterfactuals show that to improve local welfare, a policy coordinated across locations that improves ICT access can be more effective than uncoordinated local policies.

The third chapter is joint work with Zhao Chen, Zhikuo Liu, Juan Carlos Suárez Serrato, and Daniel Xu. We study one of the largest tax reforms in China—the 2009 value-added tax reform that allowed firms to deduct input value-added tax from output tax and thus reduced user cost of capital for equipment investment. Using reduced-form analysis and a quantitatively firm investment model, we find that investment stimuli that shrink firms' inaction regions, such as value-added tax reduction and investment tax credits, are more effective: Given the same tax revenue loss, those policies lead to larger investment response.

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Chapter 1

Introduction

Technology and fiscal policy have changed the landscape of firm behaviors. What are the impacts of recent technological changes and fiscal policies on firm behaviors? I tackle the question by bridging microdata, empirical analysis, and structural models. A unifying theme of my research is to leverage large-scale microdata that are increasingly available to researchers; to create a dialogue between data and model to investigate the role of technology and fiscal policies in shaping firm behavior and aggregate economic outcomes; and to use economic models to shed light on policy designs.

A large body of literature studies the impacts of technology, particularly information and communication technology (ICT), on firm behavior. In particular, I focus on the geographic organization of firms, especially multi-unit firms (i.e., firms with multiple establishments, including multinationals), and seeks to understand the causes and consequences of the rising multi-unit firms. Chapter 1 shows empirically that ICT can widen the firm's geographic span of control by reducing internal communication costs. Using the US Census microdata and quasi-experimental variation from the 1995 Internet privatization, which significantly reduced ICT costs, I show that ICT—particularly the Intranet that reduces internal communication costs across different firm units—helps firms expand production geographically. Guided by those findings, Chapter 2 develops a spatial equilibrium model where firms endogenously adopt ICT and choose multiple locations to set up production facilities. The estimated model underscores the role of multi-unit firms in facilitating technology spillover across locations. Policy counterfactuals suggest that a coordinated policy that improves ICT access across locations, such as a federal policy, can be more effective in enhancing local welfare than uncoordinated policies at the local level.

Firms' geographic organization is an under-studied area, partly due to the lack of data. My work uses comprehensive US Census data to point to one source of the rising firms'

geographic span of control. More importantly, the paper quantitatively assesses the role of multi-unit firms in technology spillover across locations, which contributes to the growing literature that studies how multi-unit firms affect the aggregate and distribution of economic activities. More importantly, the study informs current policy designs regarding nationwide broadband expansion.

As another set of prominent fiscal policies, Chapter 3 studies the impacts of tax policies on firm behavior. This chapter is based on the joint paper with Zhao Chen, Zhikuo Liu, Juan Carlos Suárez Serrato, and Daniel Xu. The paper is accepted by the *Review of Economic Studies*. We leverage novel Chinese datasets and investigates firms' investment response to one of the largest tax reforms in recent history: the 2009 value-added tax reform in China. We show theoretically, empirically, and quantitatively that tax policies can directly interact with investment frictions that generate lumpy investment. Through the lens of a dynamic investment model, the paper shows that tax policies which increase firms' likelihood of investing can be more effective.

In sum, leveraging large-scale microdata, I use rigorous reduced-form analysis to guide structural models and use the model to shed light on general equilibrium effects and to inform policy designs.

Chapter 2

Information and Communication Technology and Firm Geographic Expansion: An Empirical Analysis

2.1   Introduction

Information and communication technology (ICT) has experienced dramatic improvements over the past three decades. Both governments and firms have made significant investments in ICT infrastructure, with the premise that ICT improves within-firm communication for multi-unit firms—firms that operate in multiple locations—and widens their geographic span of control, e.g., the number of establishments a firm operates. As multi-unit firms account for a large share of economic activities, understanding their location choices in response to ICT improvements is crucial to assess the aggregate and geographic implications of ICT development and policies.[1] Causal evidence on the impact of ICT on firms' geographic expansion, however, is scarce. Moreover, we have little knowledge about the magnitude of gains from ICT associated with firm production in multiple locations and, importantly, the geographic distribution of these gains.

This paper follows two complementary strategies to study how ICT improvements affect firms' geographic span of control. Using confidential US Census data and a natural experiment from the Internet privatization in the early 1990s, I first show empirically that ICT improves firms' internal communication and facilitates their geographic expansion. To quantify the gains from ICT improvements in equilibrium, the paper then develops a quantitative model with firms endogenously adopting ICT, operating production establishments

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[1]Bernard and Jensen (2007) documents that multi-unit firms account for 78% of employment and 88% of output in the manufacturing sector based on the 1987–1997 Census of Manufactures.

across multiple regions, and using them to ship products to neighboring locations. I find that multi-unit production is important for evaluating the gains from ICT and government investment in communication infrastructure. In particular, multi-unit firms work as a channel for technology spillovers across locations, both through existing firm network and geographic expansion, thus shaping the geographic distribution of gains from ICT.

I establish these results in five steps. In the first step, I leverage a confidential US Census dataset with establishment-level ownership linkages and geographic locations and augment it with establishments' ICT adoption—in particular, network adoption—to document three facts. First, US firms have increased their geographic span of control, especially firms with multiple production sites: the average number of establishments per firm increased by 15.6% for multi-unit firms in the manufacturing sector between 1977 and 2012. Second, firms that have adopted *Intranet*, which reduces firms' internal communication costs, are associated with larger growth rates in their geographic span of control. Third, Intranet adoption increases the likelihood of within-firm communication using online networks, which further corroborates the role of declining internal communication costs in firms' geographic expansion. Identifying the effect of ICT, however, is known to be difficult, as more productive firms are more likely to adopt advanced technology and to have greater geographic coverage.

In the second step, I overcome this difficulty by exploiting quasi-experimental variation from a historic event—the Internet privatization in 1995. Before privatization, the first high-speed Internet backbone in the US—the National Science Foundation Network (NSFNET)— was managed by the NSF and predominantly served the research and higher education community; commercial use was restricted. The privatization of NSFNET was completed in 1995 and opened the Internet to the private sector; it was followed by drastic improvements in almost all aspects of ICT as well as reductions in costs. The timing of these explosive developments, however, was unexpected. As described in Greenstein (2015), it was difficult for contemporaneous observers to predict the effects of the Internet privatization. Given its unprecedented scale, companies adopted a "wait-and-see" approach and

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delayed taking significant actions in the early 1990s. The "Internet gold rush" did not happen until privatization was completed.[2]

I measure a firm's exposure to the Internet privatization by using the distance from the firm's headquarter to the nearest node site of NSFNET. These node locations reflected historical contingencies regarding military concerns and proximity to research institutes and thus were less likely to be subject to contemporary shocks at the time of privatization. At locations closer to the Internet backbone nodes, infrastructure such as underground cables was better laid out and more developed. As the construction and installation of circuits is one of internet service providers' major costs, Internet access would be cheaper for locations with better infrastructure. These locations might also benefit from thicker labor pools with ICT experience. I use a difference-in-differences approach to identify the effect of the Internet privatization on firms' geographic span of control. I find that privatization increased the average number of establishments per firm by 8.5%. In particular, multi-unit firms increased their number of establishments by 6.5%, on average, which is equivalent to half of the overall increase after privatization.

The key identification assumption is that, absent privatization, firms would have the same trend in their geographic span of control regardless of the distance to the nearest NSFNET node. I justify this assumption with four pieces of evidence. First, graphical examination shows that parallel trends hold for firms headquartered at different distances to the nodes. Second, the estimates are robust across different specifications, such as ones including controls for time-varying county characteristics and state-year and industry-year fixed effects. Third, I estimate the generalized propensity score of treatment and apply the inverse propensity score method to reweight the regression so that firms locate at different distances are balanced on both firm and county characteristics. The difference-in-differences estimate is robust to the use of these weights. Finally, I test the effect of the Internet privatization for different distance ranges. The results suggest that privatization

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[2]The history of Internet commercialization in the United States, including the deployment of Internet infrastructure, is reviewed and discussed in Greenstein (2015), Greenstein (2020).

had significant effects even if we leave out the "hot spots" surrounding NSFNET nodes. These sets of evidence offer reassurance that the baseline estimates are robust and reflect the effect of the Internet privatization.

The firm-level analysis shows that ICT improvements help firms expand geographically. What are the implications for the aggregate and geographic distribution of efficiency gains and consumer welfare? What are the implications for policies that aim at improving ICT access? To answer these questions, in the third step, I propose a spatial equilibrium model of firm ICT adoption and location choices. In the model, firms choose a set of locations, instead of a single location, to set up establishments but are subject to communication costs among establishments. Firms can adopt advanced ICT to improve firm-wide effective productivity and to reduce communication costs between the headquarters and establishments. ICT adoption and geographic expansion are complements: the benefit of expanding to more locations is higher if a firm adopts ICT; the benefit of adopting ICT is also higher for a firm with a larger number of establishments. In equilibrium, reducing the cost of ICT affects firms' geographic span of control through two channels. On the one hand, with a reduction in the cost of ICT, firms' likelihood of adopting ICT rises, which increases the benefit of having a larger set of production sites. Through this direct channel, the ICT cost reduction facilitates firms' geographic expansion. On the other hand, markets become more competitive as a larger fraction of firms adopt ICT to improve their effective productivity. This equilibrium channel compresses geographic expansion.

In the fourth step, I estimate the model by using a matched sample of firm ICT adoption and geographic footprints in three stages. First, I estimate communication costs, which rise in the distance between firms' headquarters and establishments, using within-firm employment shares of each establishment. Second, I decompose location-specific fixed effects to estimate the state of technology for each location. Third, I estimate the fixed costs of setting up establishments and the fixed cost of adopting ICT for each location and the productivity loss from low ICT via the method of simulated moments (MSM). I form three sets of moments regarding firms' geographic expansion patterns, ICT adoption,

and the relationship between the two decisions for the estimation. The key challenge for computing firms' optimal sets of locations is the curse of dimensionality. The number of location combinations increases drastically as the number of locations rises. I address this challenge by applying a recent algorithm proposed in Arkolakis, Eckert, and Shi (2021) to solve the firm's location choice problem. The estimation results show that communication costs between establishments and headquarters increase with distance and that the elasticity of communication costs with respect to distance is smaller for firms with advanced ICT. Nonetheless, even for firms with low ICT, the elasticity of communication costs is smaller than the common value of the elasticity of trade costs with respect to distance. The results also suggest that adopting ICT significantly increases firm productivity.

Finally, the model allows us to quantify the welfare gains from the Internet privatization that account for geographic spillovers through firm networks and expansion, to understand the mechanisms that drive these gains, and to shed light on the design of infrastructure policies that promote ICT adoption. The estimated model suggests that the Internet privatization increased aggregate efficiency gains by 1.1%. To understand the mechanisms behind this aggregate effect, I study the impact of a counterfactual exercise, where I reduce the costs of ICT adoption in the East South Central census division. When the local ICT costs decrease by 23%, local welfare increases by 0.025%. Moreover, the locations in which ICT costs are unchanged experience a welfare increase of 0.008%, approximately one-third of the magnitude in the East South Central census division, indicating a strong spillover of local ICT infrastructure improvements to the rest of the economy. The large spillover effect is driven by firms' multi-unit production. Decomposition of welfare changes into contributions by local firms (i.e., firms headquartered in the location) and outside firms (i.e., firms headquartered outside the location) suggests that incumbent establishments and new establishments set up by outside firms can explain the majority of local welfare changes. Compared to an alternative trade-only model, which shuts down the multi-unit production channel, gains from local ICT improvements are more geographically dispersed when we take multi-unit production into account.

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To further illustrate the role of multi-unit production in the evaluation of policies that promote ICT access, I compare two sets of policies—one that reduces ICT costs individually for each location, and the other that universally reduces ICT costs for all locations. The results show that to improve local ICT access and local welfare, a coordinated policy across locations, such as a federal policy, can be more effective than uncoordinated policies at the local level. A universal ICT cost reduction yields an elasticity of welfare with respect to the ICT cost that is 4 times larger than that generated by local policies. The difference between the two sets of policies is larger than that in a trade-only model as a result of spillover across locations through multi-unit production.

Governments worldwide have spent billions on ICT infrastructure initiatives. For instance, the recent US infrastructure bill, i.e., Infrastructure Investment and Jobs Act, includes programs promoting universal internet penetration to reduce the uneven access to the internet. My results underscore that gains from ICT improvements differ across geographic locations and that it is important to understand how firm responses in relation to ICT adoption and geographic organization shape the gains from communication infrastructure development.

Relation to Literature. This paper studies the effects of ICT on firm organization, reviewed in Bloom, Sadun, and Van Reenen (2010), Bresnahan (2010), and Goldfarb and Tucker (2019). In closely related work, Bloom, Garicano, Sadun, and Van Reenen (2014) use firm-level data and find a positive correlation between the firm span of control (i.e., whether a firm has multiple establishments) and the adoption of advanced ICT (i.e., enterprise resource planning software and Intranet). Recent papers also document that ICT facilitates vertical fragmentation of production through phenomena such as outsourcing (e.g., Fort, 2017; Jiao and Tian, 2019). To the best of my knowledge, however, there is no existing evidence on the causal relationship between ICT adoption and firm geographic span of control. This paper contributes to the literature by conducting a series of quantitative analyses to fill this gap. The linked dataset on firm ICT utilization and geographic footprints with geocodes for each establishment enables me to study this relationship. By exploiting plau-

sibly exogenous variation arising from the Internet privatization in the United States, I provide empirical evidence on the causal effects of ICT on firms' geographic span of control through reductions in internal communication costs.

This paper is also related to the literature on the effects of ICT infrastructure that exploits the interaction between time variation in the arrival of technology and geographic variation in the proximity to technology (e.g., Forman, Goldfarb, and Greenstein, 2012; Akerman, Gaarder, and Mogstad, 2015; Steinwender, 2018; Juhász and Steinwender, 2018; Hjort and Poulsen, 2019). Most of the previous literature focuses on the effects on local market outcomes such as employment and firm behavior.[3] This paper shows that in addition to direct effects on local markets, ICT improvements may have distributional effects on other locations. Specifically, I highlight the role of multi-unit firms in transmitting technology across locations. I illustrate this point in a model integrating firm ICT adoption with geographic expansion. I further use the estimated model to quantify the distribution of gains in ICT availability across locations in the United States. The results show that ignoring technology spillover through multi-unit firms may lead to underestimation of the gains from ICT improvements.

This paper contributes to a growing literature studying the location choice of firms regarding production at multiple locations (e.g., Ramondo and Rodríguez-Clare, 2013; Tintelnot, 2017; Hu and Shi, 2019; Hsieh and Rossi-Hansberg, 2019; Oberfield, Rossi-Hansberg, Sarte, and Trachter, 2020). In particular, the paper builds and extends on Tintelnot (2017) by incorporating the endogenous communication cost through ICT adoption. The paper furthers our understanding of multi-unit production by empirically and quantitatively demonstrating endogenous ICT as an additional source of heterogeneity. A key challenge for computing the firm's optimal set of production locations arises from the combinatorial choice problem; i.e., the cardinality of the choice set is on the order of 2^N, where N is the number of potential production locations. While extensively studied in several other

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[3]Notable exceptions include Steinwender (2018), who studies the effect of telegraph development in the 18th century in the United Kingdom on trade. The paper finds significant efficiency gains through the lens of a two-country trade model with information frictions.

fields such as computer science and operations research, this problem has received little attention in economics, with a few exceptions, e.g., Jia (2008), Antras, Fort, and Tintelnot (2017) and the papers mentioned above. The current paper contributes to this literature by applying the algorithm proposed in Arkolakis, Eckert, and Shi (2021) to solve the firm location choice problem and by integrating this algorithm into the estimation procedure and counterfactual exercises.

2.2   Data and Stylized Facts

2.2.1   Data Sources

The main dataset is the Longitudinal Business Database (LBD) from the US Census. It covers the universe of US establishments since 1976 and is updated annually. The LBD provides consistent identifiers at the establishment (LBDNUM) level and firm level (FIRMID), which allows me to link establishments to their parent firms and track the firms over time. The data also record the establishment location's ZIP code, county, and state; employment on March 12; annual payroll; and industry codes. As the industry classification system experienced a major change in 1997 and has been updated constantly, I use the consistent industry codes at the 6-digit NAICS level that are provided in Fort and Klimek (2018). Firms are defined by a FIRMID $\times$ 6-digit NAICS code pair.[4] This definition allows me to abstract away from firms' industry composition, and to focus on their geographic changes.[5] I use the number of establishments that a firm operates as the primary measure of the firm's geographic span of control. Nevertheless, I consider alternative measures that represent broader geographic scopes—such as the number of counties, states, and census divisions in which a firm has operations, as well as the number of establishments that are at a nondrivable distance (i.e., further than 250 miles away) from the firm's headquarter

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[4]Autor et al. (2020) use the same definition of a firm to document the rise of superstar firms.

[5]I restrict the analysis to the contiguous US states; Alaska, Hawaii, Puerto Rico and the US Virgin Islands are excluded.

or are out of state.

I obtain information on ICT adoption from the Computer Network Use Supplement (CNUS) to the 1999 Annual Survey of Manufactures. The CNUS asks establishments whether they use the internet, an Intranet, a local area network (LAN), an electronic data interchange network (EDI), an Extranet, or other networks. These network adoption variables are key to identifying the role of different types of technology in facilitating firms' geographic expansion. In addition to the network adoption items, the survey asks whether the establishment uses online networks (i.e., Internet, Intranet, EDI, or Extranet) to share information with other units in the company, external customers, or external suppliers.[6] I aggregate the establishments' ICT adoption and communication to the firm level, assuming that a firm has adopted certain networks and communicates with internal and external parties if one of the firm's establishments does so. Nevertheless, my empirical results are robust to alternative aggregation methods such as taking averages across the firm's establishments. I use communication pattern variables combined with the ICT adoption variables to show the relationship between firms' ICT adoption and communication, particularly within-firm communication.

Using the consistent FIRMID available in both the CNUS and the LBD, I create a matched sample of these two datasets, which allows me to directly link firms' geographic span of control and their ICT adoption.

Finally, I use the Census of Auxiliary Establishments (AUX) to obtain headquarters information for firms with stand-alone headquarters. The AUX is collected every five years, on years ending in 2 and 7, and covers nonproduction establishments of multi-uint firms such as their R&D centers and corporate headquarters. I augment the LBD with the AUX to identify firm headquarters' employment, payroll, and locations.[7]

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[6]The types of information include design specifications, product catalogs, demand projections, order statuses, production schedules, inventory data, and logistics and transportation information.

[7]Appendix A.1.1 documents details of how I identify firm headquarters.

Summary statistics. As the detailed variables regarding firms' ICT adoption are not available for nonmanufacturing firms, I use firms in the manufacturing sector for the main analysis. However, I show in the appendix that sectors other than the manufacturing sector experienced extensive geographic expansion as well. To document the trend of firms' increasing geographic span of control, I rely on the LBD for the census years between 1977 and 2012, i.e., years ending in 7 or 2. Panel A of Table 2.1 reports the firm-level summary statistics. There are 2,311,000 firm-year observations and 289,000 firms, on average, in each of the eight census years. Approximately 4% of the firms are multi-unit firms with more than one establishment. I restrict to a balanced sample of firms from 1987 to 2007 for the reduced-form analysis in Section 2.3, so the number of observations is smaller for the reduced-form estimations. The balanced sample includes approximately 33,500 firms and thus 702,000 firm-year observations for the twenty-one years from 1987 to 2007. Panel B of Table 2.1 shows that firms in the balanced sample are larger and more likely to be multi-unit firms. An average firm in this sample has 1.34 establishments.

Table 2.2 reports summary statistics of firms in the CNUS sample, which includes 18,500 observations. Panel A delineates the state of technology adoption at the end of the twentieth century. The adoption rate of the basic Internet is high: 72.6% of firms were connected to the Internet in 1999, showing that the Internet was available to most businesses by the beginning of the 2000s. LANs, which did not require internet connections, also had a high adoption rate of approximately 64%. However, the adoption rate was low for technologies such as Intranets, EDIs, and Extranets, which relied on high-speed internet and more sophisticated infrastructure.[8] Panel B shows that approximately one-third of firms share information inside the firm. A similar share of firms indicate that they share information with customers, while more firms—over half—share information with their suppliers. Panel C shows summary statistics for other firm characteristics. As the Annual Survey of Manufacturers tends to cover larger firms, particularly multi-unit firms, 35.7% of

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[8]Forman et al. (2003) and Forman et al. (2012) use an alternative dataset, the Harte-Hanks Market Intelligence CI Technology database, and document similar patterns of a high adoption rate for the basic Internet but a relatively low rate for Internet-enabled applications that enhance business processes.

Table 2.1: Summary Statistics of Longitudinal Business Database, Manufacturers

	N	Mean	S.D.
A. Full Sample, 1977–2012 Census Years			
Employment	2,311,000	53.8	428.2
Payroll (in thousands)	2,311,000	1759	23690
Multi-unit firm	2,311,000	0.039	0.193
Number of establishments	2,311,000	1.105	1.205
B. Balanced Sample, 1987–2007			
Employment	702,000	119.10	920.10
Payroll (in thousands)	702,000	4502	47010
Multi-unit firm	702,000	0.084	0.278
Number of establishments	702,000	1.340	2.354

Notes: This table shows summary statistics of firms in the manufacturing sector from the Longitudinal Business Database. Each firm is a FIRMID×6-digit NAICS industry pair. Panel A presents summary statistics for the sample with observations in census years from 1977 to 2012, i.e., years ending with 7 and 2. There are eight census years during this period. Panel B restricts to the balanced sample from 1987 to 2007 and presents summary statistics for the sample with observations in each year. There are twenty-one years during this period. Multi-unit firm is an indicator set to one if a firm has more than one establishment.

firms in the CNUS sample are multi-unit, with 2.3 establishments on average.

I merge the LBD balanced sample with the 1999 CNUS sample and create a matched LBD-CNUS sample. Approximately 14% of the firms in the LBD balanced sample are matched to the CNUS. Because the CNUS has wide coverage of multi-unit firms, the matching rate is higher for such firms: over 70% of them are matched.[9] While the matched sample is a selected sample with many large and multi-unit firms, these firms substantially enlarged their geographic span of control, and the rich data on their ICT adoption can help us study the role of ICT in these firms' geographic expansion. Moreover, multi-unit firms account for a majority of US employment in the manufacturing sector, and thus an understanding of how ICT affects their geographic span of control can have important aggregate implications.

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[9]Appendix Table A.1 compares the share of multi-unit firms, the number of establishments per firm, and the logarithm of employment for matched and unmatched firms in the balanced LBD sample.

Table 2.2: Summary Statistics of 1999 Computer Network Use Supplement

	N	Mean	S.D.
A. ICT Adoption			
Internet	18,500	0.726	0.446
Intranet	18,500	0.307	0.461
Electronic data interchange (EDI)	18,500	0.235	0.424
Extranet	18,500	0.070	0.254
Local area network (LAN)	18,500	0.641	0.480
Others	18,500	0.058	0.234
B. Communication			
Within Firm	18,500	0.338	0.473
Customers	18,500	0.294	0.456
Suppliers	18,500	0.533	0.499
C. Other Firm Characteristics			
Multi-unit firm	18,500	0.357	0.479
Number of establishments	18,500	2.317	4.262
Number of workers	18,500	322.6	1128
Number of production workers	18,500	239.0	853.8
Salary and wages (in thousands)	18,500	12790	59530
Production workers wages (in thousands)	18,500	8125	42520
Sales (in thousands)	18,500	103200	829800
Capital (in thousands)	18,500	41350	233100

Notes: This table shows summary statistics of firms in the Computer Network Use Supplement to the 1999 Annual Survey of Manufactures. Each firm is a FIRMID×6-digit NAICS industry pair. Panel A presents summary statistics for firms' ICT adoption. Each variable is an indicator set to one if the firm is connected to a type of networks. Panel B presents summary statistics for firms' communication patterns. Each variable is an indicator set to one if the firm communicates with other company units, external customers, and external suppliers, respectively. Panel C presents summary statistics for other firm characteristics. Multi-unit firm is an indicator set to one if a firm has more than one establishment. Sales is total value of shipments. Capital is the book value of fixed assets at the end of the year.

2.2.2 Stylized Facts

Fact I: Firms' increasing geographic span of control

Figure 2.1 shows that multi-unit firms have experienced significant expansion over the past three decades. The average number of establishments increased from 3.5 to 4 establishments, representing a 15.6% increase. The growth was largest during the mid-1990s and early 2000s, when information and communication technology, especially the Internet enabled technology, underwent rapid development. Firms' geographic expansion was not an exception confined to manufacturers but rather a secular trend in many sectors. As shown in Figure A.1, where I consider all sectors, the growth rate is even larger for nonmanufacturing sectors.[10] Here, a firm is defined by a FIRMID and 6-digit NAICS industry pair, so the increasing number of establishments captures firms' geographic expansion. To offer a contrast with the span of control from the industry composition perspective, I use an alternative definition of the firm based on the FIRMID. Figure A.2 plots the average number of industries and establishments for manufacturing firms that operate in either multiple locations or multiple industries, where the industry is at the 6-digit NAICS level. The average number of industries, in contrast to the average number of establishments, decreased over time. Combined with the within-industry geographic expansion, the overall number of establishments declined in the 1980s, driven by the decreasing number of industries, and then rose from the late 1990s, driven by the increasing number of establishments within industries, i.e., geographic expansion.

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[10]Hsieh and Rossi-Hansberg (2019) and Cao et al. (2019) also find that firms expand geographically, especially in nonmanufacturing sectors such as services. Figure A.1 include firms in the following sectors: utilities (22), construction (23), manufacturing (31-33), whole- sale trade (42), retail trade (44-45), transportation and warehousing (48-49), information (51), finance and insurance (52), real estate and rental and leasing (53), professional, scientific, and technical services (54), management of companies and enterprises (55), administrative and support and waste management and remediation services (56), educational services (61), health care and social assistance (62), arts, entertainment, and recreation (63), accommodation and food services (72), and other services except public administration (81).
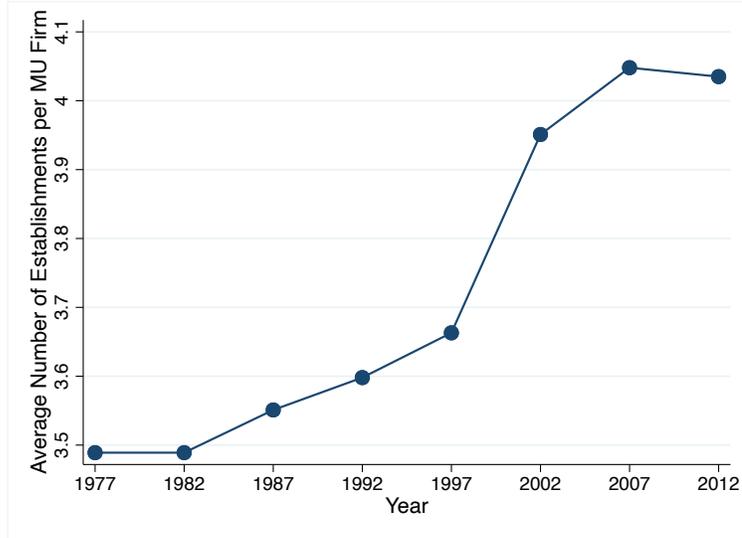
Figure 2.1: Multi-Unit Firms' Number of Establishments from 1977 to 2012

Notes: This figure plots the average number of establishments of multi-unit firms in the manufacturing sector from the Longitudinal Business Database during 1977 and 2012. Each firm is a FIRMID×6-digit NAICS industry pair. Multi-unit firms are firms with more than one establishment.

Fact II: ICT adoption and firms' geographic expansion

I use the matched LBD-CNUS sample in 1999 to link firms' geographic expansion and their ICT adoption decisions. Firms' network adoption—in particular, the *Intranet* adoption— is associated with a higher growth rate in firms' geographic span of control. I present the results in a regression framework:

$$\Delta\text{NumEstab}_{i,97-02} = \alpha + \beta_1\text{Intranet}_{i,99} + \beta_2\text{EDI}_{i,99} + \beta_3\text{Extranet}_{i,99}$$

$$+ \beta_4\text{Internet}_{i,99} + \beta_5\text{LAN}_{i,99} + X_{i,97}\gamma + \varepsilon_{i,97-02}, \qquad (2.1)$$

where the dependent variable ($\Delta\text{NumEstab}_{i,97-02}$) is the growth rate in the number of establishments of firm i from 1997 to 2002 ($= \log(\text{NumEstab}_{i,02}) - \log(\text{NumEstab}_{i,97})$), the five-year period covering the year 1999, and independent variables include indicators set to one if the firm installed an Intranet, an EDI, an Extranet, the Internet, or a LAN. To account for firm heterogeneity in, for example, initial conditions, I include controls for a

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vector of firm characteristics including the logarithm of employment, firm age fixed effects, and state fixed effects at the beginning of the period $(X_{i,97})$. Since technology intensity may differ across industries, I also include industry fixed effects at the 4-digit NAICS level.

Column (1) of Table 2.3 shows that having an Intranet installed by 1999 is associated with a 7.1-percentage-points larger growth rate in a firm's number of establishments from 1997 to 2002. If we take into account that the average growth rate was 5.9 percentage points during this period, the estimated coefficient is equivalent to a 1.2 fold increase. Compared to the significant effect of Intranet adoption, the coefficient estimates for adoption of other networks are statistically nonsignificant and economically small. As the network adoption data are available only for 1999, it is possible that firms adopted these networks after 1999. If so, my estimate may be considered a lower bound of the overall effect.

This result suggests that having an Intranet, which is supposed to reduce within-firm communication costs, helps firms increase their geographic span of control. To further corroborate the role of Intranets in facilitating within-firm communication, I leverage variables from the CNUS data on firms' communication patterns.

Table 2.3: ICT Adoption, Communication Patterns, and Geographic Expansion

	Growth Rate in	Communication		
	Number of Estab's (1)	Within-Firm (2)	Customer (3)	Supplier (4)
Intranet	0.071** (0.032)	0.303*** (0.014)	0.107*** (0.014)	0.060*** (0.016)
Electronic data interchange (EDI)	0.011 (0.037)	0.055*** (0.011)	0.093*** (0.014)	0.101*** (0.014)
Extranet	0.042 (0.047)	0.081*** (0.015)	0.177*** (0.018)	0.060*** (0.016)
Internet	0.021 (0.015)	0.085*** (0.008)	0.128*** (0.009)	0.306*** (0.012)
Local area network (LAN)	0.008 (0.015)	0.065*** (0.009)	0.071*** (0.011)	0.167*** (0.014)
N	4500	18500	18500	18500
Avg. dependent variable	0.059	0.258	0.251	0.456
R^2	0.082	0.484	0.311	0.343
Firm controls	Y	Y	Y	Y
Firm age FE	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y
State FE	Y	Y	Y	Y

Notes: This table estimates regressions of the form:

$$Y_i = \alpha + \beta_1 \text{Intranet}_i + \beta_2 \text{EDI}_i + \beta_3 \text{Extranet}_i + \beta_4 \text{Internet}_i + \beta_5 \text{LAN}_i + X_i \gamma + \varepsilon_i,$$

where independent variables are indicators set to one if firm i adopted Intranet, Electronic data interchange (EDI), Extranet, Internet, and Local area network (LAN) by 1999. X_i is a vector of firm characteristics. Column (1) uses the matched sample of the Longitudinal Business Database and the Computer Network Use Supplement. The dependent variable is the firm's growth rate in the number of establishments from 1997 to 2002. Firm controls include firms' initial condition, i.e., the logarithm of employment in 1997 and firm age fixed effect, as well as state and industry fixed effects. Column (2)–(4) use the Computer Network Use Supplement. The dependent variables are indicators set to one if any establishment of the firm provides information to other company units, external customers, and external suppliers, respectively. Firm controls include the logarithm of capital to labor ratio, the logarithm of employment in 1999, the skill mix measured by the ratio of non-production workers to production workers, firm age fixed effect, state fixed effect, and industry fixed effect. Industry is at the 4-digit NAICS level. Regressions are weighted by the weights provided in the Annual Survey of Manufacturers. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Fact III: ICT adoption and within-firm communication

I use CNUS data to provide evidence that one important channel through which the Intranet facilitates firms' geographic expansion is through reducing communication costs inside the firm. To show this, I estimate the following regression:

$$\text{Communication}_{i,99} = \alpha + \beta_1 \text{Intranet}_{i,99} + \beta_2 \text{EDI}_{i,99} + \beta_3 \text{Extranet}_{i,99}$$

$$+ \beta_4 \text{Internet}_{i,99} + \beta_5 \text{LAN}_{i,99} + X_{i,99}\gamma + \varepsilon_{i,99}, \qquad (2.2)$$

where the dependent variable is an indicator set to one if any establishment of firm i shares information with other company units. The independent variables are the same as in Equation (2.1) and represent firms' network adoption. Taking advantage of the rich data from the Annual Survey of Manufacturers, I am able to control for a wider set of firm characteristics, including the logarithm of employment, the logarithm of the capital to labor ratio, and the skill mix, measured by the ratio of nonproduction workers to production workers. I also include state and industry fixed effects.

Column (2) of Table 2.3 confirms that firms with an Intranet are more likely to communicate within the firm and that the Intranet is the most important type of network in terms of their effects on within-firm communication. While all network types are positively correlated with firms' internal communication, the estimated coefficient on Intranet adoption is the largest in magnitude. For instance, the coefficient on Intranet adoption is 3.5 times larger than on the Internet adoption.

As this regression exploits cross-sectional variation, one may be concerned that a firm's Intranet adoption is correlated with unobserved firm characteristics. Although communication is less likely to suffer from endogeneity issues than firm size and performance, I show that Intranet adoption matters less for firms' external communication. If the result for within-firm communication is driven by unobservables that are positively correlated with Intranet adoption, the estimate of the effect of Intranet adoption on external communication is likely to be upward biased as well. The last two columns of Table 2.3 report the results. The dependent variables for columns (3) and (4) are indicators set to one if any

of the firm's establishments communicates with external customers and suppliers, respectively. Extranet adoption turns out to be the most important network for communication with customers and Internet adoption for that with for suppliers. It is reassuring that Intranets play a small role in firms' communication with external parties, suggesting that their large effect on internal communication—and geographic expansion—is not merely driven by unobserved firm characteristics. Therefore, I use Intranet adoption as a proxy for firms' internal communication costs in the rest of the paper.

In the next section, I go a step beyond the correlation and leverage plausibly exogenous variation from a historical event to establish a causal relationship between ICT and firms' geographic expansion.

2.3 Reduced-Form Evidence From Internet Privatization

This section shows that improving ICT plays an important role in facilitating firms' geographic expansion. I exploit natural experimental variation from a milestone in US Internet history—the Internet privatization. The explosive development in ICT, especially Intranet, following privatization allowed firms to widen their geographic span of control.

2.3.1 The Internet Privatization

The development of the Internet has been a key part of the recent history of information and communication technology. From the time of early dial-up access to the broadband era, improvements to the Internet, including the provision of faster speeds and development of various applications, have changed every aspect of business activities. Prior to 1995, the Internet was nothing like what it currently is. The foundation of today's Internet was the National Science Foundation Network (NSFNET), the first high-speed Internet backbone in the US, launched in 1986 and operated by the government through the NSF. By the early 1990s, NSFNET connected sixteen node sites across the US. These node locations reflected historically contingent factors related to their proximity to military bases and university
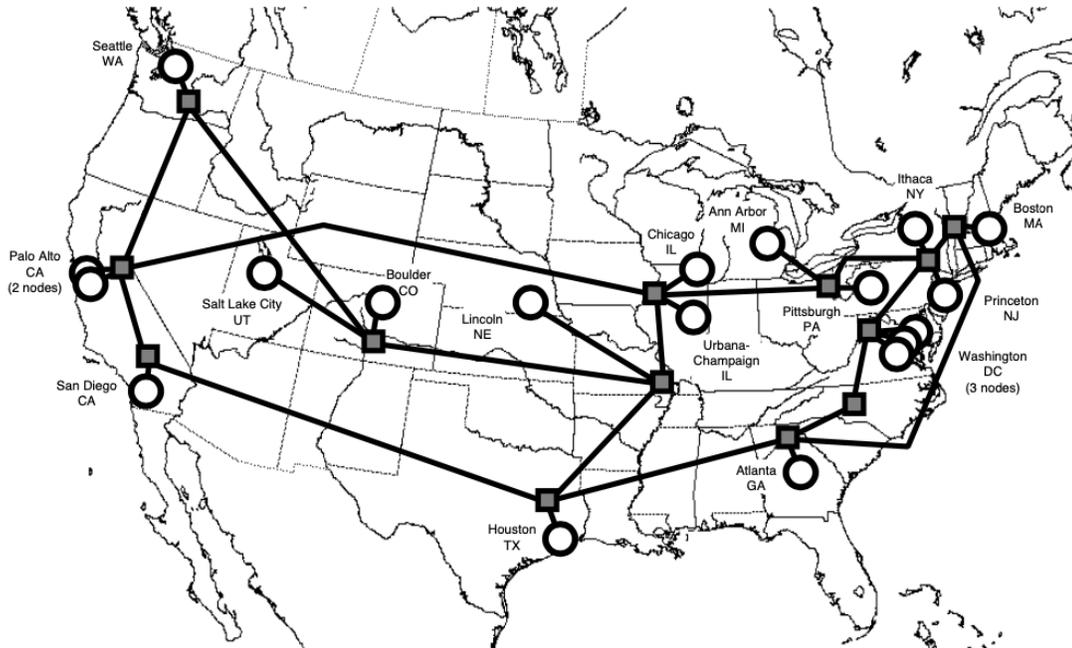
Figure 2.2: Map of the NSFNET in 1992

Notes: This figure shows the NSFNET backbones and its node sites in 1992. The circles represent the exterior nodes at the following cities: Princeton (NJ), San Diego (CA), Champaign (IL), Ithaca (NY), Pittsburgh (PA), Boulder (CO), Salt Lake City (UT), Palo Alto (CA), Seattle (WA), Lincoln (NE), Houston (TX), Ann Arbor (MI), College Park (MD), Atlanta (GA), Argonne (IL) and Cambridge (MA). The shaded square represent interior nodes connecting the exterior nodes. The black lines represent traffic flows on the network. This figure is downloaded from GenBank database at the San Diego SuperComputer Center: `ftp://genbank.sdsc.edu/pub/sdsc/anr/maps/NSFNET/t3.ps`

locations.[11] As shown in Figure 2.2, these nodes were located in Ithaca, Princeton, San Diego, Champaign, Boulder, and Lincoln, among other locations. Additionally, NSFNET utilized a three-tiered architecture. Each node was connected to regional networks, which were in turn linked to the backbone.

NSFNET was originally for the use of the research and higher education community, so commercial use was restricted. With exploding interest and demand from the commercial side, however, these restrictions were gradually lifted. Eventually, in the early 1990s, the

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[11]Several NSFNET node locations were inherited from the Advanced Research Projects Agency Network (ARPANET)—NSFNET's predecessor, a military-funded Internet backbone run by the Department of Defense.

Internet—once a government asset—was handed over to the private sector. Privatization of the Internet was finalized on April 30, 1995. Following privatization, the "Internet gold rush" started. I exploit this historical event and use the privatization of NSFNET as a natural experiment. As Greenstein (2015) notes on the role of privatization in catalyzing the explosive development in Internet-related industries, *"The complexity of privatization made it difficult for any observers to grasp the consequences of the NSF privatization... A commercially viable working prototype could not exist until the NSF finished announcing its privatization plan."*[12]

The slow-growing number of Internet service providers before 1995 and the market explosion shortly after 1995 reflect the critical role of the Internet privatization. This further justifies my empirical strategy, which uses this event as an exogenous shock to the information and communication technology.

2.3.2   Empirical Approach

I use the distance from a firm's headquarter to the nearest NSFNET node site to measure the firm's exposure to the Internet privatization. Locations closer to these nodes had better infrastructure, such as underground fiber optic lines, which was crucial for Internet access. Businesses often access the Internet through leased lines, which requires physical lines near the companies. As the construction and installation of circuits is one major cost for internet service providers, the costs of Internet access for businesses were lower if they were in locations with better infrastructure.[13] In addition, many NSFNET nodes were located

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[12]The conversation concerning privatization of the Internet started from the early 1990s. In approximately 1992, policies that allowed commercial businesses to connect to the Internet were implemented. Nevertheless, final privatization of the Internet in 1995 served as a catalyst of the "Internet gold rush."

[13]McKnight and Bailey (1998) document that costs for leased lines and routers accounted for 80% of total NSFNET costs. Bloom et al. (2014) use country-level variations in the leasing of telephone lines to instrument for firms' probability of adopting an Intranet; they use the distance to the headquarter of SAP—a world leading enterprise resource planning (ERP) provider—to measure firms' probability of adopting ERP software. Forman et al. (2012) use county-level variation of the number of nodes for ARPANET—the predecessor

on university campuses, where more talent was able to provide ICT services.

My empirical approach builds on the idea that firms located closer to the Internet backbone nodes were more able to seize the benefits following the Internet privatization. The reduced-form analysis takes the form of a difference-in-differences regression framework:

$$Y_{it} = \alpha_i + \beta \text{HQDistToNode}_i \times \text{Post}_t + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it}, \qquad (2.3)$$

where Y_{it} is a measure of the geographic span of control of firm i in year t, α_i is firm fixed effects, HQDistToNode_i is the distance (in hundreds of miles) of the ZIP code in which firm i is headquartered to the nearest NSFNET node, and Post_t is an indicator set to one for years from 1995 onward. The coefficient of interest is β, which measures the effect of the Internet privatization on a firm geographic span of control.

The degree of geographic expansion may differ across industries. For instance, industries with high trade costs added more establishments. To account for differential industry trends, I include industry-year fixed effects, where the industry is at the 4-digit NAICS level. I also include state-year fixed effects to ease the concern that the results are driven by differential expansion patterns across locations, e.g., due to state fiscal policies.

One may be concerned that firm growth may be correlated with local conditions. To control for potential local shocks that affect firms' expansion decisions, in some specifications I include a set of county-year-specific characteristics such as the logarithm of the population and median household income, the shares of the Black population and of people over 65 years old, and the share of adults with bachelor's degrees.

Local infrastructure characteristics, such as Internet accessibility, can affect firms' location choices and thus their headquarters locations. Firms with expansion plans may choose to locate their headquarters in areas with better Internet infrastructure. To eliminate concerns regarding endogenous headquarters locations and abstract from firm entry and exit, I focus on a balanced panel of firms from 1987 to 2007 for the main reduced-form analysis. Standard errors are clustered at the firm and county levels.

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of NSFNET—as an instrument for local advanced IT investment by businesses.

First-stage evidence. Although panel data on firms' ICT adoption are not available, I use the cross-sectional data from the LBD-CNUS matched sample and firms' Intranet adoption to provide first-stage evidence. Since Internet-enabled applications such as Intranet were invented after privatization, their adoption rate in 1999 reflects the change in the likelihood of use of these technologies. I sort firms according to their distance to the nearest NSFNET node, i.e., HQDistToNode, and calculate the fraction of firms that adopted Intranet in each distance quintile. Figure 2.3 presents the relationship between the Intranet adoption rate and the distance to nodes. It shows that firms located closer to nodes were more likely to have adopted Intranet in 1999 after the Internet privatization, indicating that the distance measure can capture heterogeneity in the effect of the Internet privatization on Intranet adoption.

Graphical evidence The key identification assumption is that the Internet privatization did not coincide with other location-by-year shocks, as the distance measure uses the firm's headquarter location. To validate this assumption, I first show graphical evidence that firms located close to nodes had a geographic span of control similar to those firms located farther away. I show this by estimating the following regression, which allows the coefficient on the interaction term in Equation (4.8) to vary for each year:

$$Y_{it} = \alpha_i + \beta_t \text{HQDistToNode}_i + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it}. \tag{2.4}$$

Here, I use the number of establishments of firm i in year t to measure the firm's geographic span of control. The coefficients β_t measure the relationship between the firm's distance to the nearest NSFNET node and its number of establishments for each year both before and after the 1995 Internet privatization. Figure 2.4 plots the estimates of these coefficients. For easier presentation, I normalize the coefficients by the estimate in 1994, i.e., $\beta_t - \beta_{1994}$. The coefficients are precisely estimated around zero before the Internet privatization, indicating that firms with different distances to nodes had similar trends prior to privatization. The estimated coefficients are negative from 1995, indicating that firms located *closer* to NSFNET nodes had *more* establishments.
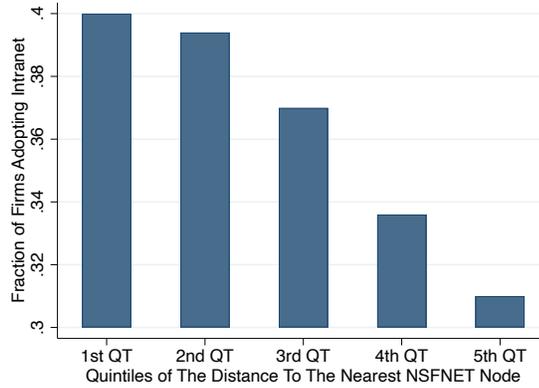
Figure 2.3: Distance to NSFNET Node and Intranet Adoption in 1999

Notes: This figure shows the relationship between firms' likelihood of adopting Intranet and their distance to the nearest NSFNET node. Particularly, I estimate the regression of the form:

$$\text{Intranet}_i = \sum_{k=1}^{5} \beta_k \mathbb{1}[\text{HQDistToNode}_i \in k\text{'s Quintile}] + \text{CountyControls}_i \gamma + \alpha_i^{\text{Industry}} + \alpha_i^{\text{State}} + \varepsilon_i,$$

where k denotes the quintile, and $\mathbb{1}[\text{HQDistToNode}_i \in k\text{'th quintile}]$ is an indicator set to one if firm i's distance belongs to the k's quintile in the distribution. CountyControls$_i$ is a vector of county characteristics, including the logarithm of the county's population and median household income, share of population below the poverty line, share of black population, share of population above 65 years old, and share of population with bachelor's degree. $\alpha_i^{\text{Industry}}$ and α_i^{State} are industry and state fixed effect, respectively. Each bar represents the coefficient β_k and is normalized by the fraction of firms adopting Intranet in the first quintile.

Following the Internet privatization, the number of establishments gradually increased for firms headquartered closer to NSFNET nodes. The gradual increase in firms' footprints may reflect the time needed to integrate ICT systems into firm operations or set up new establishments. The estimates are statistically significant at the 5% level and stable over the 2000s, suggesting that the benefits for firms close to nodes were long-lasting, e.g., due to constant arrival of new technologies or initial competitive advantages for firms expanding at an early stage.
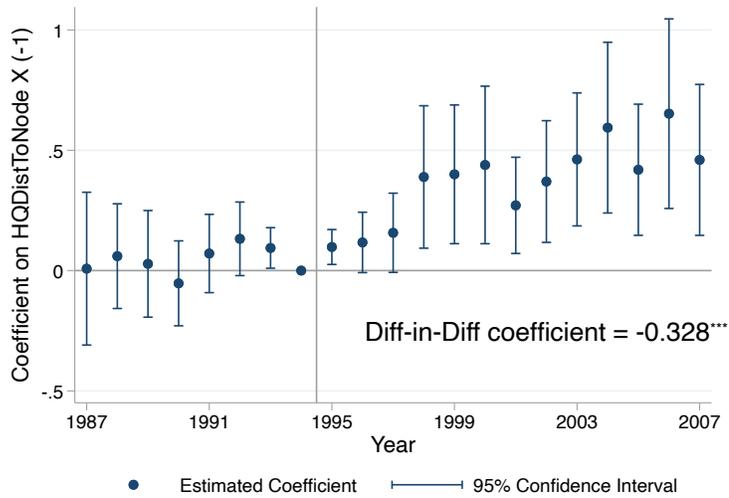
Figure 2.4: Reduced-Form Effects of Internet Privatization

Notes: This figure shows the effect of the Internet privatization on firms' geographic span of control, by estimating the regression of the form:

$$Y_{it} = \alpha_i + \beta_t \text{HQDistToNode}_i + \text{CountyControls}_i \gamma + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it},$$

where the dependent variable is the number of establishments of firm i in year t, HQDistToNode_i is the distance from the firm's headquarter to the nearest NSFNET node. CountyControls_i is a vector of county characteristics, including the logarithm of the county's population and median household income, share of population below the poverty line, share of black population, share of population above 65 years old, and share of population with bachelor's degree. $\alpha_i^{\text{Industry-Year}}$ and $\alpha_i^{\text{State-Year}}$ are industry-year and state-year fixed effect, respectively. Regression is weighted by firms' employment share. Standard errors are clustered at the firm and county level.

2.3.3   Regression Results

Table 4.3 reports the estimates from the difference-in-differences regression in Equation (4.8), which quantifies the effect of the Internet privatization on firms' geographic span of control. Regressions are weighted by firm employment shares for the baseline results. Column (1) of Panel A shows that firms located closer to NSFNET nodes experienced larger expansion after privatization. The coefficient on the interaction term between distance to the node and the postreform indicator is estimated at -0.328, indicating that firms located 100 miles *closer* to a node are associated with 0.328 *more* establishments after privatization. As the average distance is approximately 130 miles, the Internet privatization increased firms' geo-

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graphic span of control, on average, by $0.426 (= 0.328 \times 130/100)$ establishments. Given the average of 5.016 establishments per firm, this translates into a $8.5\% = 0.426/5.016 \times 100$ increase. Column (2) includes time-varying county characteristics as additional controls. The point estimate is similar, which reassures us that the effect is not driven by shocks to local conditions such as local population or education levels.

Column (3) of Panel A restricts the estimation sample to multi-unit firms and yields an estimate of -0.442. Given an average number of establishments of 8.841, this estimate implies an increase of $6.5\% (= 0.442 \times 130/8.841)$ for multi-unit firms. Another way to interpret the magnitude is to compare to the overall increase after privatization. As shown in Figure 2.1, the average number of establishments for multi-unit firms increased by approximately 12% during the postprivatization period. That is, the increase attributable to the Internet privatization accounts for half of the overall increase in multi-unit firms' number of establishments. One caveat is that the effect implied by the difference-in-differences estimate is a partial equilibrium effect, while the overall increase may reflect the general equilibrium effect. I further investigate the general equilibrium effect of the Internet privatization through the lens of a quantitative model in Section 4.5.

Table 2.4: Effects of the Internet Privatization on Firms' Geographic Expansion

	Number of Establishments				
	Baseline (1)	County Controls (2)	Multi-unit Firms (3)	Unweighted (4)	IPW (5)
HQDistToNode × Post	-0.328***	-0.323***	-0.442**	-0.044**	-0.065***
	(0.098)	(0.097)	(0.191)	(0.017)	(0.023)
N	702000	702000	34500	702000	702000
Avg. Dep. Var	5.016	5.016	8.841	1.340	1.179
R^2	0.899	0.899	0.897	0.865	0.915
County controls		Y	Y	Y	Y
Industry-Year	Y	Y	Y	Y	Y
State-Year	Y	Y	Y	Y	Y

Notes: This table estimates regressions of the form:

$$Y_{it} = \alpha_i + \beta \text{HQDistToNode}_i \times \text{Post}_t + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it},$$

where the dependent variable is the number of establishments of firm i in year t, α_i is firm fixed effect, HQDistToNode_i is the distance from the ZIP code firm i is headquartered to its nearest NSFNET node (in 100 miles), and Post_t is an indicator set to one for years since 1995. $\alpha_i^{\text{Industry-Year}}$ and $\alpha_i^{\text{State-Year}}$ are industry-year and state-year fixed effects, respectively. Column (1) reports the baseline results. Column (2) includes county characteristics as additional controls, including the logarithm of population and median household income, the share of black population and the elderly over 65 years old, and the share of adults with bachelor's degrees. Column (3) restricts the sample to firms that are multi-unit throughout the sample period from 1987 to 2007. Regressions in column (1)–(3) are weighted by the firm's employment share. Column (4) reports the unweighted regression result. Column (5) reports the regression result weighted by the inverse propensity scores detailed in Appendix Section A.2.1. Standard errors are clustered at the firm and headquarter county level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Robustness

Columns (4) and (5) of Panel A in Table 4.3 show that the result is robust to alternative weighting schemes. Column (4) shows estimates from the unweighted regression. The difference-in-differences coefficient is estimated at -0.044, equivalent to an increase of 4.3% ($= 0.044 \times 130/1.340$). The magnitude is approximately half that of the baseline estimate, where the regression is weighted by firm employment share, indicating that privatization had larger impacts on large firms.

One may be concerned that firms located closer to NSFNET nodes are different from those located far away and that locations near nodes might have larger populations or a higher education level. Although the event study graph shows that these firms had common trends before the Internet privatization, I construct the propensity scores of treatment, conditional on firm and county characteristics before privatization, and apply the inverse propensity score method to reweight the observations. Adjusting firms' makes faraway firms similar to nearby firms. As distance to the node is a continuous measure, I construct generalized propensity scores (see Robins et al., 2000; Hirano and Imbens, 2004; Abadie, 2005). Appendix A.2.1 provides more details on how I construct these scores. Figure A.3 shows that after the propensity score reweighting, firms are balanced in both firm and county characteristics. Column (5) of Panel A in Table 4.3 reports the result. The reweighted difference-in-differences estimate is 0.065. This estimate translates into a 7.2% increase in the firm's number of establishments, similar to the 8.5% increase from the baseline regression.

As another robustness check to address the potential endogeneity of firms' headquarter locations, I test whether the effect of the Internet privatization differs for firms headquartered in different ranges of distance to NSFNET nodes. If these node locations were chosen for their proximity to "intellectual hubs" and nearby firms disproportionately benefited from privatization, we should see stronger effects at shorter distances. I perform the test by grouping firms into ten equal-size bins according to their distance to nodes (i.e., HQDist-

ToNode) and estimating the following regression:

$$Y_{it,k} = \alpha_i + \sum_{k=1}^{10} \beta_k \text{HQDistToNode}_i \times \text{Post}_t + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it,k}, \qquad (2.5)$$

where $Y_{it,k}$ is the number of establishments of firm i in year t and k indicates that firm i belongs to the k'th distance bin. Panel A of Figure A.4 plots the estimated coefficient $\hat{\beta}_k$ for each distance bin. All estimates are negative, indicating that within any distance bin, firms headquartered closer to nodes increase their number of establishments. To interpret the magnitude of these estimates, I calculate the effect of the Internet privatization by $\text{Effect}_k = \beta_k \times \overline{\text{HQDistToNode}}_k$, where $\overline{\text{HQDistToNode}}_k$ is the average distance for distance bin $k = 1, \cdots, 10$. Panel B plots these estimated effects, which range from 0.25 to 1.79. Moreover, the effect is larger for firms that are headquartered far away from the nodes. Taken together, these results confirm that firms' initial selection into different locations is unlikely to drive the baseline difference-in-differences estimate.

Table 2.5 uses alternative measures of firms' geographic span of control as the dependent variable. Columns (1)–(3) report the estimation results for the number of counties, states, and census divisions in which a firm operates, respectively. The estimated coefficients are statistically significant and economically meaningful. The Internet privatization increased firms' geographic coverage by 7% at the county level, 5.5% at the state level, and 2.6% at the census division level. These results show that the baseline result is not driven by firms opening establishments in nearby locations but instead captures broad geographic expansion. Columns (4) and (5) of Panel B consider the number of establishments outside the headquarter state and at a nondrivable distance (i.e., over 250 miles away) from the headquarter, respectively. The estimated coefficients are similar to the baseline estimate, indicating that the increasing number of firm establishments is driven by those located far away from firms' headquarters.

Table 2.5: Effects of the Internet Privatization on Firms' Geographic Expansion: Alternative Measures of Firms' Geographic Span of Control

Number of	Counties	States	Census Divisions	Out-of-State Establishments	Non-Drivable Establishments
	(1)	(2)	(3)	(4)	(5)
HQDistToNode×Post	-0.249***	-0.144***	-0.048**	-0.326***	-0.321***
	(0.082)	(0.044)	(0.019)	(0.092)	(0.090)
N	702000	702000	702000	702000	702000
Avg. Dep. Var	4.587	3.406	2.439	3.777	3.327
R^2	0.916	0.928	0.921	0.896	0.887
County controls	Y	Y	Y	Y	Y
Industry-Year	Y	Y	Y	Y	Y
State-Year	Y	Y	Y	Y	Y

Notes: This table estimates regressions of the form:

$$Y_{it} = \alpha_i + \beta \text{HQDistToNode}_i \times \text{Post}_t + \text{CountyControls}_{it}\gamma + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it},$$

where the dependent variable is a measure of the geographic span of control of firm i in year t, α_i is firm fixed effect, HQDistToNode_i is the distance from the ZIP code firm i is headquartered to its nearest NSFNET node (in 100 miles), Post_t is an indicator set to one for years since 1995, and $\text{CountyControls}_{it}$ is a vector of county characteristics, including the logarithm of population and median household income, the share of black population and the elderly over 65 years old, and the share of adults with bachelor's degrees. $\alpha_i^{\text{Industry-Year}}$ and $\alpha_i^{\text{State-Year}}$ are industry-year and state-year fixed effects, respectively. The dependent variables for column (1)–(3) are the number of counties, states, and census divisions where the firm has establishments. The dependent variable for column (4)–(5) are the firm's number of establishments that are out of the headquarter's state and that are non-drivable from the headquarter, i.e., the establishments located over 250 miles away from the firm's headquarter. Regressions are weighted by the firm's employment share. Standard errors are clustered at the firm and headquarter county level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Intensive-margin effects. To highlight firms' expansion at the extensive margin, i.e., geographic expansion, I compare it to firms' overall expansion and expansion at the intensive margin, such as employment. Table A.2 reports the difference-in-differences estimates of the Internet privatization on firms' employment, employment per establishment, and wage rate. In line with the geographic expansion, the estimate for the firm's total employment is negative and statistically significant at the 10% level, indicating that privatization increased the firm's overall size. However, privatization did not have significant effects on the establishment size or wages.

Location of new establishments. Finally, I test whether firms close to nodes are more likely to set up establishments also close to the nodes. I run the baseline difference-in-differences regression using the average distance from *new establishments* of their firms to the nearest NSFNET nodes as the dependent variable. As shown in column (1) of Table A.3, the estimated coefficient is positive and statistically significant, indicating that firms headquartered in locations *closer* to nodes—those with better access to ICT—also build new establishments *closer* to the nodes. This is consistent with our premise that interlocutors at both ends of the communication channel need access to ICT. The distance to nodes, however, might be correlated with other location characteristics. Columns (2)–(7) of Table A.3 show the results with the average county characteristics of new establishments as dependent variables. For instance, column (2) shows that firms headquartered closer to nodes tend to set up establishments in counties with larger populations, but the difference is not statistically distinguishable from zero. Overall, these results suggest that firms with better access to the Internet tended to locate new establishments in counties with higher household income and younger populations and with smaller distances to nodes.

2.3.4 Firms' Internal Communication and Geographic Expansion

The reduced-form results show that the Internet privatization, which reduced the costs of accessing the Internet and ICT in general, increased firms' geographic span of control.

Multiple channels could be at play in this effect. In this section, I use the LBD-CNUS matched sample and firms' Intranet adoption as a proxy for internal communication costs to highlight the channel of firms' declining internal communication costs as a result of privatization. Specifically, I take advantage of the previous reduced-form analysis and use an instrumental variable approach to identify the effect of Intranet adoption on firms' geographic span of control.

Ideally, I would like to have a panel that records firms' Intranet adoption before and after the Internet privatization. This type of panel data, unfortunately, is not available. Nevertheless, as internet-based Intranets were first commercialized in 1996, after the Internet privatization, I create a time-varying indicator of a firm's Intranet status by interacting the firm's Intranet adoption in 1999 with a postprivatization indicator, i.e., $\text{Intranet}_{it} = \text{Intranet}_i \times \text{Post}_t$ for firm i in year t. The goal is to relate the firm's Intranet adoption to its geographic expansion. The regression representing this relationship is as follows:

$$Y_{it} = \alpha_i + \gamma\text{Intranet}_{it} + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it}, \tag{2.6}$$

where the dependent variable is the number of establishments of the firm and α_i is firm fixed effects. One concern is that the firm's ICT adoption might be correlated with its geographic expansion. For instance, a firm may expand and then decide to upgrade its internal management system, leading to reverse causality. To address this concern, I use the variation from the Internet privatization (i.e., $\text{HQDistToNode}_i \times \text{Post}_t$) to instrument for firms' Intranet adoption (i.e., Intranet_{it}). The IV regression takes the same form of Equation (2.6), but replaces the firm's Intranet adoption status with its predicted likelihood of Intranet adoption:

$$Y_{it} = \alpha_i + \gamma\widehat{\text{Intranet}}_{it} + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it}, \tag{2.7}$$

where $\widehat{\text{Intranet}}_{it}$ is generated by the first-stage regression:

$$\text{Intranet}_{it} = \alpha_i + \beta\text{HQDistToNode}_i \times \text{Post}_t + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it}. \tag{2.8}$$

As the firms in the matched sample are, on average, larger and more likely to be multi-unit firms than firms in the baseline sample for the reduced-form analysis, I estimate the conditional probability of a firm belonging to the matched sample, i.e., the propensity score, and then apply the inverse propensity scores to reweight the matched subsample (see Chen, Hong, and Tarozzi, 2008). Finally, I use the matched sample up to 1999 to minimize the scope of measurement errors resulting from the construction of my time-varying Intranet variable. Table 2.6 reports the results. Column (1) shows the first-stage estimate from Equation (2.8), showing that firms closer to NSFNET nodes were more likely to adopt Intranet after the Internet privatization. Column (2) shows the reduced-form estimate, which is consistent with the baseline estimates.[14] The IV estimate in column (3) shows that firms that adopted Intranet are associated with 1.235 more establishments, almost doubling the number relative to the average of 1.326. The exclusion restriction is that the instrument affects firms' geographic span of control only through their Intranet adoption. To test whether other online advanced applications affect the outcome, I follow the same procedure as that used to build the Intranet measure and construct the indicator AdvancedOnlineNetwork$_{it}$, which represents firms' adoption of a broader set of advanced online networks (i.e., Intranet, Extranet, or EDI) and is set to one if a firm adopted any of these networks. Column (4) shows the corresponding estimate from the IV regression. While the first-stage F-statistic is smaller than that from the Intranet regression, the point estimate is similar, which reassures us that the effect of Intranet adoption is unlikely to be driven by adoption of other types of ICT.

Taken together, the difference-in-differences estimates based on the use of the Internet privatization as a natural experiment for firms' ICT adoption suggest that firms with better ICT access were able to expand geographically. The instrumental variable approach further underscores the role of Intranet adoption—and with the declines in firms' internal communication costs—in facilitating firms' geographic expansion.

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[14]The reduced-form estimate is smaller than the baseline difference-in-differences estimates in the regressions weighted by firm employment shares but is almost the same as the unweighted one, suggesting that the inverse propensity score-adjusted regressions on the matched sample represent the full baseline sample well.

In the next chapter, I build and estimate a structural model to investigate the general equilibrium effects and efficiency gains from the Internet privatization and shed light on policy designs by conducting counterfactual exercises.

Table 2.6: Effects of ICT on Firms' Geographic Expansion

	Intranet	Number of Establishments		
	First Stage (1)	Reduced Form (2)	IV (3)	IV (4)
Intranet			1.235** (0.531)	
HQDistToNode × Post	-0.033*** (0.008)	-0.043*** (0.014)		
AdvancedOnlineNetwork				1.264* (0.672)
N	58000	58000	58000	58000
Avg. Dep. Var	0.143	1.326	1.326	1.326
F-stat			15.27	7.221
County Controls	Y	Y	Y	Y
Industry-Year FE	Y	Y	Y	Y
State-Year FE	Y	Y	Y	Y

Notes: This table uses the balanced panel from 1987 to 1999 to estimate the effect of Intranet adoption on firms' geographic span of control. Column (1) estimates the regression

$$\text{Intranet}_{it} = \alpha_i + \beta \text{HQDistToNode}_i \times \text{Post}_t + \text{CountyControls}_{it}\gamma + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it},$$

where the dependent variable is a time-varying variable of a firm's Intranet status by interacting the firm's Intranet adoption in 1999 and a post privatization indicator, α_i is firm fixed effect, HQDistToNode_i is the distance from the ZIP code firm i is headquartered to its nearest NSFNET node (in 100 miles), Post_t is an indicator set to one for years since 1995, and $\text{CountyControls}_{it}$ is a vector of county characteristics, including the logarithm of population and median household income, the share of black population and the elderly over 65 years old, and the share of adults with bachelor's degrees. $\alpha_i^{\text{Industry-Year}}$ and $\alpha_i^{\text{State-Year}}$ are industry-year and state-year fixed effects, respectively. Column (2) estimates the regression of the same form as column (1) but replaces the dependent variable by the number of establishment of firm i in year t, i.e., Y_{it}. Column (3) estimates regressions of the form:

$$Y_{it} = \alpha_i + \gamma \widehat{\text{Intranet}}_{it} + \text{CountyControls}_{it}\gamma + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it},$$

where the dependent variable is the number of establishment of firm i in year t, $\widehat{\text{Intranet}}_{it}$ is predicted values generated by the first-stage regression in column (1). Column (4) estimates the regression of the same form as column (3) but replaces the predicted values of Intranet by those of AdvancedOnlineNetwork, which is an indicator set to one if a firm adopted any of the advanced online networks including Intranet, Extranet, and Electronic data interchange (EDI). Regressions are weighted by the inverse propensity scores. Standard errors are clustered at the firm and headquarter county level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Chapter 3

A Model of Multi-Unit Firm Locations Choices and ICT Adoption

3.1 Model

I incorporate endogenous within-firm communication costs into an industry equilibrium trade model where firms can produce products in multiple locations (Tintelnot, 2017) by allowing firms to adopt advanced ICT that lowers communication costs between the headquarter and production sites.

The economy consists of N locations, denoted by $\mathcal{N} = \{1, 2, \cdots, N\}$. In the following, I use "location" and "market" interchangeably. Each location $s \in \mathcal{N}$ is inhabited by a representative consumer and a continuum of firms born in location $i \in [0, m_s]$, where m_s is the exogenous mass of the firms in location s. The representative consumer maximizes a CES utility function and engage in a perfectly competitive labor market. The settings on firms follow Tintelnot (2017), assuming each firm i produces a continuum of differentiated varieties $\omega \in [0, 1]$ that are tradable across locations. Each product is then indexed by a firm-variety combination (i, ω). Firms compete monopolistically in each product market.

I refer to a firm's birth location as the "headquarter" and denote it by o. The additional establishment locations of the firm are denoted by s, and destination markets are denoted by k.

3.1.1 Demand

All varieties produced by firms are available to all markets. The representative consumer in each market k maximizes a CES utility function aggregating all varieties with elasticity

of substitution σ:

$$U_k = \left(\sum_{o=1}^{N} \int_0^{m_o} \int_0^1 y_{ok}(i,\omega)^{\frac{\sigma-1}{\sigma}} d\omega di \right)^{\frac{\sigma}{\sigma-1}}, \qquad (3.1)$$

where $y_{ok}(i,\omega)$ is the output of variety ω shipped to market k by firm i which is headquartered at o. Here, I assume that the elasticity of substitution is identical among varieties within and across firms. In the benchmark model, I fix the set of firms in each location and abstract from firms' entry decisions. This assumption is consistent with my empirical analysis, which focused on a balanced sample of firms that existed throughout the sample period.

Given prices and the consumer's expenditure on manufacturing goods E_k, we can solve the consumer's problem and obtain the demand from market k for firm i variety ω:

$$y_{ok}(i,\omega) = E_k P_k^{\sigma-1} p_{ok}(i,\omega)^{-\sigma}, \qquad (3.2)$$

where P_k is the ideal price index of market k defined by

$$P_k = \left(\sum_{o=1}^{N} \int_0^{m_o} p_{ok}(i)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}} \quad \text{and where} \quad p_{ok}(i) = \left(\int_0^1 p_{ok}(i,\omega)^{1-\sigma} d\omega \right)^{\frac{1}{1-\sigma}}. \qquad (3.3)$$

The price index $p_{ok}(i)$ is firm specific and summarizes the prices charged to market k of all varieties produced by firm i, which is headquartered at o. The local price index P_k summarizes the prices charged to market k by all firms in the economy.

3.1.2 Production Technology

Each firm is endowed with an establishment in its birth location, called the *headquarter*, and can set up additional establishments in other locations with up to one establishment in each location.

Production at the establishment level. Production takes place in establishments. The value-added production function is Cobb-Douglas and has constant returns to scale (CRS). Productivity includes two components: firm-specific productivity, which affects all

the firm's establishments, and establishment-specific productivity. Labor is the only input here. Production in any establishments, including the headquarter, incurs an iceberg-type production loss γ_{ios}: producing one unit of output requires γ_{ios} units of labor. Potential sources of the production loss include physical shipping costs and efficiency loss in the communication process. That said, Atalay et al. (2014) uses US Census data and finds that interplant shipping is rare. In the following, γ_{ios} refers to communication costs. Specifically, the production function takes the following form:

$$y_{ios} = z_i \varepsilon_{is} l_{ios} \gamma_{ios}^{-1}, \tag{3.4}$$

where z_i is the fundamental productivity of firm i, ε_{is} is the establishment-specific productivity at location s, and l_{ios} is the local labor input. Firm-specific productivity z_i is independently and identically drawn from log-normal distribution $G(z)$. Establishment-specific productivity ε_{is} is drawn from a location-specific distribution $F_s(\varepsilon)$ and is independently and identically distributed across establishments in location s. Particularly, I assume that ε_{is} follows the Fréchet distribution with shape parameter θ and scale parameter T_s; that is,

$$F_s(\epsilon) = \exp(-(\epsilon/T_s)^{-\theta}). \tag{3.5}$$

The scale parameter T_s determines the state of technology in location s, and the shape parameter θ determines the dispersion of establishment productivity draws.

Communication costs and ICT. I assume that the communication cost depends on the firm's ICT level and allow it to vary with the firm's headquarter and establishment locations. Specifically, I assume that $\gamma_{ios} = \gamma_{os}(\varphi_i) \geq 1$, where φ_i denotes firm i's ICT level. I discretize the ICT level φ to two levels – low and high, i.e. $\varphi \in \{\underline{\varphi}, \overline{\varphi}\}$. This simplification is consistent with the data, where I observe binary network adoption choices by firms. Firms that adopt a high ICT level are associated with low communication costs.

Let o denote the firm's headquarter location. Index firms headquartered at o by their productivity z and ICT level φ. For firm (φ, z) headquartered at o, its unit cost of producing

a variety ω at an establishment in location s and shipping it to market k is:

$$c_{oks}(\omega, \varphi, z) = (z\varepsilon_s(\omega))^{-1} w_s \tau_{sk} \gamma_{os}(\varphi), \tag{3.6}$$

which summarizes the production efficiency, input costs, market access to the destination market, and communication costs between the production establishment and the headquarter. As the communication cost $\gamma_{os}(\varphi)$ decreases in the firm's ICT level φ, firms with a higher ICT level are also associated with lower unit costs.

Fixed costs. Firms can set up multiple establishments in addition to their headquarters to expand production, subject to fixed costs f_{ios}^X, where i denotes the firm, o the firm headquarter location and s the establishment location. This fixed cost depends on the pair of locations of the headquarter and establishment. For instance, firms are more likely to expand to closer locations because of their easier access. Firms also pay fixed costs if they choose to adopt a high ICT level. Guided by the empirical finding that firms headquartered closer to the Internet backbone nodes were more likely to adopt Intranet, I assume that the fixed cost of adopting ICT depends on the firm's headquarter location o and denote the fixed cost by f_{io}^{ICT}. These fixed costs f_{ios}^X and f_{io}^{ICT} are firm specific because the expansion decisions and ICT adoption vary across firms with similar characteristics. As the fixed costs and their forms are unobservable from data, I assume that both fixed costs are paid in the numeraire with the same price across locations.

3.1.3 The Firm's Optimization Problem

Firms decide whether to adopt a higher ICT level, choose optimal sets of locations for production, hire labor, produce a continuum of varieties and serve destination markets. I use backward induction to solve the firm's optimization problem. I first derive the firm's optimal profit conditional on a set of establishment locations and ICT status. Then, I take a step back and solve the firm's optimal choice of the set of locations. Finally, I solve the firm's ICT adoption decision.

Production given a set of establishment locations and state of ICT

Let the set of locations $S \in \mathscr{S}$ be fixed. For each market k, the firm chooses one of its establishments $s \in S$ that has the lowest unit cost $c_{oks}(\omega, \varphi, z)$ to serve market k. Therefore, the actual unit cost of variety ω produced by firm (φ, z) to market k is

$$c_{ok}(\omega, S, \varphi, z) = \min_{s \in S} c_{oks}(\omega, \varphi, z), \tag{3.7}$$

where $c_{oks}(\omega, \varphi, z)$ is defined in Equation (3.6). As the firm produces a continuum of varieties $\omega \in [0, 1]$ and the establishment-specific productivity draws $\varepsilon_s(\omega)$ follow a Fréchet distribution and are independently distributed across varieties and locations, the share of varieties produced at the establishment in location $s \in S$ equals the sales share of any establishment $s \in S$ relative to the total firm's sales to market k:

$$\zeta_{ok \leftarrow s}(S, \varphi) = \frac{T_s^\theta (\gamma_{os}(\varphi) w_s \tau_{sk})^{-\theta}}{\Phi_{ok}(S, \varphi)}, \tag{3.8}$$

where T_s is the scale parameter of the establishment productivity distribution in location s, θ is the corresponding shape parameter, and $\Phi_{ok}(S, \varphi)$ is defined by

$$\Phi_{ok}(S, \varphi) = \sum_{s' \in S} T_{s'}^\theta (\gamma_{os'}(\varphi) w_{s'} \tau_{s'k})^{-\theta}. \tag{3.9}$$

$\Phi_{ok}(S, \varphi)$ captures the "production potential" of the set of locations S to serve market k for firms headquartered at o and with ICT level φ. It summarizes the states of technology and wages of all the firm's establishments, the shipping cost—or market access—to market k and communication costs between the headquarter and establishments. Importantly, the production potential depends on a firm's ICT level. Given the same headquarter, set of establishment locations and market location, firms with a higher ICT level have larger production potential.

Due to the CES demand, the firm charges a constant markup relative to the marginal cost. That is, the price charged to market k by the firm is $p_{ok}(\omega, S, \varphi, z) = \frac{\sigma}{\sigma-1} c_{ok}(\omega, S, \varphi, z)$, where $c_{ok}(\omega, S, \varphi, z)$ is the lowest unit cost defined in Equation (3.7). Then, we can get the firm price index to market k:

$$p_{ok}(S, \varphi, z) = \left(\int_0^1 p_{ok}(\omega, S, \varphi, z)^{1-\sigma} d\omega \right)^{\frac{1}{1-\sigma}} = \frac{\sigma}{\sigma-1} \tilde{\Gamma}^{\frac{1}{1-\sigma}} z^{-1} \Phi_{ok}(S, \varphi)^{-\frac{1}{\theta}}, \tag{3.10}$$

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where $\tilde{\Gamma} = \Gamma\left(\frac{\theta-\sigma+1}{\theta}\right)$ and the production potential $\Phi_{ok}(S,\varphi)$ is defined in Equation (3.9). Here, we use the properties of the Fréchet distribution to derive the firm-specific price index.[1]

We can further derive that the firm's profit from market k is

$$\pi_{ok}(S,\varphi,z) = \frac{\sigma^{-\sigma}}{(\sigma-1)^{1-\sigma}}\tilde{\Gamma}z^{\sigma-1}E_k P_k^{\sigma-1}\Phi_{ok}(S,\varphi)^{\frac{\sigma-1}{\theta}}, \tag{3.11}$$

where E_k is the consumer's total spending on manufacturing goods and P_k is the ideal price index in location k. Summing the expected profit over all destination markets, we have that the firm's total profit, net of fixed costs of expansion, is:

$$\pi_o(S,\varphi,z) = \frac{\sigma^{-\sigma}}{(\sigma-1)^{1-\sigma}}\tilde{\Gamma}z^{\sigma-1}\sum_{k=1}^{N}E_k P_k^{\sigma-1}\Phi_{ok}(S,\varphi)^{\frac{\sigma-1}{\theta}} - \sum_{s=1}^{N}\mathbb{1}[s\in S]f_{os}^X. \tag{3.12}$$

The set of locations S affects the firm's total production profits through the production potential $\Phi_{ok}(S,\varphi), \forall k$ and fixed costs of setting up establishments.

Optimal Set of Locations and ICT Adoption

Firms choose the optimal ICT level and the optimal set of locations to maximize their net profits. Specifically, the firm's problem is

$$\pi_o(z) = \max_{\varphi\in\{\underline{\varphi},\overline{\varphi}\}}\left\{\max_{S\in\mathscr{S}}\pi_o(S,\varphi,z) - f_o^{ICT}\mathbb{1}[\varphi=\overline{\varphi}]\right\}, \tag{3.13}$$

where $\pi_o(S,\varphi,z)$ is the firm's profit given a set of production locations S, defined in Equation (3.12). Additionally, the inner maximization on S is a discrete choice problem involving a large number of choices (2^{N-1} in this case). I apply the methodology developed in Arkolakis et al. (2021) to solve this combinatorial discrete choice problem.

Communication technology revisited. From here on, I work with a simple yet flexible communication technology where I decompose the communication cost into the product of two terms:

$$\gamma_{os}(\varphi) = h(\varphi)d_{os}(\varphi). \tag{3.14}$$

---

[1]Appendix B.1.2 provides more details on the derivation.

The first term reflects the firm-specific communication costs and decreases in the firm's ICT level, i.e,. $h(\underline{\varphi}) \geq h(\overline{\varphi}) \geq 1$. An ICT such as Intranet may improve the firm's overall management practice and reduce firm-wide communication costs. The second term captures the communication costs due to remote production. For instance, establishments farther from the headquarter may incur higher communication costs. This term depends on the pair of the headquarter and establishment locations, and varies with the firm's ICT level. Firms with a high ICT level have lower communication costs for any location pair, i.e., $d_{os}(\underline{\varphi}) \geq d_{os}(\overline{\varphi}) \geq 1$. Finally, I normalize the remote communication costs to one for local production, i.e., $d_{oo}(\varphi) = 1, \varphi \in \{\overline{\varphi}, \underline{\varphi}\}$.

With this technological assumption, we can further decompose a firm's production potential as $\Phi_{ok}(S, \varphi) = \tilde{\Phi}_{ok}(S, \varphi)/h(\varphi)^{\theta}$, where $\tilde{\Phi}_{ok}(S, \varphi) \equiv \sum_{s \in S} T_s^{\theta}(w_s \tau_{sk} d_{os}(\varphi))^{-\theta}$. Combined with Equation (3.12), one can show that improving ICT has two effects on the firm's profit: 1) a direct effect that increases the firm's *effective* productivity $\tilde{z} \equiv z/h(\varphi)$, and 2) an indirect effect that increases the firm's production potential $\tilde{\Phi}_{ok}(S, \varphi)$, with the set of locations unchanged, by reducing the communication costs between the headquarter and establishments.

Complementarity between ICT adoption and geographic expansion. Technological upgrading and geographical expansion are complements to each other. Consider a simple case where a single-unit firm headquartered at o is deciding whether to expand its production to another location s. The firm would like to add an establishment at s if and only if the additional gross profit exceeds the fixed cost of setting up the establishment at s; that is,

$$\frac{\sigma^{-\sigma}}{(\sigma-1)^{1-\sigma}} \tilde{\Gamma} \left(\frac{z}{h(\varphi)} \right)^{\sigma-1} \sum_{k=1}^{N} E_k P_k^{\sigma-1} \underbrace{\left(\left(\tilde{\Phi}_{ok}(\{o,s\}, \varphi) \right)^{\frac{\sigma-1}{\theta}} - \left(\tilde{\Phi}_{ok}(\{o\}, \varphi) \right)^{\frac{\sigma-1}{\theta}} \right)}_{\text{Expansion increases production potential}} \geq f_{os}^X.$$

$$= \left(T_o^{\theta}(w_o \tau_{ok})^{-\theta} + T_s^{\theta}(w_s \tau_{sk} d_{os}(\varphi))^{-\theta} \right)^{\frac{\sigma-1}{\theta}} - \left(T_o^{\theta}(w_o \tau_{ok})^{-\theta} \right)^{\frac{\sigma-1}{\theta}}$$

(3.15)

The left-hand side is the benefit of expanding to location s, and the right-hand side is the fixed cost of setting up an establishment at s for the firm headquartered at o. The benefit is positive because the production potential $\tilde{\Phi}_{ok}(S, \varphi)$ increases as firms set up more establishments. High ICT increases the benefit of geographic expansion by increasing the firm's effective productivity $z/h(\varphi)$ and by raising the benefits in the production potential from expansion. All else held constant, firms with better ICT have a higher likelihood of expanding.

Similarly, a firm would like to upgrade to high ICT if and only if the benefit exceeds the fixed cost of adopting ICT; that is,

$$
\frac{\sigma^{-\sigma}}{(\sigma-1)^{1-\sigma}} \tilde{\Gamma} \left[\left(\frac{z}{h(\overline{\varphi})} \right)^{\sigma-1} \sum_{k=1}^{N} E_k P_k^{\sigma-1} \tilde{\Phi}_{ok}(S, \overline{\varphi})^{\frac{\sigma-1}{\theta}} - \left(\frac{z}{h(\underline{\varphi})} \right)^{\sigma-1} \sum_{k=1}^{N} E_k P_k^{\sigma-1} \tilde{\Phi}_{ok}(S, \underline{\varphi})^{\frac{\sigma-1}{\theta}} \right]
$$

$$
= \frac{\sigma^{-\sigma}}{(\sigma-1)^{1-\sigma}} \tilde{\Gamma} \Bigg\{ \underbrace{\left[\left(\frac{z}{h(\overline{\varphi})} \right)^{\sigma-1} - \left(\frac{z}{h(\underline{\varphi})} \right)^{\sigma-1} \right] \sum_{k=1}^{N} E_k P_k^{\sigma-1} \tilde{\Phi}_{ok}(S, \overline{\varphi})^{\frac{\sigma-1}{\theta}}}_{\text{ICT adoption increases firm's effective productivity}}
$$

$$
+ \underbrace{\left(\frac{z}{h(\underline{\varphi})} \right)^{\sigma-1} \sum_{k=1}^{N} E_k P_k^{\sigma-1} \left(\tilde{\Phi}_{ok}(S, \overline{\varphi})^{\frac{\sigma-1}{\theta}} - \tilde{\Phi}_{ok}(S, \underline{\varphi})^{\frac{\sigma-1}{\theta}} \right)}_{\text{ICT increases production potential}} \Bigg\} \geq f_o^{ICT}.
$$

The left-hand side summarizes two benefits from adopting ICT. One is an increase in the firm's effective productivity, and the other is an increase in its production potential through lower communication costs. Both benefits are larger when a firm has a larger set of establishments. First, as the production potential $\tilde{\Phi}_{ok}(S, \overline{\varphi})$ increases in the set of establishments S, $\tilde{\Phi}_{ok}(\{o, s\}, \overline{\varphi}) > \tilde{\Phi}_{ok}(\{o\}, \overline{\varphi})$. Therefore, the benefit from higher effective productivity is larger following the firm's expansion. Second, the benefit from the increasing production potential is larger when a firm includes additional establishments. Take the same example where a firm either produces locally with $S = \{o\}$ or expands to another location with $S = \{o, s\}$. The benefit from the production potential is zero for the former case $(\tilde{\Phi}_{ok}(\{o\}, \overline{\varphi})^{\frac{\sigma-1}{\theta}} - \tilde{\Phi}_{ok}(\{o\}, \underline{\varphi})^{\frac{\sigma-1}{\theta}} = 0)$ but is strictly positive for the latter $(\tilde{\Phi}_{ok}(\{o, s\}, \overline{\varphi})^{\frac{\sigma-1}{\theta}} - \tilde{\Phi}_{ok}(\{o, s\}, \underline{\varphi})^{\frac{\sigma-1}{\theta}} > 0)$, as the communication costs decrease from $d_{os}(\underline{\varphi})$ to $d_{os}(\overline{\varphi})$. Nonheadquarter establishments always benefit from lower communication

costs with the headquarter.

3.1.4 Equilibrium

To fit manufacturing into the entire economy, I assume a nonmanufacturing sector selling homogeneous products that can be traded costlessly across locations. Consumers spend a constant fraction (η) of final expenditure (G_s) on manufacturing goods. In terms of the labor market, I assume that labor is freely mobile across the two sectors. The nonmanufacturing sector is large enough such that the wage is pinned down by productivity in that sector and total income is exogenous.[2]

Let μ_o denote the exogenous measure of firms headquartered in location o, and Z the support of firm productivity. The product market clearing condition is, $\forall k = 1, \cdots, N$:

$$\eta G_k = P_k Y_k, \text{ where } P_k = \left(\sum_{o=1}^{N} \int_Z p_{ok}(z)^{1-\sigma} d\mu_o(z) \right)^{\frac{1}{1-\sigma}} \tag{3.16}$$

$$Y_k = \left(\sum_{o=1}^{N} \int_Z y_{ok}(z)^{\frac{\sigma-1}{\sigma}} d\mu_o(z) \right)^{\frac{\sigma}{\sigma-1}}$$

Here, $p_{ok}(z)$ and $y_{ok}(z)$ are the price and sales, respectively, to market k from a firm headquartered in location o and with productivity z. Employment in each location is, $\forall s = 1, \cdots, N$:

$$L_s = \int_Z l_{ss}(z) d\mu_s(z) + \sum_{o \neq s} \int_Z \mathbb{1}[s \in S_o(z)] l_{os}(z) d\mu_o(z). \tag{3.17}$$

The first term is employment of local firms headquartered at the location, and the second term is employment of firms from other locations that set up establishments at the location. An equilibrium is a vector of prices $\boldsymbol{P}$ that is consistent with firm optimization and that clears product market for each location. The price indices affect total output not only through demand, but also through firms' ICT choices and production locations choices.

---

[2]The assumptions on the labor market assume a perfectly elastic labor supply, following, e.g., Eaton and Kortum (2002) and Antras et al. (2017).

Endogenous labor market. In the benchmark model, labor supply is perfectly elastic and wages are treated as exogenous. Key mechanisms, however, are still operative in endogenous labor markets regarding the equilibrium effects on firm expansion decisions. Consider the extreme case in which labor supply is perfectly inelastic. With endogenous labor markets, as the fixed cost decreases, labor demand increases, thus driving up wages. The production potential term $\Pi_{ok}(S)$, which is a function of the inverse of wages, decreases. Price indexes decrease and expenditure increases, offsetting each other. The equilibrium effect, again, works as a countervailing force that reduces the appeal of geographic expansion.

3.2   Estimation

In the structural estimation, I define location at the *census division* level due to considerations of computational feasibility. Nevertheless, this operationalization still captures meaningful firm expansion patterns. When multi-unit firms add establishments, a majority of the new establishments are located in census divisions different from those where the firms are headquartered.

Table 3.1 summarizes the model parameters. Panel A shows the parameters that are calibrated, and Panel B shows the parameters that are structurally estimated. As outlined in Section 3.2.1–3.2.3, I estimate these parameters in three steps and, in particular, I solve the model in the third step that conducts estimation using the method of simulated moments.

Table 3.1: Parameters to Estimate

Description	Model variable	Parameterization	Parameter
A. Pre-set Parameters			
Demand elasticity	σ		$\sigma = 4$
Establishment productivity	ε_s	$\sim \text{Frećhet}(\theta, T_s)$	$\theta = 3.6$
Firm productivity	z	$\sim \text{log-normal}(\mu^z, \sigma^z)$	$\mu^z = -0.123$
			$\sigma^z = 0.767$
Trade cost	τ_{sk}	$= e^{\beta^\tau \log \text{Miles}_{sk}}$	$\beta^\tau = 0.278$
B. Estimated Parameters			
Establishment productivity	ε_s	$\sim \text{Frećhet}(\theta, T_s)$	$\{T_s\}_{s=1,\cdots,9}$
Location-pair communication cost	d_{os}	$= e^{\beta_1^d \log \text{Miles}_{os} + \beta_2^d \log \text{Miles}_{os} \times \text{Intranet}}$	β_1^d, β_2^d
Firm-specific communication cost	$h(\overline{\varphi}), h(\underline{\varphi})$	$h(\overline{\varphi}) \equiv \overline{h} = 1, h(\underline{\varphi}) \equiv \underline{h}$	$\underline{h}$
Fixed costs of setting up estabs.	f_{os}^X	$\sim \text{log-normal}(\mu_{os}^X, \sigma^X)$ where μ_{os}^X $= \beta_1^X + \beta_2^X \log(\text{Miles}_{os})$	$\beta_1^X, \beta_2^X, \sigma^X$
Fixed costs of ICT adoption	f_o^{ICT}	$\sim \text{log-normal}(\mu_o^{ICT}, \sigma^{ICT})$ where μ_o^{ICT} $= \beta_1^{ICT} + \beta_2^{ICT} \log(\widetilde{\text{HQDistToNode}}_o)$	$\beta_1^{ICT}, \beta_2^{ICT}, \sigma^{ICT}$

Notes: This table summarizes the model parameters. Panel A displays the parameters that are pre-set to simulate the model. Panel B displays the parameters to be estimated.

Pre-set parameters. I externally calibrate the elasticity of substitution across varieties (σ) to 4, the center value in the range of estimates used in the international trade literature (see Head and Mayer (2014)). This value implies a markup of approximately 33%. I also set the shape parameter of the Fréchet distributions of establishment productivity draws to $\theta = 3.6$, the medium value used in Eaton and Kortum (2002).[3] This parameter governs the dispersion of establishment locations' productivity draws and affects locations' substitutability, thus impacting firms' location choices. Specifically, a larger value of θ implies a smaller dispersion of local productivities. Locations become closer substitutes, so the benefits of having larger sets of production locations decrease. The scale parameters of the Fréchet distributions, i.e., T_s, which summarize the states of technology in each location, are structurally estimated and are discussed in Section 3.2.2. While the value of θ affects estimates of the scale parameters of the distributions, those estimates are highly correlated with different values of θ.

I assume that firm productivity follows a log-normal distribution, where the mean and dispersion is set to -0.122 and 0.767, respectively, using the estimates from Guner et al. (2008), who use the 1997 US Census of Manufactures to estimate the distribution of firm productivity.[4] One caveat is that these parameters are estimated through the lens of a model that does not take into account multi-unit production. Nonetheless, my first- and second-step estimation does not reply on the assumptions of the firm productivity distribution. The third-step estimation, where I solve and simulate the model, can be affected by the distribution of firm productivity. In this case, the dispersion in firm fundamental productivity might be overstated due to endogenous ICT adoption, or understated due to

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[3]Fajgelbaum et al. (2019) estimate θ to be in the range of 2.43-2.84 at the state level. Tintelnot (2017) and Hu and Shi (2019) assume $\theta = 7$ for EU countries. Antras et al. (2017) use the countries that US firms import from and estimate $\theta = 1.789$. Eaton and Kortum (2002) provide three measures of θ at 2.84, 3.60 and 8.28.

[4]Guner et al. (2008) estimate the distribution of firm productivity, defined as managerial ability, by matching the size distributions of US establishments. They assume that log-managerial ability is normally distributed. The estimated mean is -0.367, and the dispersion is 2.303. Since size is proportional to productivity in Guner et al. (2008) while it is proportional to productivity by a factor of $\sigma - 1$ in my setting, I apply a factor of $1/(\sigma - 1)$ to their estimated mean and dispersion to be consistent.

communication costs for multi-unit firms. The mean of firm productivity, however, does not affect firm expansion or ICT adoption patterns.

Finally, the trade cost is assumed to be log-linear in the distance between the production establishment (s) and the destination market (k). That is,

$$\tau_{sk} = e^{\beta^\tau \log \text{Miles}_{sk}}, \tag{3.18}$$

where Miles_{sk} is the distance in miles between the two locations. I set the elasticity β^τ to 0.278, which is consistent with the literature (see Disdier and Head (2008)).

Estimated parameters. The communication costs and distributions of fixed costs of expansion and ICT adoption are structurally estimated. I parameterize those model variables to ease estimation. First, I continue to use the functional form of communication costs in Equation (3.14); that is, $\gamma_{os}(\varphi) = h(\varphi)d_{os}(\varphi)$, where the first term represents firm-specific communication costs and the second term represents those costs depending on the firm's headquarter and establishments' locations. Both types of communication costs are lower when firms adopt better ICT.

As ICT is discretized to two levels (i.e., low $\underline{\varphi}$ and high $\overline{\varphi}$), the firm-specific communication costs take two values. Denote the one associated with low ICT by $\underline{h}$ and the one with high ICT by $\overline{h}$. Recall that the firm-specific communication cost acts as a shifter for firms' effective productivity; we can identify only the relative magnitude of the two values ($\underline{h}$ and $\overline{h}$). Therefore, I normalize the cost in the presence of higher ICT to 1, i.e., $\overline{h} = 1$, and estimate $\underline{h}$, which represents productivity loss associated with low ICT.

For the location-pair–dependent communication costs (d_{os}), as is common in the literature, I assume it is log-linear in the distance between the firm's headquarter and establishment. The communication costs within the headquarter are normalized to 1, i.e., $d_{oo} = 1$. Moreover, I allow the elasticity of the communication costs with respect to distance to vary between firms with low and high ICT. Following the empirical result that having Intranet lowers a firm's internal communication costs, I use firms' Intranet adoption as a proxy for ICT: Firms that adopted Intranet are associated with high ICT ($\overline{\varphi}$), and those without

Intranet are associated with low ICT ($\underline{h}$). Specifically, I assume:

$$d_{os} = \begin{cases} e^{\beta_1^d \log \text{Miles}_{os} + \beta_2^d \log \text{Miles}_{os} \times \text{Intranet}} & s \neq o \\ 1 & s = o \end{cases} \tag{3.19}$$

Fixed costs of setting up establishments are assumed to be log-normally distributed, with mean μ_{os}^X and standard deviation σ^X, where the mean is log-linear in the distance between the headquarter and establishment location: $\mu_{os}^X = \beta_1^X + \beta_2^X \log(\text{Miles}_{os})$.

Fixed costs of adopting ICT are also log-normally distributed. Furthermore, I add to the model the empirical finding that firms located closer to NSFNET nodes are more likely to adopt Intranet. I assume that the average fixed cost of adopting ICT is log-linear in the average distance to the nearest NSFNET node for firms headquartered in census division o. To account for geographic area differences at the census division level, I normalize the average distance in each census division by its land area; that is, $\widetilde{\text{HQDistToNode}}_o = \overline{\text{HQDistToNode}}_o/\text{LandArea}_o$. As the distance measure is a proxy of ICT accessibility, the scaled term measures the *density* of ICT accessibility per square mile. The normalization captures the fact that for larger areas, it is harder for an average firm to reach any node. The average distance varies across census divisions, and so does the fixed cost of adopting ICT. The mean of its distribution depends on the firm headquarter location and is log-linear in the average distance to NSFNET nodes in that location: $\mu_o^{ICT} = \beta_1^{ICT} + \beta_2^{ICT} \log(\widetilde{\text{HQDistToNode}}_o)$. The log-normal distributions have the same standard deviation σ^{ICT}.

Estimation overview. There are 18 parameters left for estimation, including the scale parameters of the Fréchet distribution for establishment productivity in each location ($T_s, s = 1, \cdots, 9$), productivity loss with low ICT ($\underline{h}$), elasticities of location-pair communication costs with respect to distance (β_1^d, β_2^d), the distribution of fixed costs of setting up establishments ($\beta_1^X, \beta_2^X, \sigma^X$), and the distribution of fixed costs of adopting ICT ($\beta_1^{ICT}, \beta_2^{ICT}, \sigma^{ICT}$). I estimate these parameters in three steps. In the first step, I use within-firm variation in establishment employment shares to estimate the elasticity of

location-pair communication costs (β_1^d, β_2^d) as well as a vector of census division fixed effects. In the second step, I use these fixed effects to back out the state of technology, i.e., the scale parameter of the Fréchet distribution (T_s), for each census division. In the third step, I use the estimated parameters to simulate the full model and estimate the rest of the parameters using the method of simulated moments.

3.2.1   The First Step

I first identify the elasticity of location-pair communication costs (d_{os}) with respect to distance. By Equation (3.8), we can obtain that the sales share of a firm's establishment to a market is the establishment's contribution to the firm's production potential to the market. Denote a firm by i, its headquarter location by o, and its set of establishment locations by S. For any market k, firm i's production potential for this market is $\Phi_{ioSk} = \sum_{s' \in S} T_{s'}^\theta (w_{s'} \tau_{s'k} d_{ios'})^{-\theta}$, where $T_{s'}$ and $w_{s'}$ are the state of technology and wage rate of location s', $\tau_{s'k}$ is the trade cost from the establishment to market k, and $d_{ios'}$ is the location-pair communication costs for firm i—depending on firm i's ICT adoption—between the headquarter o and establishment s'.

Suppose that firm i has an establishment at location $s \in S$. Then, the sales share of establishment s to market k is $\zeta_{ioSk \leftarrow s} = \text{sales}_{ioSk \leftarrow s}/\text{sales}_{ioSk} = T_s^\theta(w_s \tau_{sk} d_{ios})^{-\theta}/\Phi_{ioSk}$. Ideally, I would like to have establishment-market-specific shipments for estimation. However, the data are not broken down by destination market. Thus, I aggregate the shares across markets to the establishment level:

$$\zeta_{ioS,s} = \frac{\sum_k \text{sales}_{ioSk \leftarrow s}}{\sum_k \text{sales}_{ioSk}} = T_s^\theta (w_s d_{ios})^{-\theta} \sum E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-\theta-1}{\theta}} \tau_{sk}^{-\theta} / \sum_k E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-1}{\theta}}. \quad (3.20)$$

Taking the logarithm of the establishment's sales share, normalized by the sales share

of the headquarter, we can obtain:

$$\log \tilde{\zeta}_{ioS,s} \equiv \log \zeta_{ioS,s} - \log \zeta_{ioS,o}$$

$$= \underbrace{-\theta \log d_{ios}}_{\text{communication cost}} + \underbrace{\log \left(\sum_k \frac{E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-\theta-1}{\theta}}}{\sum_k E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-\theta-1}{\theta}}} \tau_{sk}^{-\theta} \right)}_{\text{Weighted average market access}} + \xi_s + \xi_{oS}. \qquad (3.21)$$

The first term on the right-hand side is the location-pair communication costs. The second term represents the shipping costs from establishment s to all markets, i.e., the establishment location's market access, weighted by the corresponding market's demand share. It is worthwhile to note that the impact of shipping costs on the establishment's market access may depend on the firm's ICT and geographic footprint via its production potential (Φ_{ioSk}). For instance, consider a single-unit firm and a multi-unit firm, both headquartered in the Mountain census division, with the latter having another establishment in the New England census division. The market access of the Mountain census division can be different for these two firms. Specifically, the multi-unit firm may place a larger weight on the Pacific census division's demand for its establishment in the Mountain census division as it targets nearby markets. ξ_s is an establishment-specific component, and ξ_{oS} is a headquarter-set-specific component.

To take Equation (3.21) to the data, I first approximate the weighted average market access term by $(\phi + \phi_{oS}) \log \left(\sum_k \frac{N_k \bar{y}_k}{\sum_k N_k \bar{y}_k} \tau_{sk}^{-\theta} \right) \equiv (\phi + \phi_{oS}) \log \overline{MA}_s$, where N_k is the population of location k and $\bar{y}_k$ is the location's per capita income. Here, I assume that all else held constant, the firm's ICT adoption does not change the relative weights of market demand. Nevertheless, I allow the effect of shipping costs on the establishment's sales share to differ across the firm's headquarter location and other establishment locations of the firm.

Second, as the sales data were not available in the LBD until recently and are subject to more severe measurement errors than the employment data, I instead use the *employment* share to conduct the estimation.[5]

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[5]In Appendix B.2.1, I show that the first-stage regression specification, which uses establishment employment share, is of the same form as the one that uses the sales share.

Combined with the parameterization of communication costs and trade costs in Equations (3.18) and (3.19), the estimation equation is

$$\log \tilde{\zeta}_{ioS,s} = -\theta\beta_1^d \log \text{Miles}_{os} - \theta\beta_2^d \log \text{Miles}_{os} \times \text{Intranet}_i + \phi_{oS} \log \overline{MA}_s + \xi_s + \xi_{oS} + \varepsilon_{ioS,s},$$
(3.22)

where Intranet_i denotes firm i's Intranet adoption and ξ_s and ξ_{oS} denote fixed effects for the establishment locations and combinations of the headquarter and the set of locations. The error term $\varepsilon_{ioS,s}$ captures other factors that affect communication and trade costs that are orthogonal to the firm's locations choice. Note that the common component of market access ($\phi \log \overline{MA}_s$) is absorbed by establishment location fixed effects. In particular,

$$\xi_s = \theta \log(T_s) - (\theta + 1) \log(w_s) + \phi \log \overline{MA}_s,$$
(3.23)

which summarizes the establishment location's state of technology, wage costs, and market access.

Given the estimates of coefficients in Equation (3.22) and the value of θ, we can back out the elasticity terms. Denote the estimated coefficients on $\log \text{Miles}_{os}$ and $\log \text{Miles}_{os} \times \text{Intranet}_i$ by $\hat{b}_1^d$ and $\hat{b}_2^d$, respectively. The estimates of elasticities are $\hat{\beta}_j^d = -\hat{b}_j^d/\theta, j = 1, 2$.

Estimation results. I use the LBD-CNUS matched sample to estimate the equation. Identification of the headquarter-set-specific coefficients ϕ_{oS} requires variation in the market access $\overline{MA}_s$ of nonheadquarter establishments within the same headquarter-set combination. Therefore, I further restrict the sample to firms with establishments in at least three census divisions. All else held constant, the elasticities of communication with respect to distance are identified by variation in the establishment's employment share along the distance to the firm's headquarter. Firms with Intranet versus those without help identify the coefficient on the interaction term between distance and Intranet adoption. I also include industry fixed effects at the 4-digit NAICS level to control for industry heterogeneity.

Table 3.2 reports the estimation results. Column (1) includes observations throughout 1987-2007. The coefficient on Log(Miles) is estimated to be -0.172, indicating that a 10%

reduction in the distance in miles between the headquarter and establishment census divisions leads to a 1.7% increase in the establishment's sales share. Columns (2)–(3) use observations for 1999, the year for which we have firms' ICT adoption information. In the baseline specification of column (3), the coefficient on the distance between the headquarter census division and establishment census division is estimated at -0.496. This reduced-form coefficient corresponds to the structural parameters $-\theta\beta_1^d$. As I calibrate θ to 3.6, the elasticity of communication costs with respect to the distance for firms without Intranet ($\beta_{\text{Low ICT}}^d$) is $0.138 = (0.496/3.6)$. The coefficient on the interaction of Log(Miles) and Intranet shows that the elasticity is *smaller* for firms with Intranet: $\beta_{\text{High ICT}}^d$ is $0.076 = ((0.496 - 0.222)/3.6)$, approximately half that for firms without Intranet. These results suggest that technology reduces communication costs over long distances. It is worth noting that the elasticity of communication costs is smaller, even for firms without Intranet, than that of trade costs with respect to the distance, i.e., β^τ in Equation (3.18), which is calibrated to $0.278 = (1/\theta = 1/3.6)$. This implies that a local shock, e.g., a local productivity shock, would diffuse to other locations at a larger rate through the multi-unit production channel within the firm, as compared to the trade channel.

Here, I interpret the coefficients on the distance between headquarters and establishments as communication costs. One could also interpret them as physical shipping costs if the establishment needs to physically import production inputs such as intermediates from the headquarter. Nevertheless, Atalay et al. (2014) use Commodity Flow Survey (CFS) and find little interplant shipping even within vertically integrated firms.

Table 3.2: First-Step Estimation Results

	Dep. Variable: Employment Share		
	All Years	Year 1999	
	(1)	(2)	(3)
Log(Miles)	-0.172***	-0.293**	-0.496***
	(0.047)	(0.137)	(0.179)
Log(Miles) × Intranet			0.222**
			(0.090)
N	59500	3100	3100
R^2	0.449	0.596	0.600
HQ-Set Market Access ($\phi_{oS} \log \overline{MA}_s$)	Y	Y	Y
HQ-Set FE	Y	Y	Y
Establishment Location FE		Y	Y
Industry FE		Y	Y
Establishment Location-Year FE	Y		
Industry-Year FE	Y		

Notes: This table presents the first-step estimation results. The dependent variable is the scaled within-firm employment shares of establishments. Log(Miles) is the distance between the firm's headquarter and the establishment. Column (1) uses the LBD-CNUS matched sample from 1987 to 2007. Columns (2)-(3) use the 1999 subsample of the matched sample. Regressions are weighted by the weights provided in the 1999 Annual Survey of Manufactures. Standard errors are clustered at the firm level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

3.2.2 The Second Step

The first-step regression in column (1) of Table 3.2 delivers a vector of estimates of fixed effect for each census division s and year t, i.e., ξ_{st}. In the second step, I decompose these fixed effect estimates to back out the scale parameters of the location-specific Fréchet distributions that represent the locations' state of technology T_s.

By appealing to the calibrated value of θ and Equation (3.23), which draws on the model structure, I construct "purified" location-specific fixed effects that are purged of the wage component as $\tilde{\xi}_{st} \equiv \hat{\xi}_{st} + (\theta+1) \log w_{st} = \theta \log(T_{st}) + \phi \log \overline{MA}_{st}$, where w_{st} is the education-adjusted average weekly wage of the manufacturing sector for census division s and year t.[6] Columns (1) and (2) in Table 3.4 report the raw and purified estimates, respectively, of the fixed effects for each census division in 1999 and normalize these estimates by that for the New England census division. Take the Pacific census division (consisting of the states of Washington, Oregon and California) as an example. Once I take out the high wage there, the Pacific has the largest estimated purified fixed effect. On the other hand, the East South Central division (consisting of the states of Alabama, Kentucky, Mississippi and Tennessee) has the lowest value.[7]

To estimate the coefficient on market access (ϕ), I follow the convention in the international trade literature by approximating the location-specific state of technology (T_{st}) by the local R&D stock and regress the purified location-specific fixed effects ($\tilde{\xi}_{st}$) on the logarithm of the local R&D stock ($\log \text{R\&D}_{st}$), the logarithm of local market access ($\log \overline{MA}_{st}$),

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[6]The education-adjusted wage is calculated by $w_{st}^{\text{adj}} = w_{st} \exp(\mu H_{st})$, where H_{st} is the average years of schooling in census division s and t, and μ is the return to schooling, which is set to 0.06 following Bils and Klenow (2000).

[7]The purified fixed effects depend on the value of θ, which is calibrated to 3.6 here, but the implied location's state of technology is highly correlated when I vary the value of θ.

a vector of year fixed effects (γ_t), and census division fixed effects (δ_s):[8]

$$\tilde{\xi}_{st} = b_0 + b_{RD} \log(\text{R\&D}_{st}) + \phi \log \overline{MA}_{st} + \gamma_t + \delta_s + u_{st}. \qquad (3.24)$$

Table 3.3 shows the estimated coefficients. Column (1) and (2) control for the location's R&D stock and market access, respectively. As the baseline specification in column (3), I control for both terms. Consistent with the premise that the location's appeal increases in both the location's productivity (proxied by the local R&D stock) and market access, the coefficients on both terms are positive and statistically significant. In particular, the elasticity with respect to market access (i.e., $\hat{\phi}$) is estimated at 0.743.

Then, I construct the state of technology for each census division by $\log(T_{st}) = (\tilde{\xi}_{st} - \hat{\phi} \log \overline{MA}_{st})/\theta$. Column (3) of Table 3.4 reports the state of technology for each census division, normalized by that of the New England census division. Although the state of technology is highly correlated with the purified fixed effect, they differ due to the market access. For instance, compared to the New England division, the Middle Atlantic has a higher local fixed effect but a lower state of technology, indicating that it is mostly better market access that drives up the Middle Atlantic's appeal.

3.2.3 The Third Step

In the last step, I use the method of simulated moments to estimate the firm-specific communication cost associated with a low ICT level ($\underline{h}$), the mean and dispersion of the fixed costs of setting up establishments ($\beta_1^X, \beta_2^X, \sigma^X$) and those of the fixed costs of ICT adoption ($\beta_1^{ICT}, \beta_2^{ICT}, \sigma^{ICT}$).

Denote the vector of parameters to estimate as $\phi = \{\beta_1^X, \beta_2^X, \sigma^X, \underline{h}, \beta_1^{ICT}, \beta_2^{ICT}, \sigma^{ICT}\}$, the data moments as m, and the simulated moments as $\hat{m}(\phi)$. I compute the estimate $\hat{\phi}$

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[8]I construct the local R&D stock by perpetual inventory method using industrial R&D expenditure. State-level R&D expenditure data are from the Survey of Industrial Research and Development, available from the NSF website. Before 1998, the R&D expenditure data were published only for odd years, so I interpolate the data by averaging the years before and after. For instance, $\text{R\&D}_{1990}^{\text{exp}} = (\text{R\&D}_{1989}^{\text{exp}} + \text{R\&D}_{1991}^{\text{exp}})/2$. Then, I calculate the R&D stock by $\text{R\&D}_t^{\text{stock}} = (1 - \delta_{\text{R\&D}})\text{R\&D}_{t-1}^{\text{stock}} + \text{R\&D}_t^{\text{exp}}$. Following Wilson (2009), I calibrate the depreciation rate to 0.15.

Table 3.3: Second-Step Regression Results

	Purified Estimates of Census Division Fixed Effect		
	(1)	(2)	(3)
Log(R&D stock)	0.741***		0.635***
	(0.126)		(0.106)
Log(Market access)		0.887***	0.743**
		(0.255)	(0.225)
N	189	189	189
R^2	0.966	0.965	0.972
Census Division FE	Y	Y	Y
Year FE	Y	Y	Y

Notes: The dependent variable is the census division fixed effect from 1987 to 2007 that are estimated in the first stage regression and are purged of local wages. Independent variables include the logarithm of R&D stocks and the logarithm of market access. R&D stocks are constructed by perpetual inventory method using industrial R&D expenditure at the state level and aggregated to the census division level. The market access is approximated by the average trade cost weighted by demand from each destination market. All regressions include census fixed effect and year fixed effect. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

by minimizing the following objective function:

$$g(\phi) = [m - \hat{m}(\phi)]'W[m - \hat{m}(\phi)], \tag{3.25}$$

where W is the weighting matrix. I use the identity matrix as a weighting matrix $(W = I)$.

Simulation. I simulate 10,000 firms for each location. Each firm is headquartered in its location of birth. Each firm draws a vector of 11 independent random variables. First, each firm independently draws a productivity z from log-normal distribution with mean μ^z and dispersion σ^z. Second, the firm also draws a vector of 9 independent standard normal random variables. Given the firm's headquarter location o, I transform those random variables to the fixed costs of setting up establishments (f_{os}^X) in each location s. The fixed costs of the headquarter, i.e., f_{oo}^X, are set to zero. Finally, the firm draws a standard normal random variable that I transform to the fixed costs of ICT adoption (f_o^{ICT}), given the firm's headquarter location o.

Table 3.4: Estimated Census Division Fixed Effects and State of Technology in 1999

	Census Division Fixed Effect		State of Technology
	Raw Estimates	Purified Estimates	
	(1)	(2)	(3)
New England	1.000	1.000	1.000
Middle Atlantic	2.721	1.620	0.985
East North Central	5.948	3.935	1.176
West North Central	2.314	0.695	0.807
South Atlantic	5.613	1.650	0.903
East South Central	2.166	0.536	0.793
West South Central	2.872	1.463	0.971
Mountain	1.537	0.700	0.878
Pacific	4.015	4.322	1.216

Notes: Column (1) reports the 1999 census division fixed effects estimated from the first-stage regression. Column (2) reports the purified fixed effects that adjusted by local wage of manufacturers. Column (3) reports the second-stage estimates of the 1999 census divisions' state of technology, i.e., the scale parameter of the Fréchet distribution for each census division. The shape parameter is set to 3.6. The estimated fixed effects and state of technology are normalized to those of the New England census division.

Moments and identification. Table 3.5 summarizes the moments for estimation, where I use three sets of moments constructed from the matched LBD-CNUS sample. The first set of moments regards firms' expansion patterns across census divisions, including 1) the overall share of multi-unit firms, 2) the share of multi-unit firms with employment below the median, and 3) the correlation of the share of firms that are headquartered in census division o and have establishments in another census division $s \neq o$ (i.e., %Firms$_{os}$) and the logarithm of the miles between the two census divisions. These moments are informative of the fixed costs of setting up establishments. In particular, the overall share of multi-unit firms decreases in the average fixed costs and thus helps identify the mean of those fixed costs (β_1^X). The share of multi-unit firms with employment below the median is informative of the dispersion of fixed costs (σ^X). The idea is that only the most productive firms, which

are also the largest firms, would become multi-unit if there were no dispersion in the fixed costs of setting up establishments. As these fixed costs become more dispersed, firms with low productivity may draw small fixed costs, allowing them to expand. The correlation moment helps identify the role of distance in the fixed costs (β_2^X).

The second set of moments regards firms' ICT adoption, including 1) the overall share of firms that have adopted Intranet, 2) the share of adopting firms with employment below the median, and 3) the correlation between a firm's ICT adoption and the logarithm of the average distance to the nearest NSFNET node from the firm's headquarter location. Similarly, these moments help pin down the mean and dispersion of the fixed costs of ICT adoption, as well as the role of distance to nodes in these fixed costs.

The third set of moment includes the correlation between a firm's expansion decision (i.e., whether the firm is multi-unit) and its ICT adoption. Along with the share of firms adopting ICT, the correlation helps identify the firm-specific communication cost associated with low ICT. The larger the difference in communication costs for low- and high-ICT firms, the higher is the correlation between firms' geographic expansion and ICT adoption.

Estimation results. Table 3.6 reports the estimates of the third-step estimation. The fixed costs of setting up establishments (f_{os}^X) increase in the distance between the headquarter and the establishment, with an elasticity of 0.091. Column (1) of Table 3.7 reports the conditional average fixed costs in monetary value in each census division.[9] In terms of magnitude, the average fixed costs paid conditional on firms setting up additional establishments are $2.37–$4.59 million in 1999 US dollars. The South Atlantic census division is estimated to have the highest fixed costs, followed by those of the Pacific census division.[10] The estimated fixed costs of setting up establishments are lowest in the West North Central division. Through the lens of the model, the fixed costs paid by multi-unit firms are

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[9]I calculate the costs by assuming that the ratio of average sales to the fixed costs from the model is the same as that in the data.

[10]The South Atlantic census division consists of the states of Delaware, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Georgia and Florida, as well as the District of Columbia.

Table 3.5: Data and Model-Simulated Moments

Moment	Data	Model
A. Expansion Patterns		
Share of multi-unit firms	0.343	0.343
Share of multi-unit firms with employment below median	0.020	0.022
$\text{Corr}(\%\text{Firms}_{os}, \text{Log}(\text{Miles}_{os}))$	-0.369	-0.368
B. ICT Adoption Patterns		
Share of firms adopting Intranet	0.367	0.366
Share of firms adopting Intranet with employment below median	0.048	0.050
$\text{Corr}(\text{Intranet}, \text{Log}(\widetilde{\text{HQDistToNode}}_o))$	-0.028	-0.028
C. Correlation of ICT Adoption and Multi-unit Production		
$\text{Corr}(\text{Intranet}, \text{Multi-unit})$	0.555	0.555

Notes: This table compares the model simulated moments to data moments. Panel A includes moments that summarize firms' expansion patterns: the overall share of multi-unit firms, the share of multi-unit firms with employment below the median, and the correlation of the share of firms expanding from one census division to another and the logarithm of the distance (in miles) between the two census divisions. Panel B includes moments that summarize firms' ICT adoption patterns: the overall share of firms that have adopted Intranet, the share of adopting firms with employment below the median, and the correlation between a firm's ICT adoption and the logarithm of average distance to the nearest NSFNET node in the firm's headquarter census division which is scaled by the census division's land area. Panel C is the correlation between a firm's Intranet adoption and multi-unit status.

approximately 18.64% of firms' total profits, on average. As the model does not distinguish between the sunk cost of setting up an establishment versus the flow cost paid to maintain remote establishments, the estimated fixed costs could include both types of costs.

The firm-specific communication cost associated with having a low ICT level ($\underline{h}$) is estimated to be 1.474. As the cost associated with having a high ICT level is normalized to 1, this estimate translates to a $38.8\% (= \log 1.474 - \log 1)$ increase in firm-wide communication costs. We can also interpret the estimate in terms of efficiency loss in a firm's *effective* productivity, i.e., $\tilde{z} = z/h(\varphi)$. A firm with a low ICT level would suffer a productivity disruption of 38.8% relative to the productivity of a counterpart with a high ICT level.

The estimated fixed costs of ICT adoption are relatively smaller than those of setting

Table 3.6: Third-Step Parameter Estimates

	β_1^X	β_2^X	σ^X	$\underline{h}$	β_1^{ICT}	β_2^{ICT}	σ^{ICT}	Loss Function
Estimate	1.630	0.091	2.785	1.474	0.991	0.090	3.669	1.019e-05
S.E.	(.)	(.)	(.)	(.)	(.)	(.)	(.)	

Notes: This table reports the estimates from the third-step estimation using method of simulated moments, and the corresponding loss function. Standard errors are suppressed due to pending disclosure review.

up establishments. As reported in column (2) of Table 3.7, the average fixed costs paid by firms that adopt a high level of ICT are approximately \$1.09–\$1.44 million in 1999 US dollars. Fixed costs of ICT adoption may include not only the actual monetary costs paid for hardware and software to set up the Intranet, but also the value of the time required to upgrade the system, measured as forgone profits. These fixed costs increase in the location's ICT access, proxied by the location's average distance to the nearest NSFNET node, with an elasticity of 0.090. That is, a 10% reduction in the average distance is associated with a 0.9% decrease in the fixed costs of ICT adoption. As many small and single-unit firms also adopt Intranet in the data, there is large dispersion in the fixed costs of ICT adoption.

Model fit. The last column in Table 3.5 shows that the model is able to replicate data moments well. To further validate the model, I compare the simulated bilateral expansion patterns, i.e., the share of firms that are headquartered in census division o and have establishments in census division s, to those shares from the data. Ideally, I would use the bilateral expansion shares from the LBD. Unfortunately, these bilateral expansions often have small sample sizes. Data privacy policies from the Census Bureau thus prevent me from disclosing these data. Therefore, I turn to an alternative dataset—the manufacturing package from the National Establishment Time Series (NETS) database—to calculate the bilateral expansion patterns. NETS is a comprehensive dataset that covers the universe of US establishments in the manufacturing and related sectors.[11] The database is comparable

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[11]Barnatchez et al. (2017) provide detailed assessments of the NETS database and compare

Table 3.7: Average Fixed Costs of Setting Up Establishments and Adopting ICT

Census Division	Average Fixed Costs (in Millions USD)	
	Setting Up Establishments (Establishment Location)	Adopting ICT (Headquarter Location)
New England	2.94	1.22
Middle Atlantic	3.46	1.31
East North Central	3.12	1.44
West North Central	2.37	1.18
South Atlantic	4.59	1.38
East South Central	3.08	1.25
West South Central	3.39	1.22
Mountain	2.77	1.09
Pacific	3.57	1.26

Notes: This table reports the estimated average monetary value of the fixed costs in each census division. Column (1) shows the average costs of setting up establishments in each census division for firms with establishments in multiple census divisions. Column (2) shows the average costs of adopting ICT for the firms' headquarter each census divisions for firms that adopt ICT. These costs are calculated with the assumption that the ratio of average sales to the fixed costs from the model is the same as that in data.

to the LBD in terms of its geographic coverage and firm ownership linkages. Figure 3.1 plots the model-simulated bilateral expansion patterns against data patterns from NETS, adjusted by a constant share difference. The correlation between the model-simulated moments and the data moments is high, at approximately 0.76. These shares are affected not only by the fixed costs of setting up establishments but also by the state of technology for each location that is estimated in the second step. Overall, the model does a good job in matching the targeted and untargeted moments.

3.2.4   Simulation of The Internet Privatization

Using a difference-in-differences approach, Section 3 finds that the Internet privatization increased firms' geographic span of control. In particular, privatization increased the av-

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it to confidential US Census data. Rossi-Hansberg et al. (2021) use the NETS database and document a diverging concentration at the local and national levels.
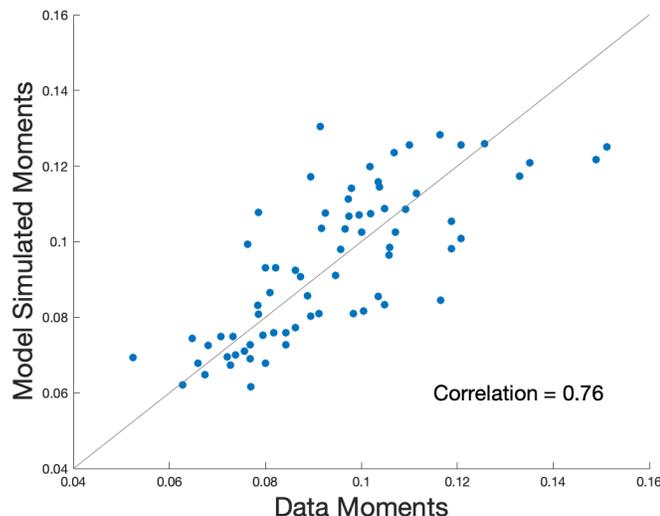
Figure 3.1: Untargeted Moments: Bilateral Expansion Patterns

Notes: This figure plots the model simulated shares of firms that expand from one census division to another against those shares calculated from the National Establishment Time Series Database (NETS). To account for difference in average expansion shares in the LBD-CNUS matched sample and NETS database, I add a constant to the bilateral expansion shares from NETS.

erage number of census divisions in which a firm had establishments by 2.56%. While the reduced-form estimates are useful for learning about the partial equilibrium effects, what are the general equilibrium effects, where prices of manufacturing goods adjust endogenously? What are the efficiency gains and how are they distributed across locations? In this section, I use the estimated model to shed light on the general equilibrium impacts of the Internet privatization.

I mimic the Internet privatization by reducing the fixed costs of ICT adoption. This experiment has a direct effect on firms' geographic span of control (due to the complementarity between geographic expansion and ICT adoption) and an indirect effect (due to equilibrium forces). In particular, lower ICT costs lead to higher ICT adoption rates, thus increasing firms' effective productivity and reducing communication costs across locations. Meanwhile, as firms' average productivity increases, markets become more competitive. Firms at the margin would downgrade in terms of size, including their geographic span of

control.

As the model is calibrated to the postprivatization economy in 1999, I first back out the prereform average fixed cost of ICT in the partial equilibrium model, fixing the equilibrium prices to those in the postprivatization equilibrium. I do so by raising the average distance to nodes proportionally to the level such that the simulated changes in the average number of census divisions per firm match the reduced-form estimates. I denote the larger prereform distance measure by $\log(\widetilde{\mathrm{HQDistToNode}}_{o,\mathrm{pre}})$ and the associated average fixed costs of ICT by $\mu_{\mathrm{pre}}^{ICT} = \beta_1^{ICT} + \beta_2^{ICT} \log(\widetilde{\mathrm{HQDistToNode}}_{o,\mathrm{pre}})$. Then, I use these prereform costs (μ_{pre}^{ICT}) to simulate the economy using the benchmark model.

Table 3.8 compares the reduced-form estimate, model-simulated partial equilibrium effects, and general equilibrium effects. Column (1) reports the estimated changes (%) from the reduced-form analysis. Column (2) reports the changes in the partial equilibrium when I reduce the average fixed cost of ICT by 82.82% for each census division by raising the average distance to the nearest node. Decreases in the fixed cost of ICT lead directly to an increase of 19.77% in the fraction of firms adopting ICT. We also see an increase in multi-unit production. By design, the change in the average number of census divisions per firm exactly matches the reduced-form estimate of a 2.56% increase. The last column shows the general equilibrium results, allowing manufacturing prices to adjust endogenously. The extent of geographic expansion is smaller than that in the partial equilibrium: the average number of census divisions per firm increases by 1.81, approximately 70% of the magnitude when aggregate prices are fixed. Finally, through the lens of the benchmark model, the Internet privatization increases welfare, on average, by 1.11%.

To highlight the role of firms' geographic expansion in increasing consumer welfare, I calculate the welfare change when firms' locations are fixed. The results suggest that approximately 64% (=0.71/1.11) of the welfare gains are accounted for by improving productivity of firms' existing establishments—including their headquarters and non-headquarter establishments in other locations. Firms' geographic expansion accounts for the remaining 36% of the welfare gains.

65

Table 3.8: Quantification of Welfare Changes From the Internet Privatization

		Model	
%Change in	Reduced-Form (1)	Partial Equilibrium (2)	General Equilibrium (3)
Average Number of Census Divisions per Firm	2.56	2.56	1.81
National Avg. Welfare (Endogenous Locations)	–	–	1.11
National Avg. Welfare (Fixed Locations)	–	–	0.71

Notes: This table shows the changes in firm geographic span of control and welfare from the Internet privatization. Column (1) reports the reduced-form estimate. Column (2) shows the simulated changes with fixed prices. Column (3) shows the simulated changes in the benchmark model with endogenous prices.

3.3 Counterfactuals

In this section, I use the parameters estimated in the previous section to conduct counterfactual analyses. I simulate two policy counterfactuals that reduce the fixed costs of ICT adoption—one at the local level and the other at the national level. I find it crucial to take multi-unit production into account when we evaluate the welfare gains from policies that reduce ICT costs, as firms' multi-unit production and geographic expansion is an important channel through which technology spills across locations. Throughout the counterfactual exercises, I treat total GDP and wages as fixed so that the welfare changes are captured by changes in the manufacturing prices.

3.3.1 Unilateral ICT Cost Reduction

Panel A of Figure 3.2 shows the averages of the estimated fixed costs of ICT adoption for each census division. The differences in ICT costs are driven by the location's average distance to NSFNET nodes. Consistent with the premise that the West coast had better ICT infrastructure and talent pools, firms in the Pacific census division had the lowest ICT adoption costs. In contrast, firms in the New England, the East South Central and Middle Atlantic census divisions faced higher ICT costs.

In the first counterfactual exercise, I simulate a policy that helps local firms in the East South Central states, including Alabama, Kentucky, Mississippi, and Tennessee, to reduce their ICT costs and catch up with Pacific firms. For instance, local governments might expand and upgrade the broadband infrastructure so that firms have better access to high-speed Internet. I simulate such a policy by reducing East South Central's average fixed costs of ICT adoption to the same level as that in the Pacific, a cost reduction of approximately 23%. As the costs of adopting ICT decrease, local firms become more likely to adopt ICT. This cost reduction in the East South Central census division increases the local ICT adoption rate by 5.3%. Because of the complementarity between ICT adoption and geographic expansion, the local share of multi-unit firms increases by 1.3%. Panel B of

Figure 3.2 shows where those East South Central firms expand their production. The West North Central census division is the favorite destinations, followed by the New England census division. These locations either have high productivity—as in the case of the New England census division—or low labor costs—as in the West North Central census division. These expansion patterns suggest that ICT infrastructure improvements in the South affect other regions, particularly those in the North, through firms' expansion.

Figure 3.3 shows the geographic distribution of welfare gains from this local ICT cost reduction. I report the results from the benchmark model in Panel A, where I take into account firms' multi-unit production, and compare them to the results from an alternative model that shuts down multi-unit production and considers only the trade channel. Through the lens of the benchmark model, consumer welfare, captured by the inverse of the manufacturing price index, increases by 0.025%.[12]

Moreover, other locations benefit substantially from this local ICT cost reduction. For instance, consumer welfare increases by 0.009% in the Pacific census division, which is the furthest location from the East South Central census division. The far-reaching effects could be attributed to two channels—trade and multi-unit production. To disentangle these two channels, I compare the benchmark model with an alternative model that shuts down the multi-unit production channel. Panel B shows that a model with only trade would underestimate the geographic scope of the effects of a local cost reduction. The gains are geographically confined to the East South Central census division and decay rapidly in the distance. One key driver of the differences between the two models is the elasticity of communication costs and trade costs with respect to the distance. The estimated elasticity of communication costs is 0.076 and 0.138, respectively, for Intranet adopters and non-adopters. Even for Intranet nonadopters, which bear high costs of communication between establishments and headquarters, the elasticity is smaller than that of trade costs with respect to the distance. Therefore, firms' multi-unit production is an important channel through which a local shock can spill over across locations.

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[12]Together with the 23% drop in the cost of ICT, we can translate these changes into an elasticity of welfare with respect to the ICT cost of approximately -0.001.
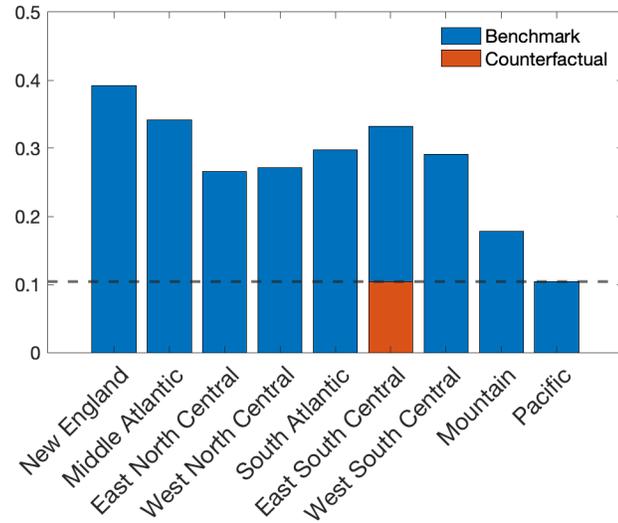
A. Logarithm of Average Fixed Costs of ICT
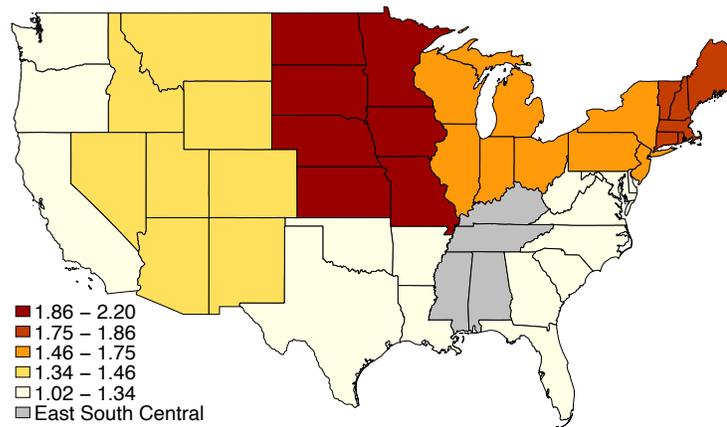
B. %Changes in Establishment Locations

Figure 3.2: Unilateral ICT Cost Reduction: Changes in Expansion Patterns

Notes: These figures show the changes for the counterfactual exercise that reduces the fixed costs of ICT adoption in the East South Central census division. Panel A shows the logarithm of the average fixed costs of ICT adoption in each census division. Panel B shows the changes in the share of firms that expanded from the East South Central census division to the other census divisions.
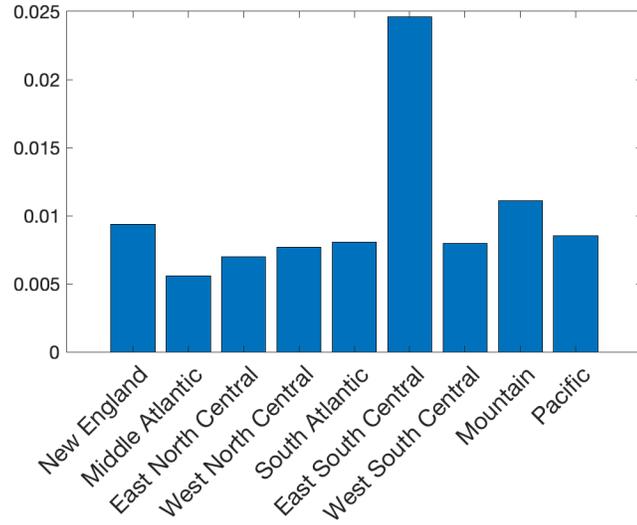
A. Benchmark Model
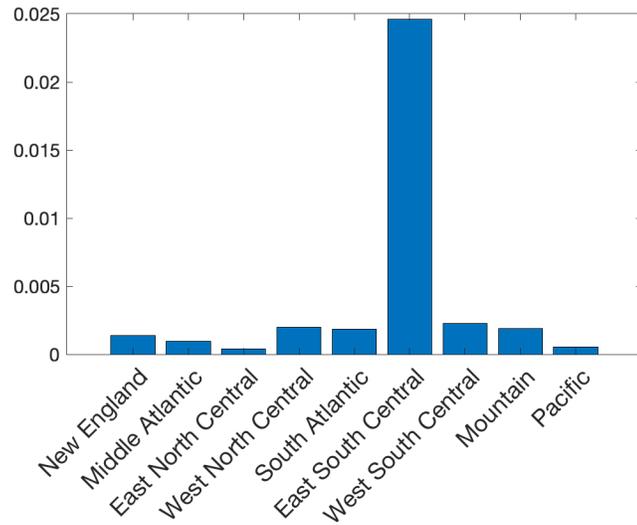
B. Trade-only Model

Figure 3.3: Unilateral ICT Cost Reduction: %Changes in Welfare

Notes: These figures show the welfare change in each census division for the counterfactual exercise that reduces the fixed costs of ICT adoption in the East South Central census division. Panel A and B correspond to the benchmark model including both trade and multi-unit production and the trade-only model, which shuts down the multi-unit production channel, respectively.

Decomposition of welfare changes. I break down the role of multi-unit production in transmitting local ICT improvements to the rest of the economy, by decomposing welfare change in each location to the contribution from different types of firms, in particular local firms (i.e., firms headquartered in that location) and outside firms (i.e., firms headquartered in another location). For outside firms, I further divide them into four groups, depending on whether they set up establishments in the location in the benchmark and counterfactual equilibrium: "stayers" denote outside firms that have establishments in the location both before and after ICT improvements in the East South Central census division; "entrants" and "exiters" denote outside firms that entered or exited the location afterward, respectively; "never-comers" denote outside firm that do not have establishments in the location either before or after the local ICT improvements in the East South Central census division.

Table 3.9 reports the contribution in welfare changes from these different types of firms. The welfare increase in the East South Central census division, where the ICT improvements occur, is primarily driven by the productivity increase of local firms headquartered in the location, as the fixed costs of ICT adoption decrease. In other locations, however, outside firms—particularly East South Central firms—account for the majority of the welfare changes. On average, "stayers" contribute to approximately half of the welfare increase in the other locations, driven by the productivity increase of the incumbent establishments set up by multi-unit firms headquartered in the East South Central census division. Because of the complementarity between ICT adoption and geographic expansion, East South Central firms expand to more locations, which further enhances the positive spillover to other locations. This effect is reflected by the contribution from "Entrants", i.e., those East South Central firms that expand to other locations after ICT improvements, which accounts for 65% of the welfare change in the other census divisions, on average. These direct channels facilitate the spillover of local ICT improvements to other locations through the multi-unit production and geographic expansion of East South Central firms. Meanwhile, as markets become more competitive, firms from other locations contract, leading to price increases and welfare decreases. "Exiters", i.e., those firms that exit the location as more produc-

Table 3.9: Unilateral ICT Cost Reduction: Decomposition of Welfare Changes

| Census Division | %Change in Welfare (1) | Decomposition (%) | | | | Local |
| | | Outside Firms | | | | |
		Stayers (2)	Entrants (3)	Exiters (4)	Never-Comers (5)	Firms (6)
East South Central	0.025	0.0	0.0	-0.3	-8.0	108.3
Other Census Divisions	0.008	55.9	64.7	-24.1	16.2	-12.7
New England	0.009	33.3	70.9	0	-4.2	0
Middle Atlantic	0.006	24.9	149.3	-9.8	34.3	-98.6
East North Central	0.007	60.2	90.5	-61.2	13.1	-2.6
West North Central	0.008	74.6	53.4	-60.7	32.8	0
South Atlantic	0.008	103.5	38.4	-59.5	18.0	-0.3
West South Central	0.008	60.5	13.8	0	25.7	0
Mountain	0.011	7.0	88.8	-1.8	6.0	0
Pacific	0.009	83.6	12.9	-0.1	3.6	0

Notes: This table shows the welfare changes in each census division for the counterfactual exercise that reduces the fixed costs of ICT adoption in the East South Central census division and decomposition of these change into different types of firms. Appendix B.3.1 provides details on the welfare change decomposition.

tive East South Central firms enter the market, have a negative impact, approximately -24% on average, on welfare changes in other locations. Similarly, local firms, which are headquartered in the location, are less likely to adopt ICT and downsize their production, leading to a 13% welfare loss. Finally, "Never-comers" contribute to the welfare changes by 16%, driven by spillover through the trade channel.

The lower panel of Table 3.9 reports the total welfare change and the corresponding decomposition for each census division. Due to heterogeneity in locations' initial shares of multi-unit firms and the expansion of East South Central firms, the contribution from each type of firm varies across locations. Nonetheless, multi-unit production, which includes "stayers", "entrants" and "exiters", play an important role in shaping the geographic distribution of welfare gains.

3.3.2 Universal ICT Cost Reduction and Equalization

Now consider an alternative policy issued by the federal government to lower the costs of ICT for all locations. In particular, I lower the ICT costs in each location to the same level as those in the Pacific census division, as shown in Panel A of Figure 3.4. The cost reduction ranges from 29% in the New England census division to 7.4% in the Mountain census division, leading to a 3.7% increase in the nationwide ICT adoption rate. Panel B of Figure 3.4 shows the corresponding changes in the share of multi-unit firms in each census division. Closely following the changes in ICT costs, locations that experience the largest cost reductions see the greatest increases in the share of multi-unit firms. It is worthwhile to note that the Pacific census division, which does not experience changes in ICT costs, shows a decrease in multi-unit firms. This is driven by the equilibrium force whereby that product markets become more competitive, such that firms at the margin contract as consumers substitute toward products with lower costs.

The bars on the left in Panel A of Figure 3.5 show the changes in welfare across locations. Despite the differential changes in ICT costs across locations, the differences in welfare changes are smaller as a result of the geographic spillover through trade and multi-unit production. I compare these welfare gains to those from another set of policies that take place at the local level and that reduce ICT costs individually for each location. Each dotted bar on the right for each census division corresponds to a local policy that reduces the fixed costs of ICT adoption only in that census division, keeping the costs constant for the other census divisions. Compared to the federal policy that reduces ICT costs for all locations, these local policies lead to smaller local gains. The difference between the federal and local policies is largest in the Mountain census division. On average, the federal policy yields an elasticity of welfare with respect to the ICT cost that is 4 times larger than that from a local policy, indicating that a coordinated policy across locations is more effective than uncoordinated local policies.

I further compare these two policies in a model with only trade, which shuts down the multi-unit production channel. As shown in Panel B of Figure 3.5, absent the spillover

across locations through multi-unit production, additional benefits from a universal rather than local cost reduction are smaller. These results underscore the importance of taking multi-unit production into account when we evaluate the gains from ICT and policy proposals that lower ICT costs. Multi-unit production and firms' geographic expansion reinforce the overall gains from ICT when locations lower their ICT costs in a coordinated manner.
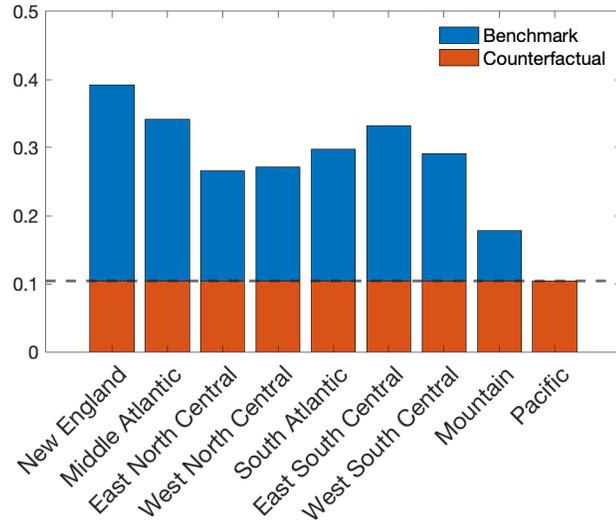
A. Logarithm of Average Fixed Costs of ICT
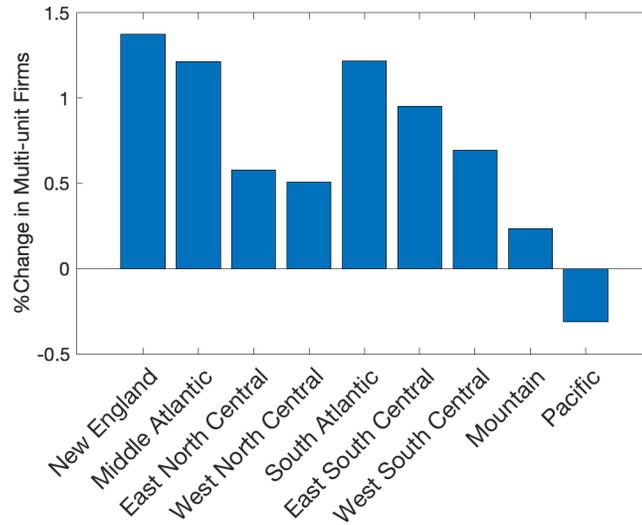
B. %Changes in Share of Multi-Unit Firms

Figure 3.4: Universal ICT Cost Reduction: Changes in Expansion Patterns

Notes: These figures show the changes for the counterfactual exercise that reduces the fixed costs of ICT adoption in all census divisions. Panel A shows the logarithm of the average fixed costs of ICT adoption in each census division. Panel B shows the changes in the share of multi-unit firms in each census division.
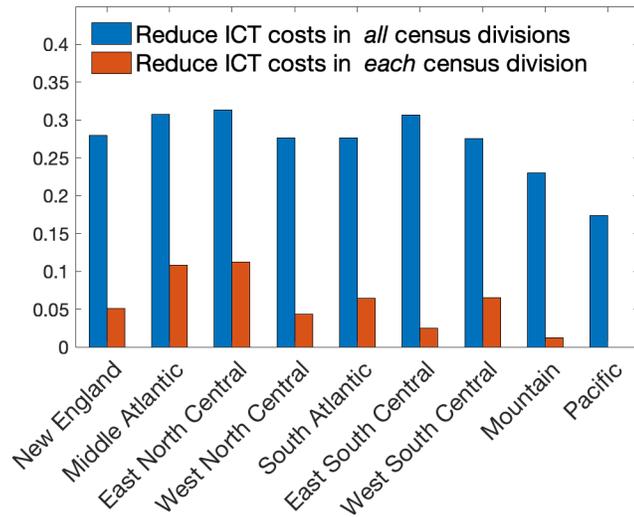
A. Benchmark Model
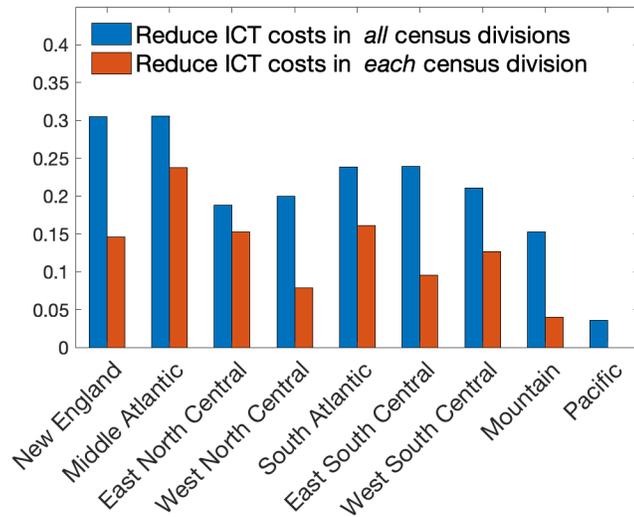
B. Trade-only Model

Figure 3.5: Universal ICT Cost Reduction: %Changes in Welfare

Notes: These figures compare the welfare change in each census division for the two sets of counterfactual exercises: one that reduces the fixed costs of ICT adoption in each census division individually and the other that reduces the costs in all census divisions. Panel A and B correspond to the benchmark model including both trade and multi-unit production and the trade-only model, which shuts down the multi-unit production channel, respectively.

Chapter 4

Tax Policy and Lumpy Investment: Evidence from China VAT Reform

This chapter is based on the joint paper with Zhao Chen, Zhikuo Liu, Juan Carlos Suárez Serrato, and Daniel Xu. The paper is accepted by the *Review of Economic Studies*.

This paper improves our understanding of how tax policy affects investment behavior by incorporating the lumpy nature of investment. Lumpy investment behavior is evident in most microdata, with firms either replacing a considerable fraction of their existing capital (spikes) or not investing at all (inaction). The prevalence of lumpy investment patterns suggests that extensive-margin investment decisions—i.e., whether to invest or not—are important determinants of overall investment. This paper shows that extensive-margin responses to tax policy are key to understanding the effects of different tax reforms and to designing effective stimulus policies.

We illustrate theoretically, empirically, and quantitatively that tax policy can impact extensive-margin investment decisions and that the effects of tax policy are shaped by investment frictions. Firms invest in lumpy increments because adjusting the physical stock of capital can entail fixed disruption costs and because investment is partially irreversible—i.e., the price of new capital is greater than the resale price of used capital. We integrate various tax policies into a model with these frictions. Tax policies can be a source of partial irreversibility, since input taxes and tax credits impact the wedge between the purchase and resale prices of capital. Other policies, such as income taxes and depreciation deductions, indirectly affect lumpiness by changing the after-tax value of fixed disruption costs. Different tax incentives have distinct effects on the frictions that determine whether firms undertake investment projects. As a result, policies that change the user cost of capital by the same degree can have different implications for firm investment.

Our analysis is grounded in one of the largest tax incentives for investment in recent

history: China's 2009 value-added tax (VAT) reform. The reform unexpectedly allowed domestic firms to deduct input VAT on purchases of new equipment. This policy change lowered the user cost of capital by 15% and reduced the wedge between the after-tax prices of new and used capital.[1] Understanding how tax policy impacts investment in China is of first-order importance since corporate investment comprises 30% of China's GDP and since—as shown in Figure 4.1—investment in China has long surpassed investment levels in the United States and the European Union. We use comprehensive firm-level tax data to shed light on this stimulus program and to develop insights into how tax policy interacts with the frictions that generate lumpy investment.

We start by developing intuition for how tax policies interact with firm frictions in Section 4.1. We embed important tax policies—income tax, VAT, and depreciation deductions—into a standard model of dynamic investment that is rich enough to characterize our empirical setting. As in Cooper and Haltiwanger (2006), fixed costs and partial irreversibility rationalize lumpy investment patterns, and convex costs dampen investment responses to changes in taxes or productivity. We then provide intuition for how different tax policies interact with these frictions. While the VAT reform lowered the after-tax cost of capital and reduced the degree of partial irreversibility, it did not directly interact with adjustment costs. In comparison, while a corporate income tax cut has a smaller effect on partial irreversibility, it lowers the after-tax cost of capital and affects the after-tax value of adjustment costs. The model shows that to fully grasp how tax policy affects investment, it is necessary to account for the dual effects of tax policy on adjustment frictions and the cost of capital.

The second step of our analysis estimates the reduced-form effects of China's 2009 VAT reform. As we discuss in Section 4.2, we evaluate the effect of the reform by comparing

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[1] By way of comparison, the recent tax reform in the United States lowered the user cost of capital by about 4% (Barro and Furman, 2018). In the Chinese setting, eliminating the corporate income tax or allowing for immediate depreciation deductions (i.e., expensing) would lower the user cost of capital by 3.5%. The VAT reform lowered partial irreversibility since, prior to the reform, firms paid VAT on equipment but did not collect VAT on the sale of used equipment.
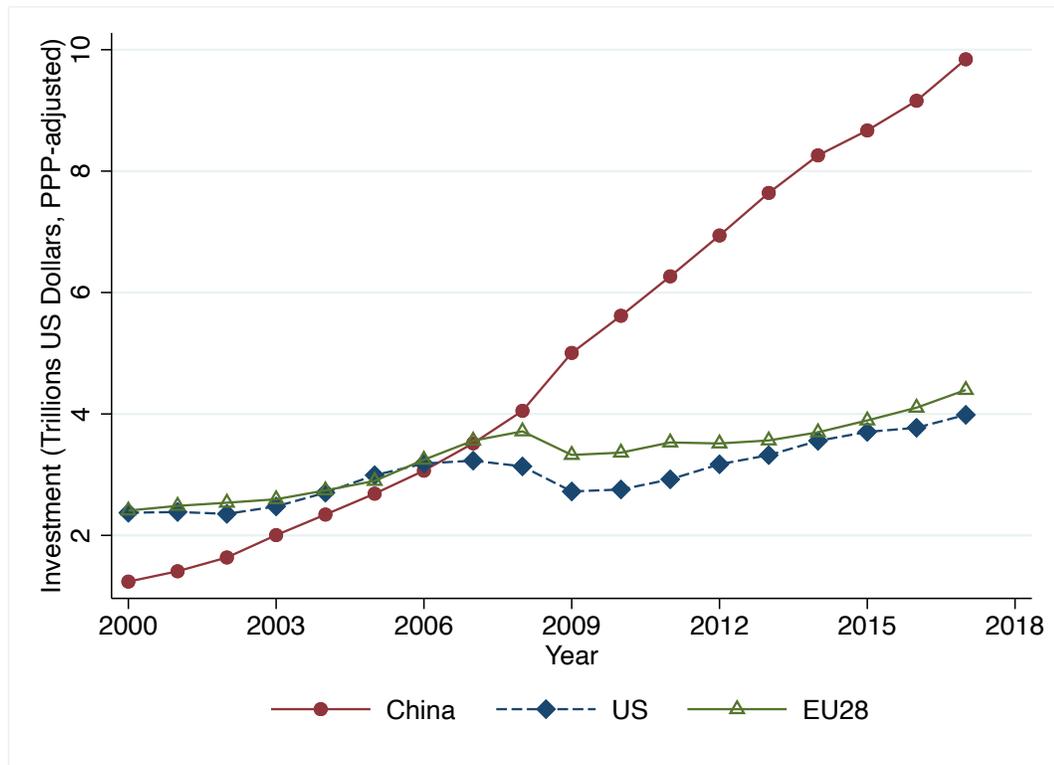
Figure 4.1: Cross-Country Comparison of Investment

Notes: This figure displays investment in the United States, the European Union, and China from 2000 to 2017 as reported by the OECD. The figure shows that investment in China has long surpassed investment levels in the US and the European Union and that it has increased drastically since 2000.

domestic and foreign firms, since foreign firms with preferential treatment were able to deduct input VAT on equipment prior to the reform. We implement this research strategy using a novel tax survey dataset from the Chinese State Administration of Tax. We describe these data in Section 4.3. As we show in Section 4.4, we find substantial effects of the reform on firm investment. On the extensive margin, relative to foreign firms, the fraction of domestic firms investing in equipment increased by 5 percentage points, or a 10% increase. On the intensive margin, relative investment increased by 3.6% of the existing capital stock, for a 36% increase in investment. We then highlight the importance of interactions between tax policies and the frictions that generate lumpy investment. Specifically, we find that the majority of the investment response was due to a surge in the number of firms that went from not investing to undertaking investment projects that were greater than 20% of their capital (i.e., investment spikes).

The validity of this research design rests on the assumption that, absent the reform, domestic firms would have had the same investment trends as foreign firms. Three sets of auxiliary results suggest that foreign firms are a suitable control for domestic firms. First, we show that both sets of firms had similar investment trends prior to the reform. Second, the results are robust to a number of checks including using alternative measures of investment, different sample restrictions, reweighting the data to match the characteristics of foreign and domestic firms, and controlling for firm-level characteristics and other changes in tax policy. Finally, we conduct two placebo tests to further validate our identifying assumption. The first placebo test uses domestic and foreign firms that were included in a pilot program allowing firms to deduct input VAT from new investments starting in 2004. We find no evidence that the 2009 reform differentially affected foreign and domestic firms in the pilot program. This result suggests that there were no other time-varying shocks that differentially affected foreign and domestic firms and that might confound our estimates. In a second placebo test, we use the fact that the VAT reform did not impact the tax treatment of investment in structures. Because the reform did not differentially affect how foreign and domestic firms invested in structures, it is unlikely that our results

are confounded by differential shocks to foreign and domestic firms. Additionally, triple-difference specifications that use these placebos as additional controls yield similar estimates of the reform. These results significantly limit the risk that our main results are a spurious feature of the data and are not driven by the tax reform.

To quantify the interactions between investment frictions and tax policy, in Section 4.5 we estimate our dynamic model of investment. Our estimation relies on the method of simulated moments (MSM) to recover fixed and convex adjustment costs while allowing the VAT reform to influence partial irreversibility. Our model targets two sets of moments: (1) pre-reform statistics on investment patterns, such as measures of lumpiness and the autocorrelation of investment, and (2) the reduced-form estimates of the effects of the reform. We validate our model of investment by showing that it can match the reduced-form effects of an actual reform, including untargeted moments such as the effects of the reform on investment spikes. Simultaneously matching both of these sets of moments indicates that the VAT-induced price gap between used and new capital was the major source of partial irreversibility.[2]

We then use the model to compare the fiscal effectiveness of alternative tax policies in Section 4.6. We measure the effectiveness of a given policy by comparing the tax revenue cost to the change in investment. We find that policies that increase the likelihood of investment spells are more effective at stimulating investment. For instance, lowering the VAT distortion is more effective at stimulating investment than lowering the corporate income tax rate. One reason a corporate income tax cut is less effective is that a large fraction of firms are inframarginal to the tax cut—their investment is unaffected, but they benefit from the lower tax rate. In addition to having a large effect on the extensive margin of investment, policies that shrink the price gap between new and used capital—such as an

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[2]While the empirical investment literature relies on the asymmetry between the positive and negative ranges of the investment distribution to separately identify fixed costs from partial irreversibility, the lack of asset sales in tax data makes this approach infeasible. We instead use a reform that reduced the price gap between new and used capital to measure the relative importance of partial irreversibility for extensive-margin investment decisions.

investment tax credit—only benefit firms that increase their investment. For this reason, introducing an investment tax credit is just as effective as reducing the VAT distortion. We also find that China's 2009 VAT reform stimulated more investment relative to lost tax revenue than a counterfactual policy that mirrors the 2017 Tax Cut and Jobs Act in the United States.[3] Section 4.7 concludes by noting that this lesson is relevant for tax policy in other countries that rely on sales taxes, VATs, and investment tax credits since such measures directly impact the extensive margin of investment.

Related Literature

This paper is related to a long line of research in public finance dating to Jorgenson and Hall (1967). Recent work has revolutionized our understanding of how firms respond to taxation by exploiting credible identification strategies with administrative tax data (e.g., Yagan, 2015; Maffini et al., 2016; Rao, 2016; Zwick and Mahon, 2017; Ohrn, 2018a,b; Moon, 2019).[4] Papers that study how Chinese firms respond to tax incentives include Cai and Harrison (2016), Liu and Mao (2019), Chen et al. (2016), and Chen et al. (2019).[5] The main contribution of our paper is to improve our understanding of how tax policy impacts investment by providing a coherent framework to interpret the intensive- and extensive-

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[3] While our analyses focus on a partial equilibrium setting, we show that our quantitative results are robust to alternative assumptions regarding the supply of capital goods and effects of the reform on interest rates, concomitant aggregate productivity shocks, additional sources of partial irreversibility, and interactions between income taxes, adjustment costs, and interest costs.

[4] Our paper is also related to classic papers that follow a model-centric estimation approach. For instance, Abel (1980), Salinger and Summers (1981), Summers (1981), and Hayashi (1982) rely on a q-theory approach for quantifying the roles of taxes on investment. Dynamic models with adjustment costs have also been considered by Auerbach (1986), Auerbach (1989), and Auerbach and Hines (1988).

[5] Cai and Harrison (2016) and Chen et al. (2016) use manufacturing survey data to study the effects of the pilot reform in 2004. In concurrent work, Liu and Mao (2019) use tax data to study the reduced-form effects of the rollout of the reform from 2004 to 2009 using small taxpayers as a control for large domestic firms. Using different empirical strategies, we find comparable effects of the reform on investment. Relative to Liu and Mao (2019), this paper contributes to the literature by uncovering the importance of lumpy responses to the tax reform and by providing a coherent model that synthesizes the effects of different tax policies on the intensive and extensive margins of investment.

margin effects that have been documented in quasi-experimental studies. Deploying this framework to measure the effects of a large natural experiment using comprehensive tax data, we highlight the importance of investment spikes in understanding the effects of tax reforms as well as the potential for tax policy to generate partial irreversibility.

This paper also contributes to the investment literature by investigating a real-world tax reform through the lens of a workhorse model of investment (e.g., Caballero and Engel, 1999; Cooper and Haltiwanger, 2006; Gourio and Kashyap, 2007; Khan and Thomas, 2008; David and Venkateswaran, 2019; Lanteri, 2018; Winberry, 2020). Previous research in this literature has simulated the effects of tax policy changes through their effects on the after-tax cost of investment (e.g., Winberry, 2020). We highlight the importance of accounting for interactions between tax policy and the frictions that generate lumpy investment. In particular, we show that tax policies that have the same effect on the after-tax cost of capital can have different effects on firm investment.[6] We also contribute to this literature by using quasi-experimental estimates of the effects of tax reform to estimate adjustment costs. As argued by Cummins et al. (1994), tax reforms generate large and plausibly exogenous shifts in economic fundamentals and are useful in uncovering the nature of investment frictions. Our unified approach is therefore well suited to simulating the effects of potential tax reforms and comparing their effectiveness at stimulating investment.

The results of this paper have implications beyond China. First, policymakers can introduce partial irreversibility through indirect taxation. This can occur when VATs do not allow for the deductibility of investment or when businesses pay indirect taxes on investment goods (e.g., Desai et al., 2004). In the United States, Cline et al. (2005) document that businesses pay over $100 billion in state sales taxes on inputs, including investment

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[6]The focus of this paper is the interaction between tax instruments and producer-level investment behavior. Recent papers (e.g., Khan and Thomas, 2008; Bachmann et al., 2013; Winberry, 2020) have clarified the conditions under which micro-level investment frictions have aggregate implications in general equilibrium. In particular, Winberry (2020) shows that lumpy investments have aggregate implications when interest-rate dynamics match the observed covariance with productivity. In Appendix F, we show that our main conclusions are robust to allowing for potential equilibrium effects on the interest rate or on the price of capital goods.

purchases. Second, VATs can generate partial irreversibility when credits are not refundable. While China started refunding excess VAT credits in 2019 (Ministry of Finance, 2019), excess credits are not refundable in 24 other countries (EY, 2017).[7] Finally, interactions between different tax policies influence the effectiveness of different forms of stimulus. For instance, a corporate income tax cut can be more effective at stimulating investment when other policies, such as an investment tax credits (e.g., Chirinko and Wilson, 2008), are simultaneously used to lower the price gap between new and used capital.

4.1 Modeling Tax Policy and Lumpy Investment

Empirical models of investment use adjustment costs to rationalize two empirical features of investment data. First, the observed pattern of infrequent and lumpy investment suggests firms face fixed costs and partial irreversibility. Second, the sluggish response of investment to changes in economic fundamentals suggests that investment is subject to convex costs of adjustment. We first characterize how frictions that lead to lumpy investment affect the effectiveness of different tax policies in a simple, static model. We then describe a dynamic investment model and show that the intuition from the static model carries over to the dynamic world. Appendix A presents detailed derivations.

4.1.1 Theoretical Motivation

Consider a firm with preexisting capital K_0, productivity A, and profit function $A^{1-\theta}K^\theta$, where $\theta < 1$ is the curvature of the profit function. The firm pays a corporate tax rate τ on profits. We model the *after-tax* price of capital $p = p_k(1 + \nu)(1 - \tau z)$, where p_k is the capital goods price, ν is a tax wedge on the capital price, and $z \leq 1$ is the discounted present value of depreciation deductions.[8] Prior to the 2009 reform, capital equipment

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[7]Excess VAT credits correspond to the positive difference between input VAT payments and output VAT receipts.

[8]z is determined by the tax depreciation schedule of capital. We provide more details of how the tax depreciation schedule maps into z in the dynamic model. While this static

was not deductible from the VAT base, so that ν equals the VAT rate. For simplicity, we refer to a reduction in this wedge as a VAT cut, with the understanding that this change is driven by partial or full deductibility of capital and not by the VAT rate. Absent additional frictions, the firm solves the problem:

$$\max_{K}\ (1-\tau)A^{1-\theta}K^{\theta} - p(K - K_0) \implies K^* = A\left[\frac{1}{\theta}\underbrace{\frac{p_k(1+\nu)(1-\tau z)}{(1-\tau)}}_{\text{UCC}}\right]^{\frac{-1}{1-\theta}}. \quad (4.1)$$

Equation 4.1 implies that the firm will adjust its capital in response to all changes in taxes or productivity. There is no inaction or scope for an extensive-margin response. The user cost of capital (UCC) is given by $\frac{p_k(1+\nu)(1-\tau z)}{(1-\tau)}$. The symmetric effect of p_k and the tax term of the user cost of capital $\frac{(1+\nu)(1-\tau z)}{(1-\tau)}$ is one reason the empirical public finance literature estimates the user cost elasticity of investment. In this model, this elasticity is governed by the curvature of the profit function and equals $\frac{-1}{1-\theta}$.[9]

Partial Irreversibility

Partial irreversibility occurs when firms face different prices to purchase and sell equipment. This distortion can arise from imperfections in the market for used capital or from tax policies. For instance, sales taxes on equipment purchases increase partial irreversibility and have been shown to affect the investment of US firms (e.g., Desai et al., 2004). On the other hand, investment tax credits at the state level in the US (e.g., Chirinko and Wilson, 2008) decrease partial irreversibility. In the case of China, the pre-2009 VAT system increased the purchase price of capital by a factor of $(1+\nu)$, where ν is the VAT rate. Firms selling used capital could not charge the VAT rate. The effective after-tax purchase price is then $p^b = p_k(1+\nu-\tau(1+\nu)z)$ and the sales price is $p^s = p_k(1-\tau(1+\nu)z)$.[10]

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model abstracts away from how real depreciation impacts investment, this important force is present in our dynamic model, and we estimate the rate of depreciation in our structural model in Section 4.5.

[9]As an example, when firms face a downward-sloping residual demand curve, assuming $\theta = 0.75$ implies a markup excluding capital costs of 25% and results in $\frac{-1}{1-\theta} = 4$.

[10]Note that the VAT also increases the value of depreciation deductions.

Partial irreversibility generates inaction—a range of productivity in which firms do not adjust their capital stock in response to small changes in economic fundamentals. While firms usually set the after-tax marginal product of capital (MPK) equal to the price of capital, firms do not adjust their capital when the marginal product of their existing capital falls in the range $[p^s, p^b]$. The dashed line in Panel A of Figure 4.2 shows how the marginal product of capital increases with productivity. The two horizontal lines denote p^b and p^s. The inaction region is the range of productivity where the marginal product of capital falls between these two lines and is given by:

$$[\underline{A}, \bar{A}] \equiv \left[\left(\frac{p^s}{\theta(1 - \tau)} \right)^{\frac{1}{1-\theta}} K_0, \left(\frac{p^b}{\theta(1 - \tau)} \right)^{\frac{1}{1-\theta}} K_0 \right].$$

Panel B of Figure 4.2 shows how p^b, p^s, and the inaction region affect the firm's policy function—the relation between productivity and capital.

To see how tax policies influence the inaction region, note that:

$$\bar{A} - \underline{A} = \left(\frac{\mathrm{UCC}}{\theta} \right)^{\frac{1}{1-\theta}} \left[1 - \left(\frac{\frac{1}{1+\nu} - \tau z}{1 - \tau z} \right)^{\frac{1}{1-\theta}} \right] K_0. \tag{4.2}$$

According to this equation, a reduction in ν will narrow the inaction region both by lowering the user cost of capital and by closing the price gap $\left[1 - \left(\frac{\frac{1}{1+\nu} - \tau z}{1 - \tau z} \right)^{\frac{1}{1-\theta}} \right]$. In contrast, increasing z has two countervailing effects on the inaction region. While increasing z lowers the user cost of capital, this change also widens the price gap. Thus, changes in tax policies with the same impact on the user cost of capital can have different extensive-margin responses.
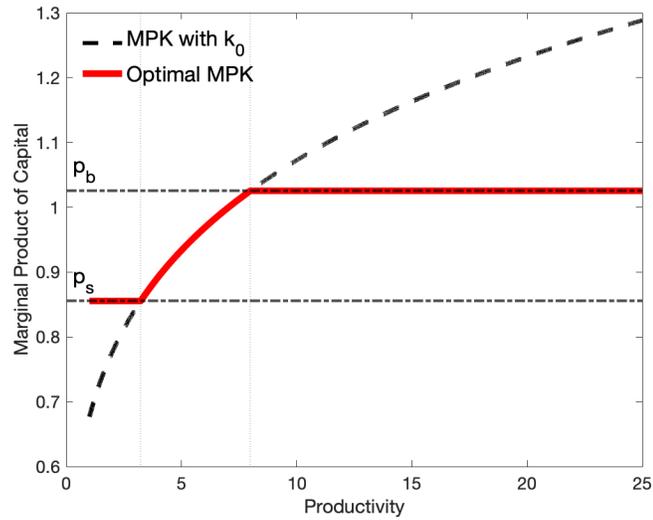
A. Marginal Product of Capital
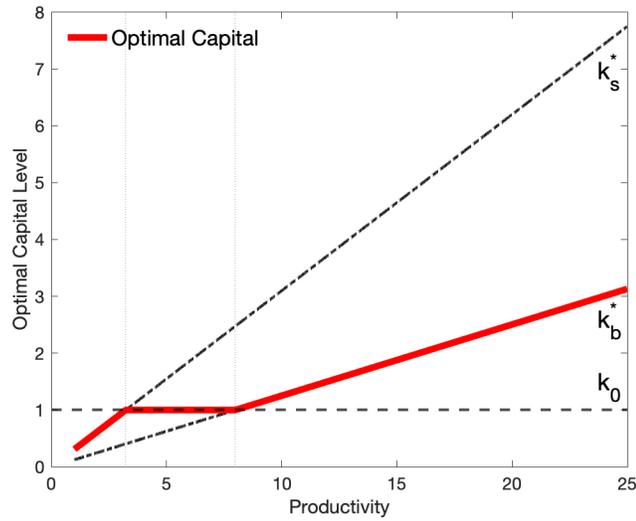
B. Optimal Capital

Figure 4.2: Effects of Partial Irreversibility

Notes: These figures plot the marginal product of capital and the optimal capital level against productivity in a simple static model with only partial irreversibility; i.e., the resale price (p^s) is smaller than the purchase price (p^b). Panel A plots the marginal product of capital (MPK) against productivity. The dashed line corresponds to the MPK at initial capital stock k_0. The upper horizontal line indicates the purchase price p^b. The lower horizontal line indicates the resale price p^s. The red line indicates the MPK at associated optimal capital levels. In Panel B, the red line plots the optimal capital level against productivity.

Fixed Costs

In addition to partial irreversibility, fixed costs also generate inaction. Following the literature (e.g., Caballero and Engel, 1999; Cooper and Haltiwanger, 2006), we interpret fixed costs as technological constraints, including production disruptions and short-run capacity limits that firms face when they replace machinery. We therefore assume that the firm has to pay a non-tax-deductible fraction ξ of its desired capital stock (K^*) to adjust its capital stock. To highlight the role of fixed costs, we abstract from partial irreversibility by assuming that $p^s = p^b = p_k(1 + \nu - \tau(1 + \nu))$.

A firm decides to adjust its capital if its profits after making the adjustment, $(1 - \tau)A^{1-\theta}K^{*\theta} - p(K^* - K_0) - \xi K^*$, are greater than the profits from inaction, $(1 - \tau)A^{1-\theta}K_0^{\theta}$. Comparing the relative profit levels from these two alternatives, we have:

$$\underbrace{\overbrace{\left[\frac{(1-\theta)}{\theta}\mathrm{UCC} - \frac{\xi}{1-\tau}\right]\left[\frac{\theta}{\mathrm{UCC}}\right]^{1/(1-\theta)}A + \mathrm{UCC}K_0}^{\text{Profit conditional on adjusting to optimal capital } K^*} = \overbrace{K_0^{\theta}A^{1-\theta}}^{\text{Profit using initial capital } K_0}.}_{}$$

$$\underbrace{\left[\frac{(1-\theta)}{\theta}\mathrm{UCC} - \frac{\xi}{1-\tau}\right]\left[\frac{\theta}{\mathrm{UCC}}\right]^{1/(1-\theta)}}_{\text{Slope}} A + \underbrace{\mathrm{UCC}K_0}_{\text{Intercept}} = K_0^{\theta}A^{1-\theta}. \tag{4.3}$$

The inaction region is characterized by the two values $\underline{A}$ and $\bar{A}$ that satisfy this indifference condition. The solid black line in Panel A of Figure 4.3 plots the after-tax profit in the case of no adjustment costs. The fixed cost ξ flattens the slope and rotates this line clockwise (shown by the dot-dashed line). The inaction region $[\underline{A}, \bar{A}]$ is defined by the intersection of this rotated line and the curved profit line (in dashes) that holds capital at the initial level. The optimal profit with fixed costs is the red envelope of these two lines. Panel B shows how fixed costs generate inaction in capital adjustment.

Equation 4.3 can be used to illustrate the dual effects of tax policy on the cost of capital and adjustment frictions. Consider first a policy that reduces the user cost of capital through changes in z or ν. These policies would shrink the inaction region by lowering the intercept and increasing the slope. A cut in τ that lowers the user cost of capital by the same amount as changes in z or ν will shrink the inaction region more by reducing the after-tax value of the fixed cost.

As Equations 4.2–4.3 show, in an environment with lumpy investment, the user cost

of capital is not a sufficient statistic to capture the extensive-margin effects of tax policy changes. Because fixed costs and partial irreversibility have different interactions with tax policies, measuring the relative importance of these frictions is crucial for understanding the effects of tax policy.[11] The fact that tax policy can directly influence firms' extensive-margin investment decisions should be taken into account when modeling the effects of tax policy changes.

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[11]Appendix A.1 further describes how convex adjustment costs interact with tax parameters in this static setting.
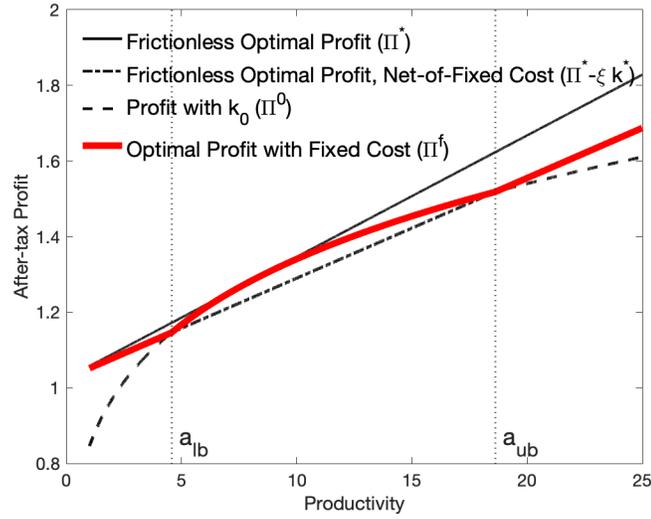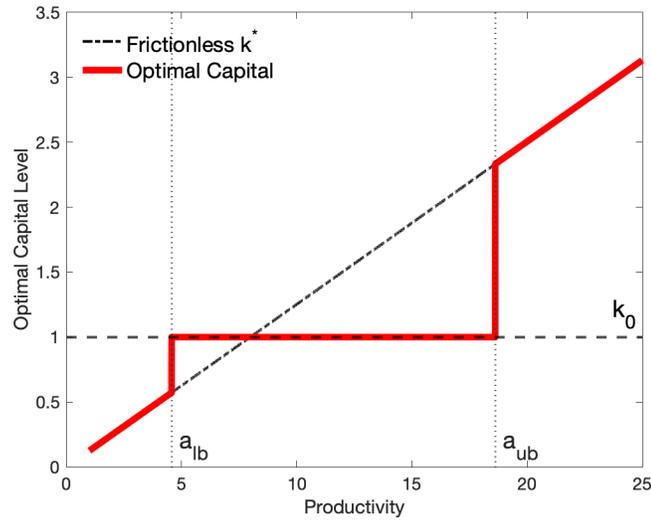
Figure 4.3: Effects of Fixed Costs

Notes: These figures plot the optimal profit and capital against productivity in a simple static model with fixed costs only. In Panel A, the solid line indicates the optimal profit without any frictions (Π^*). The dot-dashed line indicates the optimal profit net of fixed cost ($\tilde{\Pi}^* = \Pi^* - \xi k^*$). The dashed line indicates the profit evaluated at the initial capital level (Π^0). The red line indicates the upper envelope of $\tilde{\Pi}^*$ and Π^0, which is the optimal profit in the presence of fixed costs. In Panel B, the dot-dashed line indicates the frictionless optimal capital level (k^*) against productivity. The dashed line indicates the initial capital k_0. The red line indicates the optimal capital level taking into account the fixed costs.

4.1.2 A Dynamic Model of Tax Policy and Lumpy Investment

We now incorporate how investment frictions interact with tax policy in a dynamic model built on Cooper and Haltiwanger (2006) that is rich enough to characterize our empirical setting.[12]

Pre-Tax Profit Function

Firms have a profit function given by:

$$\Pi(K, A^{\Pi}) = (A^{\Pi})^{1-\theta} K^{\theta}, \tag{4.4}$$

where K is the predetermined capital stock and A^{Π} is a profit shock that is realized at the beginning of the period.[13] $a_{it} \equiv \log(A_{it}^{\Pi})$ denotes a firm's log profitability, which has three components:

$$a_{it} = b_t + \omega_i + \varepsilon_{it}, \tag{4.5}$$

where b_t is an aggregate shock, ω_i captures firm-specific permanent heterogeneity, and ε_{it} is an idiosyncratic transitory shock. Firms draw ω_i from a normal distribution. The aggregate shock b_t and the transitory shock ε_{it} follow AR(1) processes.

Taxes

Firms pay the VAT rate ν on purchases of new equipment. Consistent with the Chinese institutional setting, we assume that new capital purchases cannot be deducted from output

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[12]To focus on the role of adjustment costs and lumpy investment, we abstract from the role of financial frictions. Combining financial frictions and lumpy investment raises additional modeling and identification challenges. Recent models that focus on financial frictions but abstract from lumpy investment include Hennesy and Whited (2007); Arellano et al. (2012); Ottonello and Winberry (2019).

[13]We view this as a reduced-form way to model the profit function, but it is easy to microfound it as the result of a static profit-optimization problem. We give an example using a decreasing-returns-to-scale (DRTS) production function and competitive final good market in Appendix A.2. An alternative is to assume a monopolistic competitive environment with constant-returns-to-scale (CRTS) technology.

VAT. Firms pay corporate income tax at rate τ on profits and depreciate a fixed fraction $\hat{\delta}$ of the end-of-year book value of the capital stock in each period. We summarize the impact of the depreciation schedule on the effective capital purchase price with the sufficient statistic z: the present discounted value of depreciation deductions.[14] The depreciation schedule interacts with both τ and ν since depreciation is deductible from the corporate income tax base and the VAT affects the book value of capital.

Adjustment Costs

Firms face three types of adjustment frictions: a convex adjustment cost, a fixed disruption cost, and partial irreversibilty. We assume that the only source of irreversibility is the non-deductible VAT on equipment purchases, so the resale price is set to one.[15] Firms incur a fixed disruption cost ξK^* when adjusting the capital stock. ξ is assumed to be independent and identically distributed (i.i.d.) across firms and over time and is drawn from the distribution $G(\xi)$.[16] Finally, the convex cost follows the quadratic form $\frac{\gamma}{2} \left(\frac{I}{K} \right)^2 K$.

Normalization and Recursive Formulation

We normalize the firm problem relative to a given permanent productivity by defining $k = K/\exp(\omega)$. This normalization reduces the state space to (k, b, ε, ξ).[17] In any given

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[14]By abstracting from the depreciation schedule, this assumption allows us to study the firm's problem recursively. $z = \hat{\delta} + (1 - \hat{\delta})\beta\mathbb{E}[z']$. Assuming a fixed and exogenous real interest rate r, $\beta\mathbb{E}[z'] = \frac{z}{1+r}$. This formulation builds on arguments in Winberry (2020). We show that this result holds in our setting in Appendix A.3.2.

[15]Partial irreversibility arises naturally from the fact that firms need to pay VAT to sellers when purchasing capital but do not retain VAT payment when selling capital. Section 4.6 shows our results are robust to allowing for additional sources of partial irreversibility.

[16]We represent the units of the fixed disruption cost in terms of the "desired capital level" K^*, as in the frictionless benchmark in Equation 4.1. In the dynamic setting, $K^* = \mathbb{E}[A'|A] \left[\frac{1}{\theta} \frac{p_k(1+\nu)(1-\tau z)}{1-\tau} \right]^{-1/(1-\theta)}$ with $p_k = r + \delta$, where r is the interest rate defined by $r = 1/\beta - 1$, and δ is the economic depreciation rate.

[17]This normalization allows us to account for firm-level permanent heterogeneity in firm-level productivity or unmodeled frictions (see, e.g., David and Venkateswaran, 2019). This result follows from the fact that the profit function (Equation (4.4)) and the costs

period, the firm's value is the maximum of the value from buying capital, selling capital, or inaction:[18]

$$v(k, b, \varepsilon, \xi) = \max\{v^b(k, b, \varepsilon, \xi), v^s(k, b, \varepsilon, \xi), v^i(k, b, \varepsilon, \xi)\},$$

where

$$v^b(k, b, \varepsilon, \xi) = \max_{i>0} \ (1-\tau)\pi(k, b, \varepsilon) - \left[[1 + \nu - \tau z(1+\nu)]i + \frac{\gamma}{2}\left(\frac{i}{k}\right)^2 k + \xi k^*\right]$$

$$+ \beta\mathbb{E}\left[v^0\left(k', b', \varepsilon'\right)|b, \varepsilon\right],$$

$$v^s(k, b, \varepsilon, \xi) = \max_{i<0} \ (1-\tau)\pi(k, b, \varepsilon) - \left[[1 \qquad - \tau z(1+\nu)]i + \frac{\gamma}{2}\left(\frac{i}{k}\right)^2 k + \xi k^*\right]$$

$$+ \beta\mathbb{E}\left[v^0\left(k', b', \varepsilon'\right)|b, \varepsilon\right],$$

$$v^i(k, b, \varepsilon, \xi) = (1-\tau)\pi(k, b, \varepsilon) + \beta\mathbb{E}\left[v^0\left(k(1-\delta), b', \varepsilon'\right)|b, \varepsilon\right],$$

where $k' = (1-\delta)k + i$, δ is the economic rate of depreciation, and where the *ex ante* value function (before the fixed cost draw is realized) is given by:

$$v^0(k, b, \varepsilon) = \int_0^{\bar{\xi}} v(k, b, \varepsilon, \xi)dG(\xi).$$

$v^b(k, b, \varepsilon, \xi)$ is the value function conditional on investing. The costs of investing include convex and fixed adjustment costs, as well as the VAT-inclusive price of capital $(1 + \nu)$ minus depreciation deductions $\tau z(1 + \nu)$. When the firm decides to disinvest, the value function $v^s(k, b, \varepsilon, \xi)$ differs by not including ν in the resale price. This difference is the source of partial irreversibility. In the last case, that of inaction, the firm collects profits and transitions to the next period with depreciated capital. Notice that our model embeds a "time-to-build" assumption since investment in this period does not affect current profits.

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of investment are homogeneous of degree one in the pair (K, A) and thus on $(K, \exp(\omega))$. The value function is also homogeneous of degree one in the pair $(K, \exp(\omega))$. See Appendix A.3.3 for additional details.

[18] As in Cooper and Haltiwanger (2006), our model does not allow for "vintage effects," so that firms would never have positive and negative investment spells at the same time.

Implications for Policy Reform

We now solve the model numerically to characterize how different policies affect the investment policy function and to confirm that many of the lessons from the static model are applicable in the dynamic setting.

Figure 4.4 plots the policy function against the firm's transitory productivity shock to illustrate how various policy reforms affect the firm's investment decisions. Panel A plots the pre-reform baseline. The dotted line is the firm's optimal capital choice in a frictionless environment without adjustment costs. In this case, the optimal capital choice is log-linear in the firm's transitory productivity shock. The slope is determined by the return-to-capital parameter θ and the persistence of the idiosyncratic shock ε.

The dashed line in Figure 4.4 plots the optimal policy in the presence of all investment frictions. Both the partial irreversibility generated from the VAT and the fixed investment cost create an inaction region where firms do not respond to small productivity shocks. When the productivity shocks are large enough, firms adjust their capital. However, the convex adjustment cost and partial irreversibility prevent firms from directly adjusting to the optimal capital level, which gives the policy function a flatter slope with respect to productivity shocks.

Panels B-D compare the effects of different tax policies on the firm's policy function. For comparability, we consider three policies that have the same impact on the tax term of the user cost of capital. The red solid line in Panel B of Figure 4.4 shows a VAT cut from 17% to 12.9%.[19] The VAT cut directly reduces the user cost of capital, which affects investment along the intensive margin. Additionally, the VAT cut reduces the asymmetry between the purchase and sale price of capital. This change shrinks the inaction region and allows firms to adjust their capital under more modest productivity shocks. The reform generates extensive-margin responses from firms with productivity shocks that fall outside of the red inaction region but that would otherwise be inside the black dashed inaction

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[19]For simplicity, we assume that, after the reform, firms use the post-reform VAT rate when calculating the present value of their depreciation deductions.

region.

In Panel C, we report the policy function following a corporate income tax cut. To match the user cost of capital effect of the small VAT cut in Panel B, we consider the effect of reducing τ from the average effective rate in our data from 15.4% to 0%. Relative to Panel B, the corporate income tax cut has a smaller effect on the inaction region, primarily driven by the lack of response by firms with low productivity shocks.

Panel D reports the effects of a policy of bonus depreciation—which accelerates the timing of depreciation deductions and increases the value of z. By shifting the red line to the left, this reform affects the investment decisions of firms with low and high productivity shocks. Consistent with our theoretical insight, the inaction region does not narrow considerably, and a significant fraction of firms do not respond to this incentive. Panels B, C, and D show that, relative to a corporate income tax cut and bonus depreciation, a VAT cut would lead to stronger responses along the extensive margin.

Extensive-margin responses also drive the fiscal effectiveness of different policies. Because all firms—even those in the inaction region—benefit from a corporate income tax cut, the government collects less revenue from a large fraction of firms that do not undertake new investment projects. In contrast, only firms that invest benefit from a VAT cut or from bonus depreciation. Tax revenues are also impacted by dynamic effects of different policies on future profit flows.

While the red lines in Figure 4.4 compare reforms with similar effects on the user cost of capital, the blue line in Panel B shows the effects of the actual VAT reform. By lowering the UCC, the VAT reform would increase investment along the intensive margin by shifting the policy function to the left. At the same time, by eliminating a margin of partial irreversibility, the reform shrinks the inaction region. An insight from this figure is that investment spikes should play an important role in explaining the investment effects of the reform. In Section 4.5, we estimate an empirical version of this model that is consistent with the reduced-form effects of the reform to quantitatively compare the effects of alternative tax policies. Based on this discussion, an important test that our model correctly measures

the relative importance of fixed costs and partial irreversibility is whether it matches the extensive-margin effects of China's VAT reform, including spikes in investment.
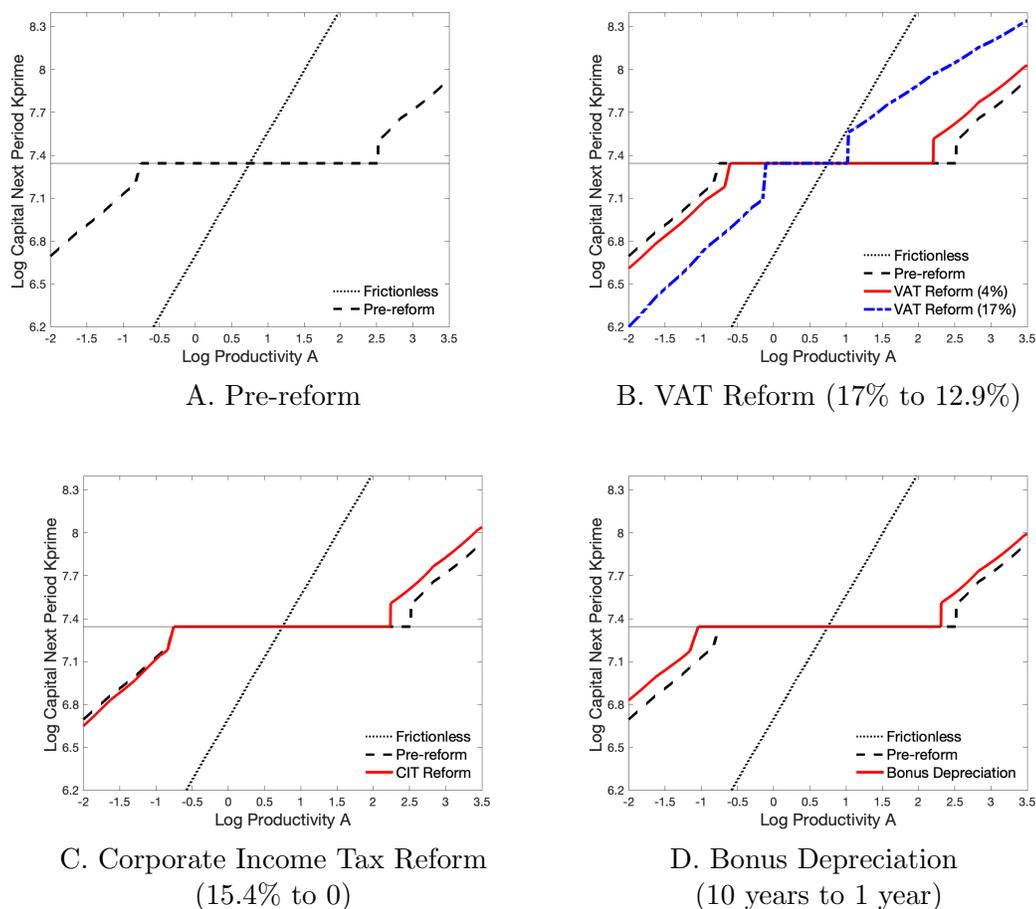
Figure 4.4: Effects of Tax Policy and Investment Frictions on Policy Functions

Notes: These figures display the policy functions against productivity in a dynamic investment model before and after the VAT reform, a corporate income tax reform, and the introduction of bonus depreciation, respectively. The three reforms generate the same reduction in the tax component of the user cost of capital. In Panel A, the dotted straight line indicates the optimal policy (the logarithm of the capital stock in the next period as a function of productivity) in the frictionless case. The dashed line indicates the optimal policy before the reform in the presence of all investment frictions—convex costs, fixed costs and partial irreversibility. Panel B adds the policy function (the red line) after reducing the VAT rate from 17% to 12.9%; Panel C plots the policy function after reducing the corporate income tax rate from 15.4% to 0; Panel D plots the policy function after a bonus depreciation policy that fully accelerates the timing of depreciation deductions.

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4.2 Policy Background: China's 2009 VAT Reform

China's 2009 reform was one of the largest tax incentives for investment in recent history. This section describes the reform and how it generated quasi-experimental variation in the after-tax cost of investment.

The VAT is the largest source of tax revenue in China. In 2016, VAT revenues comprised 39% of overall tax revenue. By comparison, corporate and personal income taxes accounted for 22% and 8% of tax revenue, respectively (NBS China, 2018). Note that China's reliance on the VAT for tax revenues mirrors much of the developed and developing world. China has a standard VAT rate of 17%, which applies to the majority of sales.[20]

The Reform as a Natural Experiment

One of the purported benefits of the VAT is that it does not distort the choice of production inputs—that is, it preserves "production efficiency." In practice, however, VATs can distort input choices depending on how they are implemented (Ebrill et al., 2001). Before 2004, China's "production-based" VAT allowed firms to offset output VAT on sales with VAT paid on inputs such as materials and factory expenses. In contrast, firms were not allowed to deduct the VAT on fixed investment from their VAT base. This lack of deductibility discouraged investment, which works against the production efficiency of the VAT. To correct this distortion, China launched a reform to transition to a "consumption-based" VAT that allows for the deductibility of investment. Because this reform was part of long-term central government plans dating to 2003, firms deemed the chance of policy reversal to be extremely low.[21]

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[20]The VAT is calculated using a credit-invoice method. Exports are zero-rated and some selected goods face a lower rate of 13%. Most of the goods affected by the reform face a 17% rate.

[21]The Chinese government announced the gradual transition from the production-based VAT to consumption-based one at the Third Plenary Session in October 2003. Plenary sessions are among the highest-level government meetings. Decisions made at these meetings are meant to be permanent and are very rarely revoked.

The Chinese government experimented with this transition starting in 2004. The reform was first piloted on firms in selected industries in Northeastern China.[22] As with most other reforms in China, the reform was designed to follow a slow rollout to allow for trial and error. However, the government unexpectedly announced on December 19, 2008, that the reform would be extended *nationwide* in 2009. This announcement broke with existing expansion plans. Prior to this announcement, authorities had last announced on July 30, 2008, that the rollout of the program would continue in two additional provinces. Starting on January 1, 2009, all firms were able to deduct the input VAT on equipment from the VAT on sales.[23]

The reform was an unexpected and permanent change to firms' after-tax cost of investment. Because the timing of the reform was unexpected, it is unlikely that firms delayed their investment plans in anticipation of the reform. Because the reform was permanent, the effects we measure are likely not due to other forms of inter-temporal substitution.

The reform generated a natural experiment since it had no effect on the after-tax cost of investment for a group of foreign firms. Specifically, foreign firms in industries categorized by the government as *encouraged* had previously been allowed to deduct equipment purchases from VAT on sales.[24] Our research strategy uses foreign firms in encouraged

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[22]The initial provinces included Heilongjiang, Jilin, Liaoning, and the city of Dalian. From 2004 to 2008, the pilot was extended to Inner Mongolia and to areas affected by earthquakes in the province of Wenchuan. Appendix B documents the legislative background and timeline for the reform from 2004 through 2009. Cai and Harrison (2016) and Chen et al. (2016) study the effects of the pilot reform.

[23]Equipment includes machinery, mechanical apparatus, means of transportation, and other equipment, tools, and fixtures related to production and business operations that are used for over 12 months. Purchased and self-made housing, buildings, and other real estate were not included in the reform.

[24]Qualified foreign firms were able to deduct input VAT on purchases of equipment starting in 1999. Starting on April 1, 2002, the government classified foreign investment projects as *encouraged, allowed, restricted* or *prohibited*. The *Catalogue for the Guidance of Foreign Investment Industries* lists the encouraged, restricted and prohibited projects. If a foreign project is not included in the previous three categories in the *Catalogue*, it is considered as falling within the allowed category. Additionally, firms participating in the Midwest Advantageous Project list also qualified for preferential treatment. As a robustness check, we also use all foreign firms as controls, and we find similar results. This suggests that

industries as a control group for domestic firms. The identifying assumption behind this strategy is that treated and control firms are not subject to differential shocks in this time period. Since foreign firms were able to deduct equipment purchases from the VAT base prior to the reform, we would expect a higher fraction of these firms to invest in any given year and for foreign firms to have a higher investment rate, on average. We would then expect to see some degree of convergence in the investment patterns of domestic and foreign firms after the reform.

One set of potential concerns is related to the fact that the Chinese government implemented a broad stimulus package in responses to the financial crisis, which was colloquially known as the 4 trillion yuan package. Through this program, the central government provided low-cost credit through the local financing vehicles of regional governments. As Bai et al. (2016) show, these loans were used for railways, roads and other infrastructure (38%), reconstruction following the Wenchuan earthquake (25%), affordable housing (10%), and social welfare projects (27%). Importantly, these loans did not target the manufacturing sector. In contrast, the 2009 VAT reform—which was also part of this stimulus package—directly affected the manufacturing sector. For these reasons, we do not expect that other aspects of the stimulus package would confound the effects of the VAT reform.

Nevertheless, we conduct a number of checks to ensure that our results are driven by the VAT reform and not by other aspects of the stimulus package that may differentially affect foreign and domestic firms. First, because the credit provision was channelled through regional governments, we control for province-by-year fixed effects in our baseline specifications. Second, because Cong et al. (2019) show that the credit expansion disproportionately benefited state-owned enterprises (SOEs), we show that our results are robust to excluding SOEs or listed firms. Third, we also find similar effects for firms in industries that have weak input-output linkages to the industries that benefited the most from the stimulus package. Finally, we conduct two sets of placebo tests to show that we are capturing the effects of the VAT reform. Because the reform did not impact the investment incentives of

selection into the encouraged category is not central for our results.

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domestic firms that were part of the 2004 pilot, we would not expect investment in these firms to be affected by the reform. Similarly, we leverage the fact that, apart from minor affiliated structures, the VAT reform did not change the tax treatment of investment in major structures. We find that the 2009 reform did not significantly impact investment in pilot firms or on major structures. Additionally, we obtain similar results in triple-difference analyses relative to these placebos. We provide more details behind this identifying variation in Section 4.4, where we also discuss different strategies that support the assumption that foreign firms' investment is a suitable counterfactual for domestic firms' investment.[25]

The VAT and the After-Tax Cost of Investment

To see how the reform affected the after-tax cost of investment, consider a domestic firm purchasing equipment at a price of 1,000 RMB. Table 4.1 shows that, prior to the reform, the VAT-included cost would be 1,170 RMB, since the firm would pay a 17% VAT on the purchase. The asset generates depreciation deductions according to Chinese accounting standards, which have a discounted present value of 948 RMB.[26] At a corporate income tax rate of 25%, these deductions reduce the firm's corporate income tax obligations by 237 RMB. The after-tax cost of the equipment purchase is therefore 932 RMB.

The reform modifies this calculation in two ways. First, the firm's direct cost of investment decreases by 170 RMB, since the VAT paid on the equipment is deducted from the VAT on sales. Second, depreciation deductions only lower corporate income tax obligations by 202.7 RMB since the book value no longer includes the VAT payment. Because the direct effect is larger than the effect on depreciation deductions, the after-tax cost of in-

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[25] An alternative research strategy would be to use small-scale taxpayers as controls since the reform only targeted general taxpayers (as in Liu and Mao, 2019). We focus on large firms since they conduct over 99% of overall investment in China. In general, we avoid issues related to selection into VAT by excluding small-scale taxpayers from the analysis. Because small-scale taxpayers only constitute 0.58% of the data, we do not expect to find significantly different results by including these observations.

[26] This calculation assumes a discount rate of 5%. According to Chinese accounting standards, the book value of the asset would be depreciated over 10 years using the straight-line depreciation method.

Table 4.1: VAT Reform and Investment Costs: Example of a 1,000 RMB Equipment Purchase

	Pre-reform	Post-reform	Change
VAT-Included Cost	1170	1170	
Deductible from VAT	**0**	**170**	**+ 170**
Book Value	1170	1000	-170
PV of Total Depreciation	948.6	810.8	-137.8
Deductible from Corporate Income Tax	237.2	202.7	-34.5
After-Tax Cost of Investment	**932.8**	**797.3**	**-135.5**

Notes: This calculation assumes a discount rate of 5% and a marginal corporate income tax rate of 25%. According to Chinese accounting standards, the book value of the asset would be depreciated over 10 years using a straight-line depreciation method. This calculation assumes a zero salvage value.

vestment drops to 797.3 RMB. In total, the reform lowered the after-tax cost of investment by close to 15%.[27]

The results of Table 4.1 can also be expressed by extending the framework of Jorgenson and Hall (1967) to include the effect of the VAT:

$$\text{TUCC} = (1 + \nu)\frac{1 - \tau z}{1 - \tau}, \tag{4.6}$$

where TUCC is the tax component of the user cost of capital, which depends on the VAT rate ν, the corporate income tax rate τ, and the present value of depreciation deductions z. As in Table 4.1, the VAT has a direct effect on the purchase price of equipment, $(1 + \nu)$, and an indirect effect on the value of depreciation deductions, $(1 + \nu)\tau z$.

While Equation 4.6 is not a sufficient statistic for tax policy, we can use it to compare the VAT reform to potential policies and recent reforms. As illustrated by the example in Table 4.1, the VAT reform lowers the TUCC by 15% even if we ignore the impact of the reform on the resale price gap. Another approach to lowering the TUCC is to accelerate the depreciation schedule with the goal of increasing z. However, even setting $z = 1$ through a policy of expensing (or 100% bonus depreciation) only lowers the TUCC by 6%.

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[27]Equivalently, the non-deductibility of investment purchases (prior to the reform) raised the after-tax cost of investment by 17%, relative to the post-reform value.

Recent bonus depreciation policies in the US decreased the TUCC by 2.4%–3.8% (Zwick and Mahon, 2017). Alternatively, consider the effects of changing the corporate income tax. Eliminating the income tax would only lower the TUCC by 6%. Barro and Furman (2018) calibrate that the recent US tax reform reduced the average TUCC by 4%. Finally, consider that undoing the effect of the VAT distortion on the TUCC would require an investment tax credit of 13.6%. This rate is greater than the last federal investment tax credit in the US (the 8% investment tax credit was eliminated in 1986, Cummins et al., 1994) as well as current state-level investment tax credits (which average 4%, Chirinko and Wilson, 2008). These calculations give context to the claim that the VAT reform comprised one of the largest incentives for investment in history. They also highlight the importance of studying the effects of indirect taxes on investment (e.g., Desai et al., 2004; Cline et al., 2005).

One potential concern with our identification strategy is that other reforms may also affect the after-tax cost of investment of foreign and domestic firms. In particular, the VAT reform occurred shortly after a reform of the corporate income tax system in 2008. While this reform harmonized the statutory income tax for foreign and domestic corporations, it had almost no effect on the TUCC of foreign and domestic firms. We observe almost no change in the TUCC of foreign and domestic firms before 2008. In 2009, we see that the VAT reform lowered the TUCC of domestic firms by 15%.[28] The fact that the TUCC is not affected by the corporate income tax reform is reassuring for our analysis focused on the VAT reform. In addition, we report robustness checks that control for firms' corporate income tax rates in our empirical analysis.

4.3   National Tax Survey Database

The main dataset we use comes from the National Tax Survey Database of the Chinese State Administration of Tax (SAT) from 2007 to 2011. The sampling of our dataset ensures that

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[28]Table F.1 shows these calculations by year and ownership. We implement Equation 4.6 using firms' effective tax rates. We also assume $r = 5.26\%$, which implies $z = 80\%$. The TUCC for foreign firms increases from 1.023 to 1.035 between 2007 and 2009, a 1% difference. In contrast, the TUCC of domestic firms drops from 1.22 to 1.042.

large firms are included every year and that smaller firms are included on a rotating basis. This dataset contains detailed information on VAT payments and investment in fixed assets. We restrict our analysis to firms with non-negative values of fixed assets for production and to firms that do not change ownership type in our sample. Importantly, these data directly measure investment and separate investments in buildings and structures, which are not part of the reform, from other types of investment. Finally, the dataset includes a flag that identifies firms that were part of the pilot program as of 2007. Appendix C provides additional details on our data sources.

Table 4.2 reports summary statistics of the firms in our sample, where we winsorize all variables at the 1% level. Our sample includes data on close to 315,000 firm-year observations. Because our main analysis relies on a balanced panel of firms that stay in the data for all five years and that have non-missing investment in all years, the number of observations used in our estimations is smaller. For robustness, we compare our results with a sample that also includes firms with missing investment spells. Average total investment is 4.7 million RMB. The policy we study affected the after-tax cost of equipment investment, which constitutes 67% of total investment. Table 4.2 shows that, while foreign firms invest more on average, the average investment rate (equipment investment relative to the stock of fixed assets) is 10% for both domestic and foreign firms.[29]

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[29]The 10% average investment rate is unconditional on whether firms invest or not.

Table 4.2: Summary Statistics

	All Firms			Domestic Firms			Foreign Firms		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
Equipment Investment (million RMB)									
Investment	3.15	12.37	221,069	2.61	11.02	202,155	9.01	21.27	18,914
Investment Rate	0.10	0.19	215,813	0.10	0.19	197,050	0.10	0.16	18,763
Log Investment	6.50	2.31	118,913	6.36	2.27	104,929	7.54	2.36	13,984
Other Characteristics (million RMB)									
Total Investment	4.70	17.27	258,736	4.00	15.71	234,475	11.40	27.33	24,261
Fixed Assets	33.77	100.32	310,003	28.85	91.57	282,582	84.48	156.65	27,421
Sales	133.80	390.83	314,595	114.79	351.52	287,033	331.77	643.16	27,562
Cash Inflow	126.74	384.06	283,694	106.45	344.23	257,280	324.38	622.06	26,414
Debt	85.13	241.28	313,074	77.58	228.86	285,570	163.49	334.81	27,504

Notes: This table presents summary statistics of equipment investment and other variables from tax data that are used in the analysis. Investment is reported in million RMB and deflated by the national price index of equipment investment. The investment rate is defined as the ratio of investment to the capital stock measured in terms of the book value of net fixed assets, unconditional on investing. Total investment includes investments in equipment, buildings and structures, and other productive capital. Fixed assets are measured in terms of the book value, deflated by the national price index of fixed-asset investment. Sales are the total sales including domestic and export sales. Cash flow is the business cash inflow from the cash-flow statement. Debt is the total debt at the end of the year. Variables are winsorized at the 1% level.

As in many other countries, investment data in China is lumpy. Panel A of Figure 4.5 shows the distribution of investment rates and shows that 49% of firms do not invest in a given year. In addition, 17% of firms replace more than 20% of their capital stock in a given year. These lumpy data patterns suggest that investment decisions are subject to fixed costs or partial irreversibility and motivate our study of how taxes affect lumpy investment decisions. By way of comparison, Zwick and Mahon (2017) report that 34% of firms in the US replace less than 1% of their capital and that 16% of firms replace more than 20%.[30] As in other settings that rely on tax data to measure investment, we do not observe equipment sales.[31]

Panel B of Figure 4.5 shows that, despite the large number of firms that do not invest in a given year, the investment rate has a serial correlation of 0.20. The positive correlation suggests firm investment is also subject to convex adjustment costs. The comparable number for the US is 0.40 (Zwick and Mahon, 2017), which reflects a lower likelihood of inaction.

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[30]Similarly, Levinsohn and Petrin (2003) report that about 60% of Chilean firms replace less than 1% of their capital. Additional data for the US can be found in Cooper and Haltiwanger (2006). Since we use firm-level tax data as opposed to plant-level data, the statistics from Zwick and Mahon (2017) are more comparable to our setting.

[31]One concern is that this limits us from studying the role of partial irreversibility. However, as we discuss in Section 4.1, the VAT reform reduced partial irreversibility by decreasing the gap between the purchase and resale price of equipment. We use the fact that this change in partial irreversibility impacts the fraction of firms that make large investment decisions to quantify the role of partial irreversibility in lumpy investment decisions.
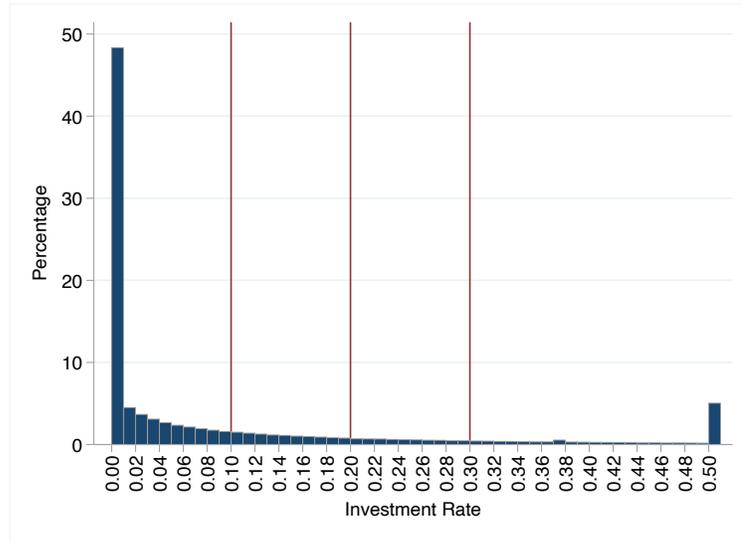
A. Distribution of the Investment Rate
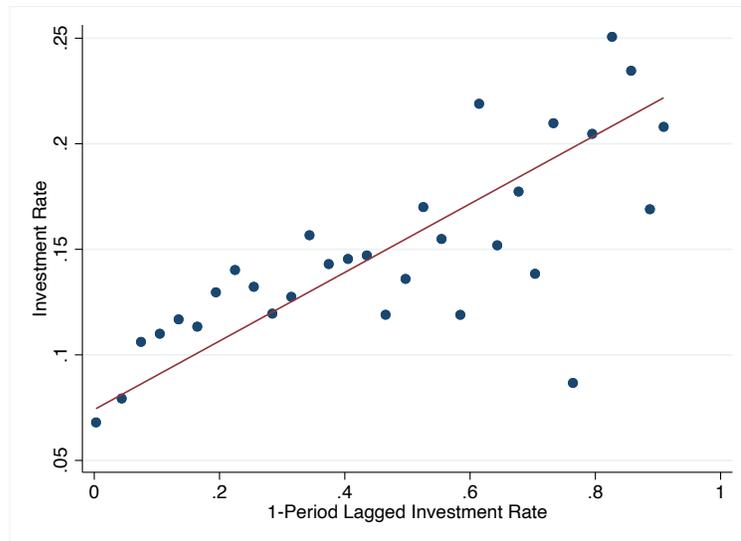
B. Autocorrelation of the Investment Rate

Figure 4.5: Distribution and Autocorrelation of the Investment Rate

Notes: These figures display notable features of the investment in our tax data. Panel A plots the distribution of the investment rate of domestic firms before the reform. We winsorize the investment rate at the top 5%. Panel B plots the investment rate against the one-period-lagged investment rate. We group the lagged investment rate into equally sized bins from 0 to 1 and then calculate the average investment rate for each bin. The red line is the OLS linear fit line.

Table 4.2 also reports data on firm sales, fixed assets, cash flow, and debt for both domestic and foreign firms. We use these variables as controls in some specifications. Since these variables show that foreign firms are larger than domestic firms, we follow Yagan (2015) by showing that our results are robust to reweighting our data to match the distribution of firm characteristics between domestic and foreign firms. Specifically, we first estimate a propensity score model that controls for firm industry, region, exporting status, sales, and interaction terms between these variables. We then generate estimation weights following DiNardo et al. (1996). As we show in Figure F.2, this inverse probability weighting (IPW) method ensures that our treatment and control groups are comparable (see Appendix D.1 for details).

We complement these tax data with two additional datasets. First, we use data on foreign direct investment records from the Ministry of Commerce (MOC). This dataset covers the universe of foreign firms in China and contains information on the type of foreign firms: encouraged, restricted, or whether the project is considered advantageous under the Midwest program. We merge this dataset with our main dataset from SAT to identify the foreign firms that enjoyed the preferential VAT prior to the reform. Second, we merge our tax return data with survey responses from the Chinese Annual Survey of Manufacturing (ASM) from 2005 to 2006. This merge allows us to confirm that foreign and domestic firms have similar investment trends for a longer period of time.[32]

Finally, we discuss the role of SOEs in the Chinese economy. SOEs make up 8.4% of all firms, account for 4% of large manufacturing firms (those with sales above 5 million RMB), and have an investment rate of 11%, which is similar to other firms. In our estimation sample, SOEs account for 3% of observations and 5.2% of total investment in equipment. Our empirical results are robust to excluding SOEs.

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[32]The Chinese Annual Survey of Manufacturing (ASM) focuses on large firms with annual sales over 5 million RMB. In contrast, the National Tax Survey Database covers a wide range of firms, especially small firms. Appendix C provides more details on matching the ASM and the foreign direct investment records with the tax data.

4.4 Reduced-Form Effects of China's VAT Reform

We now estimate the reduced-form effects of the reform on investment. Our main results rely on a difference-in-differences research strategy that exploits the different policy treatments of domestic and foreign firms prior to the reform. As detailed in Section 4.2, most domestic firms were not able to deduct input VAT on equipment before 2009. In contrast, foreign firms in encouraged sectors enjoyed preferential treatment that allowed them to deduct equipment from VAT. For this reason, the reform significantly reduced the investment cost for domestic firms, but it did not affect foreign firms. As with any difference-in-differences estimation, the identifying assumption that control and treated firms would have followed the same investment trends absent the reform is fundamentally untestable. While there may be reasons that foreign and domestic firms differ in their initial investment levels, we provide a battery of robustness checks that allay concerns that could confound the identification strategy. In addition, we show that our main results are robust to two alternative triple-differences strategies that rely on pilot firms and investment in non-eligible structures as additional controls. Finally, we provide evidence that extensive margin responses were important drivers of the effects of the reform. The combined evidence from these analyses limits the risk that our results are driven by other shocks that differentially impact foreign and domestic firms in this period.

4.4.1 Estimation Strategy and Baseline Results

We begin our analysis by estimating the following difference-in-differences specification:

$$Y_{ijt} = G_i \gamma_t + \mu_i + \delta_{jt} + X'_{it}\beta + \varepsilon_{ijt}, \tag{4.7}$$

where Y_{ijt} is a firm-level measure of investment for firm i in industry j in year t.[33] We measure extensive-margin responses with the fraction of firms with positive investment and intensive-margin responses with the investment rate. G_i is an indicator for treatment that

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[33]We use CIC (Chinese Industrial Classification) codes, which are comparable to 3-digit NAICS (North American Industry Classification System) codes.

takes a value of 1 for domestic firms and 0 for foreign firms.[34] The parameters of interest—γ_t—measure whether domestic and foreign firms have different trends prior to the reform as well as how investment in domestic firms is affected by the reform. μ_i is a firm fixed effect that controls for firm-specific unobservables. Industry-year fixed effects δ_{jt} control for industry-specific trends, which rule out the possibility that our results are driven by differential growth rates across industries. In some specifications, we also include province-year fixed effects. These fixed effects assuage concerns that differential growth rates across provinces—e.g., due to differential concentrations of foreign and domestic firms—impact our results. Finally, we also show that our results are robust to including firm-level controls, X_{it}, which include lagged cash-flow measures and corporate income tax rates, as well as quartic expansions of sales, firm age, and profit margin. We cluster standard errors at the firm level.

The key identifying assumption is that no other unobserved ownership-year-specific shocks coincide with the reform. We first show graphical evidence that domestic and foreign firms had similar investment trends before the reform. Figure 4.6 plots investment trends from 2005 to 2011. Panel A plots the fraction of firms investing in any given year and shows that domestic (shown in red) and foreign firms (shown in navy) had similar trends prior to the reform. Panel B plots the same figure for the investment rate.[35] Panels C and D report the coefficients γ_t in Equation 4.7 and show that the parallel trends observed in Panels A and B result in statistically insignificant estimates before 2009.[36] These parallel trends are consistent with our assumption that domestic and foreign firms would have had the same investment trends absent the reform. After the reform, however, we see that

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[34]Our main specification only includes foreign firms with preferential treatment and excludes domestic firms in the pilot program.

[35]To create this figure, we use tax data that has information on equipment investment for years 2007 to 2011 as well as total investment data in the ASM from 2005 to 2006. Since the ASM only reports total investment, this figure assumes that firms invest in equipment and other assets proportionately. Finally, the light blue lines normalize investment outcomes to domestic levels in 2008.

[36]We report the coefficients in Figure 4.6 in Table F.5. Table F.6 shows that these results are robust to the same robustness checks performed in our difference-in-differences analysis.

domestic firms are more likely to invest (Panels A and C) and that their overall investment rate is also higher (Panels B and D). The red and navy lines in Panels A and C show that the likelihood of investing and the investment rate of domestic firms got closer to those of foreign firms after the reform.

A. Extensive Margin

B. Investment Rate

C. Extensive Margin

D. Investment Rate
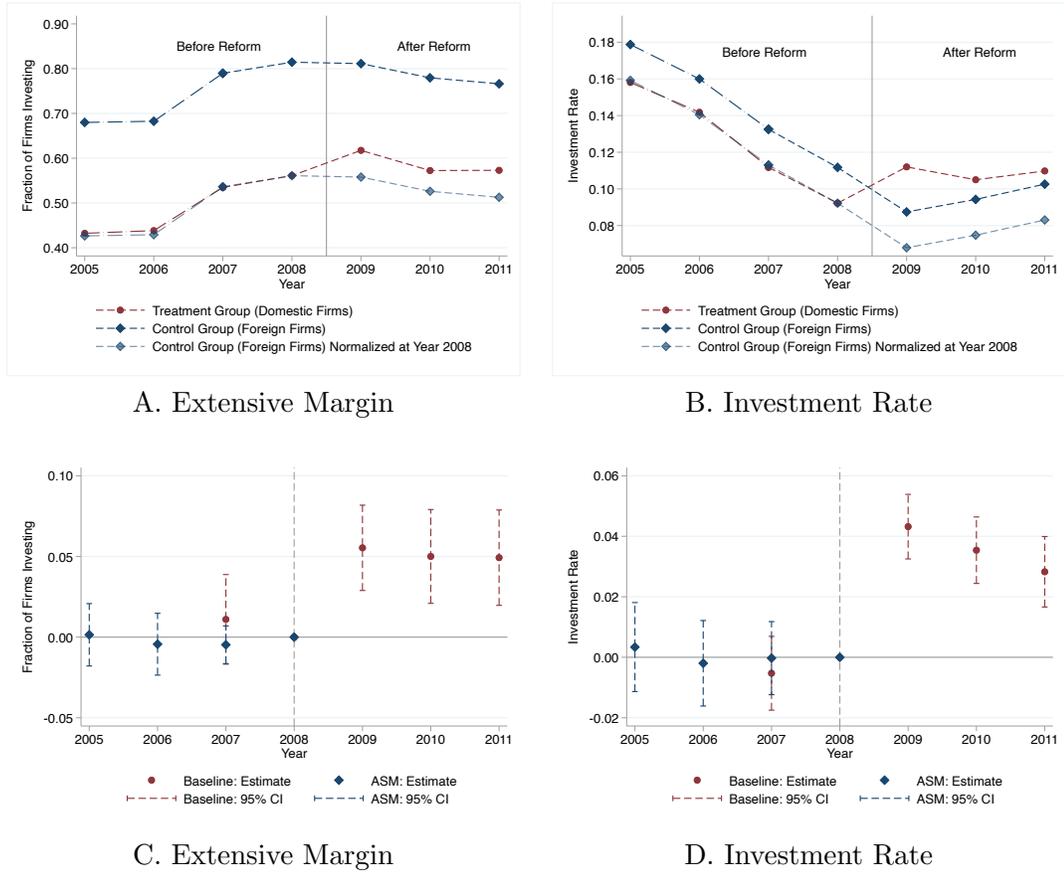
Figure 4.6: Reduced-Form Effects of China's 2009 VAT Reform

Notes: These figures show the effects of the VAT reform on the investment of domestic and foreign firms. Panel A plots the fraction of firms investing in equipment in each year for domestic firms (the treatment group) and foreign firms (the control group). The red line represents investment of domestic firms, the navy blue line represents investment of foreign firms, and the light blue line represents the investment of foreign firms that is normalized to that of domestic firms in 2008. To construct the figure, we first use tax data to calculate the fraction of firms investing in equipment for each year from 2007 to 2011 for domestic and foreign firms. In addition, we complement the tax data with Chinese Annual Survey of Manufacturing (ASM) data. That is, we merge the 2005-2006 ASM data with the tax data and calculate the fraction of firms with positive total investment for each year for domestic and foreign firms, which allows us to extend the pre-reform investment to 2005. For easier comparison, we set 2008 as the base year and align the fraction of firms investing in equipment for foreign firms to that for domestic firms in 2008, as showed in the light blue line. Similarly, Panel B plots the average investment rate of equipment for each year for domestic and foreign firms. Panel C plots the differences in the fraction of firms investing between domestic and foreign firms. The red dots correspond to the estimates from the tax data from 2007 to 2011; The blue dots correspond to the estimates from the extended data with ASM. Again, for easier comparison, we set 2008 as the base year. That is, we subtract the difference in the fraction of firms investing between domestic and foreign firms in 2008 from the difference of each year. Similarly, Panel D plots the differences in average investment rate in equipment between domestic and foreign firms.

To quantify the effects of the reform, Table 4.3 provides estimates of the following difference-in-differences regression using our tax data:

$$Y_{ijt} = \gamma G_i \times Post_t + \mu_i + \delta_{jt} + X'_{it}\beta + \varepsilon_{ijt}. \qquad (4.8)$$

The first three columns in Panel A show that the reform increased the fraction of domestic firms reporting positive investment by close to 5 percentage points. To connect these results with the visual evidence in Figure 4.6, the light blue lines in Panels A and B normalize investment measures of foreign firms to those of domestic firms in 2008. These graphs show that the difference between the red and light blue lines line up very well with our regression estimates. Relative to a base participation of 50%, this change represents a 10% increase in the fraction of firms with positive investment. Given this large effect on the extensive margin of investment, it is crucial to have a model that accounts for firms' decisions to undertake new investment projects. These columns also show that this result is robust to including industry-by-year and province-by-year fixed effects.

The last three columns of Panel A report average effects of the reform on the investment rate. These columns show that, relative to foreign firms with preferential treatment, domestic firms increased investment by about 3.6% of the capital stock. Relative to an average investment rate of 10%, the estimate from Table 4.3 represents a 36% increase in investment and implies a user-cost elasticity of $2.4(\approx \frac{36\%}{15\%})$.[37]

An important caveat is that our data measure capital expenditures, including both increases in the quantity of equipment capital and changes in the pre-tax price of investment goods. Since we do not see an increase in the aggregate price index of fixed asset

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[37]In Appendix D, we also estimate the effect of TUCC changes on investment outcomes. We find that the tax-driven reduction in the cost of capital increased the investment-to-capital ratio by 0.19. This estimate is significantly lower than the recent estimate of 1.6 for the US (Zwick and Mahon, 2017) and the range of $[0.5, 1]$ used by Hassett and Hubbard (2002) to summarize previous studies. One possibility is that recent estimates using variation from bonus depreciation find larger effects due to interactions with liquidity constraints. In contrast, the VAT reform does not impact the timing of firms' cash-flow obligations. In Appendix D.4, we show that firms in industries with higher external finance dependence do not see larger increases in investment. Additionally, it may be possible that tax coefficients are not constant and that our smaller estimate is related to the much larger change in the TUCC, relative to prior studies.

investments, we conduct a simple decomposition of investment responses, assuming that part of the tax cut is passed through to capital suppliers. Using the passthrough estimate in Goolsbee (1998) of 56%, a back-of-the-envelope calculation implies that the 36% investment increase was driven by a 9.52% increase in the price of investment goods and a 24% increase in the quantity of investment.[38] House et al. (2017) provide updated passthrough estimates, which imply that almost all of the estimated increase in investment is driven by quantity and not price effects.[39]

4.4.2 Robustness Checks

Panel B of Table 4.3 shows that these results are robust to the set of firms used in our estimation. First, columns (1) and (4) show that our results are robust to weighting observations to ensure that foreign and domestic firms have similar observable characteristics.[40] The remaining columns of Panel B show that our results are robust to including observations missing investment spells (Unbalanced) or to using all foreign firms (and not just those in preferential industries) as controls.

Panel C further shows that our results are robust to the set of firms used in our estimation. Since foreign firms are also more export intensive, one concern is that they are more severely affected by the financial crisis. Columns (1) and (4) show that we obtain similar estimates when we restrict the sample to non-exporters. Another concern is that SOEs differentially benefited from the stimulus program. Columns (2) and (4) show that we find very similar effects when we exclude SOEs from the estimation.[41] Finally, our estimates

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[38]The decomposition is $1 + 36\% = (1 + 9.52\%) \times (1 + 24\%)$.

[39]Goolsbee (1998) finds that capital prices increased by 5.6% when investment tax credits increased by 10%, implying a 56% pass-through rate to capital suppliers. House et al. (2017) redo these estimations using updated data over a longer period and find little evidence of price increases.

[40]We describe this inverse-probability weighting (IPW) strategy in Section 4.3. See Appendix D.1 for more details.

[41]Table F.7 additionally shows that we obtain similar estimates on firms with weak links to industries that benefited the most from the stimulus package.

are robust to also excluding publicly listed firms, as we show in columns (3) and (6).

Panel D of Table 4.3 shows that our estimates are also robust to controlling for firm-level characteristics. Columns (1) and (4) include a measure of lagged cash flow, and columns (2) and (5) control for quartics in sales, firm age, and profit margin. Finally, columns (3) and (6) show that our results are robust to controlling for changes in the corporate income tax rate. As we discuss in Section 4.2, while a 2008 reform changed the statutory corporate income tax rate for foreign and domestic firms, the reform had very small effects on firms' effective tax rates. These columns show that controlling for this policy change does not affect our main estimate.[42] This panel shows that firm-level characteristics and other observable policies are not driving our results. By including these controls, we also limit the number of potential unobservable shocks that can challenge our identifying assumption.

The last panel in Table 4.3 shows that our results are robust to how we measure investment outcomes. Columns (1)–(3) now report the effects of the reform on the logarithm of investment. Precisely because lumpy investment patterns imply that firms will have zero investment in many years, using the logarithm of investment limits the number of observations in our regressions. Nonetheless, we find similar estimates in this selected sample. Specifically, we find that investment increases by 40%–45%, which is close to the 36%–38% increase implied by columns (4)–(6) in Panel A. Finally, columns (4)–(6) of Panel E report effects on the inverse hyperbolic sine (IHS) of investment, i.e., $\log(I + \sqrt{1 + I^2})$. The IHS has the advantage that it can deal with zero values of investment, and it also approximates the logarithm for large values of investment. These estimates imply larger effects than the log specification, with increases of 63%–72%. However, because the derivative of the IHS is greater near zero, these estimates place considerable weight on extensive-margin responses. These results show that the conclusion that the reform led to significant increases in investment by domestic firms does not rely on how we measure investment outcomes.

As a final robustness check, we consider whether firms could avoid or evade the VAT on equipment. It is unlikely that firms could evade this tax since China's VAT system with

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[42]This result is also visible in Figure 4.6, since there is no change in investment patterns in 2008.

third-party reporting makes it likely that firms would get caught misreporting, especially when it comes to a large purchase, such as production equipment. One potential worry is that firms could avoid paying this tax by leasing instead of owning equipment. To explore this possibility, we estimate the effects of the reform on a measure of capital utilization that includes changes in leased equipment and investment.[43] Table F.8 reports the results of these estimates and finds similar estimates to those of Panel A of Table 4.3. This result suggests that evasion and avoidance are not important concerns for the interpretation of our reduced-form results.

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[43]When a firm acquires the equipment by financial leasing, the lease payment is measured by Minimum Lease Payment; that is, either the fair value of the leased assets or the discounted present value of rental payments over the lease term (including the value of purchase option if applicable), whichever is smaller. In data, around 1.4% of firms report positive leasing payments.

Table 4.3: Estimates of Difference-in-Difference Regressions

	Extensive Margin: % Firms			Intensive Margin: Investment Rate		
	(1)	(2)	(3)	(4)	(5)	(6)
A. Main Results						
Domestic × Post	0.058***	0.044***	0.046***	0.036***	0.037***	0.038***
	(0.010)	(0.010)	(0.010)	(0.004)	(0.004)	(0.004)
N	86870	86870	86870	81270	81270	81270
Industry × Year FE	Y		Y	Y		Y
Province × Year FE		Y	Y		Y	Y
B. Robustness Checks: Sample Selection						
	IPW	Unbalanced	All Foreign	IPW	Unbalanced	All Foreign
Domestic × Post	0.060***	0.053***	0.045***	0.033***	0.044***	0.039***
	(0.021)	(0.008)	(0.006)	(0.008)	(0.003)	(0.003)
N	82785	221069	107255	79195	215813	100980
Industry × Year FE	Y	Y	Y	Y	Y	Y
Province × Year FE	Y	Y	Y	Y	Y	Y
C. Robustness Checks: Different Samples						
	Non-Exporters	Non-SOE	Non-Public	Non-Exporters	Non-SOE	Non-Public
Domestic × Post	0.067***	0.046***	0.046***	0.037***	0.037***	0.038***
	(0.020)	(0.010)	(0.010)	(0.009)	(0.004)	(0.004)
N	61195	83653	85360	56445	78238	79855
Industry × Year FE	Y	Y	Y	Y	Y	Y
Province × Year FE	Y	Y	Y	Y	Y	Y
D. Additional Firm-Level Controls						
	CF	Firm Controls	CIT	CF	Firm Controls	CIT
Domestic × Post	0.043***	0.048***	0.052***	0.038***	0.035***	0.036***
	(0.010)	(0.010)	(0.012)	(0.004)	(0.004)	(0.005)
N	83418	86284	86870	79547	80823	81270
Industry × Year FE	Y	Y	Y	Y	Y	Y
Province × Year FE	Y	Y	Y	Y	Y	Y
E. Alternative Investment Measures						
	Log Investment			IHS Investment		
Domestic × Post	0.449***	0.404***	0.414***	0.711***	0.624***	0.646***
	(0.052)	(0.054)	(0.054)	(0.083)	(0.086)	(0.087)
N	20720	20720	20720	86870	86870	86870
Industry × Year FE	Y		Y	Y		Y
Province × Year FE		Y	Y		Y	Y

Notes: This table uses tax data to estimate difference-in-difference regressions of the form:

$$Y_{it} = \gamma G_i \times Post_t + \mu_i + \delta_{jt} + X'_{it}\beta + \varepsilon_{ijt},$$

where Y_{it} is equipment investment, G_i is the treatment indicator set to 1 for domestic firms and 0 for foreign firms, and $Post_t$ is the post-reform indicator set to 1 for years since 2009. μ_i is the firm fixed effect. Panel A reports the baseline results. The dependent variable for columns (1)–(3) is a dummy variable set to 1 if a firm makes an investment; the dependent variable for columns (4)–(6) is firm's investment rate. Columns (1) and (4) control for industry-year fixed effects. Columns (2) and (5) control for province-year fixed effects. Columns (3) and (6) include both fixed effects. Panel B reports robustness checks: column (1) weights observations by the inverse probability weighting (IPW); column (2) uses an unbalanced panel; column (3) uses all foreign firms as the control group. Panel C reports another set of robustness checks: column (1) exclude exporters; column (2) exclude state-owned firms (SOEs); column (3) excludes public firms. Panel D augments the regression with additional controls. Column (1) controls for firms' net cash flow scaled by the capital stock. Column (2) adds quadratics in sales, profit margin, and age. Column (3) adds the statutory corporate income tax rate. Panel E runs the baseline specification with the log and inverse hyperbolic sine of investment as dependent variables. All regressions include firm fixed effects. Standard errors are clustered at the firm level.

Table 4.4: Estimates of Placebo Tests

	Extensive Margin: % Firms Investing			Intensive Margin: Investment Rate		
	(1) Baseline	(2) Pilot	(3) Structures	(4) Baseline	(5) Pilot	(6) Structures
Domestic × Post	0.046***	-0.010	0.023**	0.038***	0.017	-0.002
	(0.010)	(0.032)	(0.011)	(0.004)	(0.013)	(0.003)
N	86870	13932	81270	81270	12340	81270
Industry × Year FE	Y	Y	Y	Y	Y	Y
Province × Year FE	Y	Y	Y	Y	Y	Y

Notes: This table uses tax data to estimate difference-in-difference regressions of the form:

$$Y_{it} = \gamma G_i \times Post_t + \mu_i + \delta_{jt} + \eta_{st} + \varepsilon_{it},$$

where Y_{it} is a measure of investment, G_i is the treatment indicator set to 1 for domestic firms and 0 for foreign firms, and $Post_t$ is the post-reform indicator set to 1 for years since 2009. μ_i is the firm fixed effect. δ_{jt} and η_{st} are industry-year and province-year fixed effects, respectively. Column (1) and (4) report the baseline results, where the non-pilot domestic firms are the treatment group and foreign firms with preferential treatment are the control group. Column (2) and (5) use domestic firms and foreign firms in the pilot program as the treatment and control groups, respectively. Column (3) and (6) use investment in buildings/structures as dependent variables, and the treatment and control groups are the same as those in the baseline analysis. The dependent variable for column (1) and (2) is a dummy variable set to 1 if a firm makes an investment in equipment; the dependent variable for column (3) is a dummy variable set to 1 if a firm makes an investment in structures with investment rate larger than 1 percent. The dependent variable is firm's equipment investment rate for column (4) and (5), and is firm's structures investment rate for column (6). All regressions include firm fixed effects as well as industry-year and province-year fixed effects. Standard errors are clustered at the firm level.

4.4.3 Placebo Tests and Triple-Differences Analyses

To further explore our identifying assumption, we conduct two sets of placebo tests on firms and types of investment that were not affected by the reform. We first compare foreign firms and domestic firms that were part of the pilot reform in 2004. Since these firms were already able to deduct equipment purchases from the VAT, the reform should not have affected their investment decisions. Columns (2) and (5) of Table 4.4 report the results of this placebo test. These results show that foreign and domestic firms in the pilot had statistically indistinguishable investment patterns. Moreover, these null effects are precisely estimated and can rule out our main effects in columns (1) and (4). These results shows that foreign and domestic firms did not face differential shocks at the time of the reform.

Our second placebo test uses the fact that the tax treatment of investment in structures was not affected by the reform. Column (3) of Table 4.4 estimates the extensive-margin effect of the reform on structures.[44] We find small effects on the extensive margin that

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[44]To focus on major investment in structures and exclude minor investments in affiliated

are less than half of those on equipment investment. These results suggest firms may need to retrofit existing structures through minor investments to accommodate new equipment. Consistent with this conjecture, column (6) of Table 4.4 finds no impact on the intensive margin of investment in structures. These results show that foreign and domestic firms had similar investment patterns in assets that were not affected by the reform.

We now expand our specification in Equation 4.8 by including our two placebo groups as additional controls. The advantage of these triple difference specifications is that—by absorbing time-varying shocks—they ensure that the effects of the reform are not confounded by shocks that specifically affect foreign or domestic firms. Columns (2) and (3) of Table 4.5 report our triple-difference estimates on the extensive margin of investment. Relative to pilot firms and investment in structures, we find effects on equipment investment that are in the range of those in Table 4.3. Columns (5) and (6) also show that we obtain very similar estimates on the intensive margin as in our baseline difference-in-differences specification. Taken together with the two placebo tests, these results support our identifying assumption that foreign and domestic firms did not face differential shocks that would confound the effects of the reform.

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facilities to buildings (e.g., pipes and elevators), we define the extensive margin of investment on structures in Table 4.4 as expansions of the capital stock by more than 1%. Table F.9 shows that our results are robust to using different thresholds to define the extensive margin.

Table 4.5: Estimates of Triple-Differences Regressions

	Extensive Margin: % Firms Investing			Intensive Margin: Investment Rate		
	(1) Baseline	(2) Pilot	(3) Structures	(4) Baseline	(5) Pilot	(6) Structures
Domestic × Post	0.046*** (0.010)	-0.036 (0.030)	0.028** (0.011)	0.038*** (0.004)	0.011 (0.012)	0.002 (0.003)
Domestic × Post × Non-Pilot		0.080** (0.032)			0.030** (0.013)	
Domestic × Post × Equipment			0.036** (0.015)			0.033*** (0.005)
N	86870	100040	162540	81270	92875	162540
Industry × Year FE	Y	Y	Y	Y	Y	Y
Province × Year FE	Y	Y	Y	Y	Y	Y

Notes: This table uses tax data to estimate triple-differences regressions. For comparison, columns (1) and (4) report the baseline estimates from difference-in-difference regressions. Columns (2) and (5) use firms in the pilot program as an additional control group and estimate the triple-differences regression of the form:

$$Y_{it} = \gamma_1 G_i \times Post_t + \gamma_2 P_i \times Post_t + \gamma_3 G_i \times P_i \times Post_t + \mu_i + \delta_{jt} + \eta_{st} + \varepsilon_{it},$$

where Y_{it} is equipment investment, P_i is an indicator set to 1 for pilot firms and 0 for non-pilot firms, G_i is the treatment indicator set to 1 for domestic firms and 0 for foreign firms, and $Post_t$ is the post-reform indicator set to 1 for years since 2009. μ_i is the firm fixed effect. δ_{jt} and η_{st} are industry-year and province-year fixed effects, respectively. Columns (3) and (6) use investment in structures as an additional control group and estimate the triple-differences regression of the form:

$$Y_{kit} = \gamma_1 G_i \times Post_t + \gamma_2 A_k \times Post_t + \gamma_3 G_i \times A_k \times Post_t + \gamma_4 G_i \times A_k + \mu_i + \delta_{jt} + \eta_{st} + \varepsilon_{kit},$$

where k denotes the investment type, i.e., equipment and structures. A_k is an indicator set to 1 for investment in equipment and 0 for investment in structures. The other variables are defined the same as above. The dependent variable for columns (1)–(3) is a dummy variable set to 1 if a firm makes an investment; the dependent variable for columns (4)–(6) is the firm's investment rate. All regressions include firm fixed effects as well as industry-year and province-year fixed effects. Standard errors are clustered at the firm level.

4.4.4 Tax Policy and Investment Spikes

We now provide further evidence that the effects of the VAT reform were driven by inter-actions between tax policy and the frictions that generate lumpy investment. Specifically, we show that the majority of the investment increase was due to the stimulus of additional investment spikes. We follow the literature (e.g., Cooper and Haltiwanger, 2006; Gourio and Kashyap, 2007) in defining investment spikes as events when the investment rate is greater than 20%. We generate three new measures of investment responses to measure the importance of spikes. First, we define a dummy variable that takes the value of 1 when the investment rate is greater than 20% (i.e., $D_{it}^{spike} = \mathbb{1}\{IK_{it} \geq 0.2\}$) to capture the effect of the reform on the likelihood of an investment spike. Second, we define the spike investment rate as the product of the investment rate and the investment spike dummy, i.e., $IK_{it}^{spike} = IK_{it} \times \mathbb{1}\{IK_{it} \geq 0.2\}$. Finally, we also consider the non-spike investment rate, i.e., $IK_{it}^{non-spike} = IK_{it} \times \mathbb{1}\{IK_{it} < 0.2\}$.

Table 4.6 reports difference-in-differences estimates of the effects of the reform on these outcomes. Columns (1)–(3) show that the fraction of firms undergoing investment spikes increased by 7.3 percentage points, which is greater than the effect on the likelihood that firms report positive investment (4.6 percentage points). This effect increases the spike rate from 16.6% to 23.9%. Columns (4)–(6) report effects on the spike investment rate and columns (7)–(9) report effects on the non-spike investment rate. Algebraically, the sum of the effects on the spike and non-spike investment rates add up to the total effect in Panel A of Table 4.3 (columns (4)–(6)). Comparing the spike investment rate to the total effect, we find that the 23.9% of firms with a spike are responsible for 86%–92%($\approx \frac{0.031}{0.036} - \frac{0.035}{0.038}$) of the effect on the investment rate. These results further show the importance of accounting for extensive-margin responses when studying the effects of tax policy on investment behavior.[45]

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[45]In the Appendix D.5, we provide two pieces of evidence that these effects might be driven by the impact of the reform on partial irreversibility. First, we use the fact that firms with excess VAT payments continued to face a gap between the purchase and resale prices of capital. The reform had much smaller effects on the extensive-margin response of these

Overall, the results of this section show that China's 2009 VAT reform had a large effect on the investment of domestic firms. Relative to the magnitude of the reform, however, the estimates imply elasticities in the lower range of the previous literature (Hassett and Hubbard, 2002). Moreover, we find that spikes in investment account for the majority of the investment response to the reform. While these estimates evaluate the current reform, the results from Section 4.1 suggest that the estimated effects are not sufficient to evaluate the effects of other reforms.

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firms. Second, we test whether the reform had different effects on industries that rely on specifically tailored assets. We show that, since the pre-reform price wedge induced by the VAT was less important in industries with more asset specificity, the reform leads to smaller effects on investment in these industries.

Table 4.6: Estimates of Difference-in-Difference Regressions: Investment Spikes

	Extensive Margin:			Intensive Margin:					
	% Firms Investing with $IK \geq 0.2$			Spike Investment Rate			Non-Spike Investment Rate		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Domestic × Post	0.070***	0.071***	0.073***	0.031***	0.034***	0.035***	0.005***	0.003**	0.003**
	(0.009)	(0.009)	(0.010)	(0.004)	(0.004)	(0.004)	(0.001)	(0.001)	(0.001)
N	81270	81270	81270	81270	81270	81270	81270	81270	81270
Industry × Year FE	Y		Y	Y		Y	Y		Y
Province × Year FE		Y	Y		Y	Y		Y	Y

Notes: This table uses tax data to estimate difference-in-difference regressions of the form:

$$Y_{it} = \gamma G_i \times Post_t + \mu_i + \delta_{jt} + \eta_{st} + \varepsilon_{it},$$

where Y_{it} is a measure regarding investment spikes, G_i is the treatment indicator set to 1 for domestic firms and 0 for foreign firms, and $Post_t$ is the post-reform indicator set to 1 for years since 2009. μ_i is the firm fixed effect. δ_{jt} and η_{st} are industry-year and province-year fixed effects, respectively. The dependent variable for columns (1)–(3) is a dummy variable set to 1 if the investment rate is larger than 0.2, i.e., $D_{it}^{spike} = \mathbb{1}\{IK_{it} \geq 0.2\}$, where IK_{it} is the investment rate of firm i at time t. The dependent variable for columns (4)–(6) is the spike investment rate, defined by $IK_{it}^{spike} = IK_{it} \times \mathbb{1}\{IK_{it} \geq 0.2\}$; the dependent variable for columns (7)–(9) is the nonspike investment rate, defined by $IK_{it}^{non-spike} = IK_{it} \times \mathbb{1}\{IK_{it} < 0.2\}$. All regressions include firm fixed effects. Standard errors are clustered at the firm level.

4.5 Estimating a Dynamic Investment Model

The previous section provides evidence that taxes interact with investment frictions. To quantify the importance of these interactions and to study the fiscal effectiveness of alternative policy tools, we now estimate the dynamic model of investment outlined in Section 4.1. We estimate this model in two steps. First, we use the dynamic panel data model of Blundell and Bond (2000) to estimate the parameters that govern firms' static profit functions and productivity processes. Second, we estimate adjustment frictions using a simulated method of moments approach that targets pre-reform investment statistics as well as the reduced-form effects estimated in Section 4.4. By showing that our model can reproduce the effects of an actual reform, we ensure that the model predicts reasonable investment responses to tax changes.

4.5.1 Estimating the Profit Function and Decomposing Productivity

Recall that our model of firm profit (Equations 4.4–4.5) implies:

$$\pi_{it} = \theta k_{it} + (1 - \theta)a_{it} = \theta k_{it} + (1 - \theta)(b_t + \omega_i + \varepsilon_{it}), \qquad (4.9)$$

where π_{it} is log profit and k_{it} is log capital. The profitability term a_{it} is composed of an aggregate term b_t, an idiosyncratic transitory shock ε_{it}, and a firm-specific permanent term ω_i. ω_i captures unobserved firm-level heterogeneity as well as unmodeled frictions. ε_{it} follows an AR(1) process with persistence and standard deviation $(\rho_\varepsilon, \sigma_\varepsilon)$. b_t also follows an AR(1) process with parameters (ρ_b, σ_b). ω_i is normally distributed with mean zero and standard deviation σ_ω. The main parameters of this equation are the curvature of the profit function, θ, and the parameters governing productivity $(\rho_\varepsilon, \sigma_\varepsilon, \rho_b, \sigma_b, \sigma_\omega)$.

Two sets of challenges prevent us from estimating Equation (4.9) directly. First, it is hard to measure economic profit using accounting data. To overcome this issue, we follow Cooper and Haltiwanger (2006) by assuming that profits are proportional to revenue.[46]

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[46]Appendix A.2 gives examples where this assumption holds either with a DRTS produc-

A second set of concerns with Equation (4.9) is that capital may be measured with error and that it may also be correlated with productivity. We address these concerns by using the system GMM estimator of Blundell and Bond (2000). This estimator uses the assumption that the idiosyncratic productivity term ε_{it} is an AR(1) process to rewrite Equation (4.9) in a more favorable form. Specifically, using the fact that $\varepsilon_{it} = \rho_\varepsilon \varepsilon_{i,t-1} + e_{it}$, where e_{it} is an innovation term independently and identically distributed across firms and over time, and that $\varepsilon_{i,t-1}$ can be expressed as a function of lagged capital and revenue, we obtain the following equation:

$$r_{it} = \rho_\varepsilon r_{i,t-1} + \theta k_{it} - \rho_\varepsilon \theta k_{i,t-1} + b_t^* + \omega_i^* + m_{i,t} - \rho_\varepsilon m_{i,t-1} + (1-\theta)e_{it}, \qquad (4.10)$$

where we replaced π_{it} with r_{it} (log-revenue), where m_{it} is a classical measurement error (or an unexpected optimization error), and where b_t^* and ω_i^* are year and firm-level fixed effects.[47] We can then write this equation in first differences to obtain:

$$\Delta r_{it} = \rho_\varepsilon \Delta r_{i,t-1} + \theta \Delta k_{it} - \rho_\varepsilon \theta \Delta k_{i,t-1} + \Delta b_t^* + \Delta m_{i,t} - \rho_\varepsilon \Delta m_{i,t-1} + (1-\theta)\Delta e_{it}. \quad (4.11)$$

To avoid problems arising from endogenous capital, we instrument this equation using lagged revenue r_{it-s} and capital k_{it-s}, $s \geq 3$. Finally, to avoid potential problems of weak instruments, we use the system GMM estimator of Blundell and Bond (2000), which jointly estimates Equation (4.10) using changes in lagged revenue Δr_{it-s} and capital Δk_{it-s}, $s \geq 2$ as additional instruments.[48]

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tion function and perfect competition or with constant-elasticity-of-substitution (CES) demand and monopolistic competition—two cases that are commonly analyzed in the macro investment literature. In addition, without loss of generality, we can also decompose revenue shocks as $a_{it}^R = b_t + \omega_i + \varepsilon_{it}$. When logarithms are taken, the profit and revenue shocks differ by a constant, which implies that a_{it}^R and a_{it} have the same persistence and variance.

[47]This follows from writing Equation (4.9) in terms of revenue ($r_{it} = \theta k_{it} + (1-\theta)b_t + (1-\theta)\omega_i + (1-\theta)\varepsilon_{it} + m_{it}$), replacing ε_{it} with $\rho_\varepsilon \varepsilon_{i,t-1} + e_{it}$, then replacing $\varepsilon_{i,t-1}$ with $(r_{it-1} - \theta k_{it-1})/(1-\theta) - b_{t-1} - (1-\theta)\omega_i - m_{it-1}/(1-\theta)$, and finally setting $b_t^* = (1-\theta)b_t - \rho_\varepsilon(1-\theta)b_{t-1}$ and $\omega_i^* = (1-\theta)(1-\rho_\varepsilon)\omega_i$. See Appendix E for more details.

[48]The exclusion restriction is that Δe_{it} is uncorrelated with the twice-lagged values of revenue and capital and that e_{it} is uncorrelated with the twice-lagged changes in revenue and capital.

Panel B of Table 4.7 reports the results of this estimation. This procedure delivers an estimate of $\theta = 0.734$. To better understand how θ affects the curvature of the profit function, we compute the implied markup in a simple model of monopolistic competition. Our estimate of θ yields a markup of 1.224, which is comparable to values used in the literature.[49] We use this estimate of θ to compute firm-level productivity $\hat{a}_{it} = r_{it} - \hat{\theta}k_{it}$.

The system GMM estimator also delivers an estimate of the persistence coefficient ρ_ε of 0.860.[50] We then recover the distributions of b_t, ω_i, and ε_{it} by decomposing the variance of the estimated productivity $\hat{a}_{it}$—see Appendix E.3 for more details. Due to the short panel nature of our data, aggregate shocks play a relatively small role. Our estimate of the standard deviation of aggregate shocks σ_b is 0.010, and the estimate of its persistence ρ_b is 0.009. Nonetheless, including aggregate productivity shocks in our framework allows us to consider counterfactual scenarios where changes to tax policy coincide with shocks to aggregate productivity. We estimate that the standard deviation of transitory shocks σ_ε equals 0.529 and that the permanent heterogeneity term has a standard deviation of $\sigma_\omega = 0.854$. As a result, a large fraction of the dispersion in profitability comes from permanent heterogeneity across firms.[51] However, despite the fact that the distributions of the capital stock and firm size depend on permanent heterogeneity, investment dynamics are mostly determined by transitory shocks.

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[49]We show this in Appendix E.2 by assuming that the firm has a CRTS production function and faces CES demand. In this case, the markup excluding the capital cost is constant and equals $\frac{1}{\theta}\frac{\alpha(1-\sigma)}{(1-\alpha)(1-\sigma)+\sigma} + 1$, where α is the share of capital in value added and σ is the share of materials. Assuming $\alpha = 0.5$ (Bai et al., 2006) and $\sigma = 0.7$ (Jones, 2011), the implied markup is 1.224. For comparison, the ratio of total sales to major business costs in the data is 1.223.

[50]Cooper and Haltiwanger (2006) estimate a value of 0.85, and Winberry (2020) fixes this parameter at 0.9.

[51]As in David and Venkateswaran (2019), accounting for permanent heterogeneity is important when estimating investment models with adjustment costs.

Table 4.7:   Summary of Assigned and Estimated Parameters

Description		Value (S.E)
Panel A. Fixed Parameters		
Discount factor	β	0.950
VAT rate	ν	0.170
CIT rate	τ	0.154
PV depreciation schedule	z	0.803
Panel B. Parameters Estimated via System GMM		
Profit curvature	θ	0.734 (0.031)
Persistence firm transitory shocks	ρ_ε	0.860 (0.011)
SD firm transitory shocks	σ_ε	0.529 (0.005)
SD firm permanent shocks	σ_ω	0.854 (0.007)
Persistence aggregate shocks	ρ_b	0.009 (0.152)
SD aggregate shocks	σ_b	0.010 (0.001)
Panel C. Parameters Estimated by MSM		
Convex cost	γ	1.434 (0.066)
Upper bound of fixed cost	$\bar{\xi}$	0.118 (0.004)
Economic depreciation rate	δ	0.071 (0.001)

Notes: This table summarizes the parameters from Section 4.5. Panel A displays the parameters we set (i.e., those not estimated) to simulate the model. Specifically, we set tax parameters to their empirical counterparts. Panel B summarizes the estimated parameters from the first-stage production function estimation and productivity decomposition. In particular, we estimate the profit curvature (θ) and the persistence of firm transitory shocks (ρ_ε) using system GMM. Standard errors are reported in parentheses. The rest of the parameters in Panel B are the results of the productivity decomposition (see Section 4.5.1). The standard errors of those parameters (i.e., σ_ε, σ_ω, ρ_b, and σ_b) are calculated from 100 bootstrap samples. Panel C displays the estimated adjustment frictions and depreciation rate using the method of simulated moments (MSM) (see Section 4.5.2). Standard errors of those parameters (i.e., γ, $\bar{\xi}$, and δ) are calculated from 100 bootstrap samples.

4.5.2 Estimating Adjustment Costs

We now estimate the adjustments costs of investment using the method of simulated moments (MSM). This approach simulates the investment decisions of a large number of firms by numerically solving the dynamic investment model in Section 4.1 subject to the profit function and productivity shocks estimated in the previous section. We simulate these firms until the distribution reaches the steady state. We then measure key investment statistics in the simulated data, and we also simulate a VAT reform mirroring the difference-in-differences research design of Section 4.4.[52] Finally, the estimated adjustment cost parameters are those that best reconcile the simulated data with the actual data.

Before we detail the MSM estimator, we first discuss three sets of fixed parameters. First, we set the discount factor β to 0.95. Second, we set the corporate income tax rate to the average effective rate in the data, 15.4%, and we set the VAT rate to 17%—the statutory rate before the reform. Third, we set the present value of depreciation deductions z to 0.803.[53]

We estimate two models that differ by the distribution of fixed costs. The first model is based on Cooper and Haltiwanger (2006) and assumes a degenerate distribution $G(\xi)$ with a single mass point at $\bar{\xi}$. The second model assumes that ξ is drawn from a uniform distribution over the interval $[0, \bar{\xi}]$, as in Caballero and Engel (1999); Khan and Thomas (2008); Winberry (2020). We estimate three parameters for each model: the economic rate of depreciation δ, the convex adjustment cost parameter γ, and the parameter of the fixed cost distribution $\bar{\xi}$.

We now form the criterion function for the MSM estimator. Denote $\phi = \{\delta, \gamma, \bar{\xi}\}$, $\hat{m}$ as the data moments, and $m(\phi)$ as the simulated moments. The estimate $\hat{\phi}$ minimizes the

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[52]We simulate two sets of 10,000 firms for the simulated difference-in-differences: a set of treatment firms that experience a drop in the VAT rate from $\nu = 17\%$ to zero and a set of control firms unaffected by the reform. We assume the reform is unexpected and permanent and occurs at the initial steady state. To match our empirical analysis, the simulated difference-in-differences measure effects on investment over a three-year period.

[53]This value follows from using an interest rate $r = 5.26\%(= 1/\beta - 1)$ to depreciate deductions using a straight-line depreciation rule over a 10-year period.

criterion function:

$$g(\phi) = [\hat{m} - m(\phi)]'W[\hat{m} - m(\phi)].$$

We include two sets of moments in $\hat{m}$:

1. The first set of moments (m^A) is based on pre-reform stationary moments (as in Figure 4.5):

   (a) the mean and the standard deviation of the investment rate;

   (b) the empirical distribution of the investment rate, defined by the fraction of firms with an investment rate below 10%, 20% (i.e., 1-spike rate), and 30%; and

   (c) the 1-year autocorrelation of the investment rate.

   These moments are widely used to identify adjustment costs in the investment literature.[54] As in other settings that rely on tax data (e.g., Zwick and Mahon, 2017; Winberry, 2020), we do not observe equipment sales. Since asset sales are often used to disentangle the roles of fixed costs and partial irreversibility (e.g., Cooper and Haltiwanger, 2006), a potential concern is that excluding sales data will impact our estimates of fixed costs. Because China's 2009 VAT reform reduced partial irreversibility by lowering the purchase price of equipment, we use the effects of the reform on the intensive and extensive margins of investment to overcome this concern.

2. The second set of moments (m^B) is based on the difference-in-differences (DID) estimates reported in Table 4.3:

   (a) the DID estimate of the effect of the reform on the investment rate; and

   (b) the DID estimate of the effect of the reform on the fraction of firms with positive investment.

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[54]For example, among other moments, Cooper and Haltiwanger (2006) use the spike rate and the autocorrelation coefficient; Winberry (2020) uses the standard deviation of the investment rate and the spike rate; and Clementi and Palazzo (2016) use the standard deviation and autocorrelation of the investment rate.

We use these reduced-form moments to validate our adjustment-cost estimates based on the moments in m^A and as a way to provide overidentifying restrictions.

To compute the simulated moments, $m(\phi)$, we simulate the investment statistics for each value of ϕ. Similarly, we mirror the actual reform by measuring the effects of a simulated VAT reform for three years after the tax change.

We use the identity weighting matrix in our estimation. This allows the estimate $\hat{\phi}$ to be informed by both m^A and m^B.[55]

Identification

We briefly discuss the identification of the model parameters since they follow standard arguments in the investment literature. The first set of stationary moments (m^A) is sufficient to identify the three structural parameters. The economic depreciation rate δ is closely tied to the average investment rate.

The convex adjustment cost γ affects investment moments through two channels. First, a higher γ increases the serial correlation of investment by incentivizing firms to smooth investment over time. It also decreases the likelihood of an investment spike. Second, a higher γ lowers firms' steady-state capital levels and—by increasing the relative importance of fixed costs—leads to less frequent investment spells. When γ is sufficiently large, the second channel dominates and a higher γ leads to a smaller serial correlation of investment (see Figure F.4). In contrast, a higher $\bar{\xi}$ increases the fraction of firms with lumpy investment as well as the standard deviation of the investment rate. At the same time, a higher $\bar{\xi}$ also reduces the serial correlation of investment.

One concern is that additional sources of partial irreversibility may bias our estimates of γ and $\bar{\xi}$ that only rely on the moments in m^A. The reduced-form moments m^B help

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[55]Models that rely on m^A moments result in similar estimates when W is the identity matrix or when we use the bootstrapped variance-covariance matrix of the moments. While the moments m^B are precisely estimated (with t-stats around 4 or 8), the cross-sectional moments in m^A have very small variances (with t-stats between 100-500). For this reason, models that weight m^A and m^B using the variance-covariance matrix give very little weight to the moments in m^B.

assuage this concern. As we discuss in Section 4.1, γ and $\bar{\xi}$ both lower the effect of a VAT cut on the investment rate. In addition, a lower $\bar{\xi}$ would increase the effect of the reform on the extensive margin. By simultaneously matching a reform that eliminated an important source of partial irreversibility, these moments help us evaluate the robustness of our estimates.

As a complement to this discussion, we conduct a systematic analysis of how these moments affect $(\hat{\delta}, \hat{\gamma}, \hat{\bar{\xi}})$ in Appendix E.4 by calculating the sensitivity measure proposed by Andrews et al. (2017).

Estimates of Adjustment Costs

Table 4.8 reports estimates of the adjustment costs γ and $\bar{\xi}$ and the depreciation rate δ and compares the data moments with the simulated moments. The second row reports estimates from a model that only uses the pre-reform stationary statistics m^A as target moments and where ξ is fixed at a single value. While this model does a relatively good job of matching the spike rate and the average investment rate, it overpredicts the fraction of firms with an investment rate below 10% as well as the standard deviation of the investment rate. The low convex cost and high fixed cost in this model result in a "bang-bang" investment function where firms either do not invest at all or replace more than 30% of their capital. Notably, there are no firms with investment rates in the 10%-30% range. As a consequence, the model predicts that the VAT reform would have increased both the fraction of firms investing and the investment rate by 15 percentage points. These effects are 3–4 times larger than our reduced-form estimates.

The third row of Table 4.8 reports estimates of a model that only targets pre-reform stationary statistics m^A and that allows ξ to be i.i.d. with a uniform distribution. The estimate of $\bar{\xi}$ implies a larger upper bound for the fixed costs, and we also estimate a larger value of γ relative to the first model. The randomness of the fixed cost lowers the serial correlation of investment and results in an overall better match of the whole investment rate distribution. In particular, the model implies that 14% of firms have investment rates

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between 10% and 30% (relative to 17% in the data).[56] One potential concern is that the lack of data on equipment sales makes it hard to estimate fixed costs separately from the role of partial irreversibility. Because the VAT reform decreased partial irreversibility by lowering the price of new equipment, we can validate our baseline model estimates using the reduced-form effects of the reform. While this model does not target the difference-in-differences estimates, it does a relatively good job of matching the effects of the reform. The model predicts slightly smaller increases in the fraction of firms investing (3 percentage points) and in the investment rate (2.8 percentage points) than those measured in the data.[57]

The fourth row of Table 4.8 reports estimates of a model that targets both m^A and m^B. This model results in very similar estimates of the structural parameters. However, the small changes in the estimates result in an improved fit of the standard deviation and the serial correlation of investment. Not surprisingly, the model results in a slightly better fit of the moments m^B.[58] The model predicts an increase of 3.6 percentage points in the fraction of firms investing and an increase of 3 percentage points in the investment rate. It is worth noting that the last two models have slightly lower average investment rates. Overall, relative to the average investment rate, the last two models predict that the VAT reform would increase investment by 35%–40%, which is remarkably close to our reduced-form estimates.

As we discuss in Section 4.4, the majority of the increase in the investment rate following

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[56]Baley and Blanco (2019) show that it is important to match cross-sectional investment patterns to characterize the role of lumpy investment in aggregate impulse response functions to a policy reform.

[57]The data moments in Table 4.8 characterizes the investment behavior of domestic firms. As we show in Figure 4.6, foreign and domestic firms have similar investment rates after the reform, but foreign firms continue to have a higher propensity to invest. In Appendix F.3, we show that our model results in similar simulated difference-in-differences estimates when we allow foreign firms to have different fixed costs that rationalize preexisting differences in investment patterns. These results show that accounting for differences in fixed adjustment costs explains cross-sectional differences between domestic and foreign firms, and that these level differences do not impact our difference-in-differences estimates.

[58]Figure F.3 shows that the criterion function is concave and rises sharply around the estimated parameters.

the reform was due to additional investment spikes. We use the estimated effect of the reform on investment spikes as additional overidentifying moments. Table F.17 reports that the model predicts a 5.8-percentage-point increase in the likelihood of an investment spike (relative to a measured 7.3 percentage points). Similarly, the model predicts an increase in the spike investment rate of 3.3 percentage points (relative to a measured 3.5 percentage points). These results show that our model is able to quantitatively match the empirical finding that the extensive margins of investment are key determinants of the effects of the VAT reform. Moreover, because the effects of tax policy depend on the relative magnitudes of fixed costs and partial irreversibility, this overidentification check is evidence that our estimated model properly captures the importance of these frictions.

Finally, we now consider the economic magnitude of the estimated adjustment costs. The estimated convex cost parameter $\hat{\gamma}$ is 1.434. Given the model's average investment rate of 8%, the convex adjustment cost at the average investment rate would amount to $0.46\%(= \frac{1.434}{2} \times (0.08)^2)$ of capital. To grasp the magnitude of the fixed adjustment, note that the estimated upper bound of 0.118 implies an average fixed cost of 5.95% of the desired capital stock. However, since firms select into investment, the average fixed cost paid by firms with positive investment is only 2.4% of the desired capital stock. Table 4.7 collects all of the parameters that define our model.

Overall, the model does a remarkable job of matching stationary investment statistics and the effects of an actual tax reform as well as untargeted moments that highlight the importance of investment spikes. Given these results, we expect the estimated model to provide a solid foundation to compare the effects of alternative tax policies.

Table 4.8: Structural Estimation and Moments

Model	Parameters			Moments							
	γ	$\bar{\xi}$	δ	Avg i	Share $i < 0.1$	Share $i < 0.2$	Share $i < 0.3$	$Corr(i, i_{-1})$	SD i	DID. Ext	DID. Int
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Data				0.102	0.720	0.834	0.891	0.200	0.186	0.046	0.038
				(0.001)	(0.003)	(0.002)	(0.002)	(0.013)	(0.002)	(0.010)	(0.004)
Fixed	0.427	0.074	0.087	0.113	0.838	0.838	0.840	0.273	0.249	0.078	0.086
(A)	(0.141)	(0.012)	(0.001)								
Uniform	1.594	0.118	0.071	0.080	0.742	0.793	0.879	0.198	0.138	0.027	0.026
(A)	(0.090)	(0.003)	(0.001)								
Uniform	1.434	0.118	0.071	0.081	0.747	0.795	0.875	0.208	0.140	0.036	0.030
(A+B)	(0.066)	(0.004)	(0.001)								

Average Fixed Cost (conditional on investing): 0.024

Notes: This table displays estimates of the convex adjustment cost γ, upper bound of fixed cost $\bar{\xi}$, and economic depreciation rate δ using the method of simulated moments. Columns (4)–(11) show the simulated moments: 1) Set A includes pre-reform static moments, namely, the average investment rate; the fraction of firms with an investment rate smaller than 0.1, 0.2 and 0.3, the one-period serial correlation of the investment rate, and the standard deviation of investment rate. 2) Set B includes difference-in-difference estimates at the extensive and intensive margins. In particular, we simulate 10,000 firms over 200 periods, with the reform taking place at the 100th period. We use the last 20 periods before the reform to calculate the pre-reform static moments. Meanwhile, we simulate another counterfactual economy where the reform does not take place using the same productivity shocks. The difference-in-difference moments are calculated by taking the difference between the two simulated economies. The first row reports the data moments with standard errors in parentheses calculated using 100 bootstrap samples. The second row assumes the fixed cost is non-random and uses the pre-reform static moments for estimation. The third and the fourth rows (i.e., Uniform (A) and Uniform (A+B)) assume that the fixed cost is independently and identically distributed across firms and over time, following a uniform distribution over $[0, \bar{\xi}]$. The third row uses pre-reform static moments for estimation. The fourth row uses both pre-reform static moments and the difference-in-difference moments for estimation. In the last row, using model Uniform (A+B), we report the average fixed cost for firms making a positive investment. The standard errors of the estimates are reported in parentheses below the point estimates.

4.6   Simulating Alternative Tax Reforms

As we show in Section 4.1, the effectiveness of different types of tax incentives at stimulating investment depends on how tax policies impact the extensive margin of investment. We now use the estimated dynamic model to quantify which policies are more effective at stimulating investment and firm value relative to their total fiscal cost. We first build intuition by studying the effects of different changes to the VAT cut and the corporate income tax rate and by considering the introduction of an investment tax credit.[59] We then quantify the effects of potential reforms that are closely modeled on the recent US tax reform. Throughout, we consider the effects of unexpected and permanent tax policy changes.

4.6.1   Extensive-Margin Responses and Fiscal Effectiveness

One of the benefits of our model is that it allows us to provide a menu of policy options for government officials who want to stimulate investment. Figure 4.7 allows a government official to compare reforms that result in a similar loss of tax revenue. Panel A of Figure 4.7 compares the effects on investment of a corporate income tax cut versus those of a VAT cut. The solid blue line reports the effects of reducing the corporate income tax rate from 15.4% to 1%. Each marker in the line represents the simulated effects of reducing the corporate income tax rate to a given rate, where we calculate the effects over a 10-year window. For example, the x-axis shows that reducing the corporate income tax rate to 10% results in a tax revenue loss of 20% (which includes VAT and corporate income tax revenue). The y-axis shows that this reform results in an investment increase of close to 15%. The dashed red line allows us to compare this corporate income tax cut with a VAT cut that has the same effect on tax revenue. Specifically, cutting the VAT rate to 3% would result in a similar revenue loss as the corporate income tax cut discussed above, but would

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[59]As in Section 4.1, we refer to a VAT cut as a reduction in the wedge driven by the lack of capital deductibility from the VAT base, not by a change in the VAT rate. For this reason, our simulated effects on VAT revenue only include the effect of allowing for this deductibility.

increase investment by 35%.

By comparing investment and tax revenues, Figure 4.7 helps us determine which policies are more effective at stimulating investment.[60] The blue line in Panel A shows that the effect on investment is always smaller than the effect on tax revenue and implies an investment-to-tax-revenue elasticity of close to 0.67.[61] Because the dashed red line is always above the 45-degree line, the investment-to-tax-revenue elasticity is always greater than one. These simulations show that a VAT cut is more effective at stimulating investment for a given revenue cost than a corporate income tax cut.

The superior fiscal effectiveness of the VAT reform is driven by extensive-margin responses, as they impact both the cost of these reforms and their effects on investment. First, extensive-margin responses drive the costs of different policies. Appendix Figure F.5 decomposes the changes in tax revenues into direct tax losses and tax revenues from additional investment. This figure shows that total tax revenue changes are primarily driven by direct tax losses, which are larger than additional tax revenues from behavioral responses. Corporate income tax cuts are more costly since they benefit all firms—even those in the inaction region—while only firms that invest benefit from a VAT cut. Second, following the intuition from Figure 4.4 in Section 4.1, cuts to the VAT rate narrow the inaction region, leading more firms to undertake new investment projects. To illustrate the importance of this mechanism, we use our simulated data to study the composition of investment responses. In the case of the VAT reform (setting $\nu = 0$), of the overall 43% increase in investment, 64% was driven by extensive-margin responses. In contrast, while cutting the corporate income tax rate to 7.4%—at the cost of a similar impact on revenue—increases investment by 20%, only 34% of this increase was due to extensive-margin responses.

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[60]In contrast, approaches that rely on TUCC elasticities to forecast the effects of different stimulus policies may not correctly capture extensive-margin responses. This result is partly driven by the fact that policies with similar effects on the TUCC can lead to different extensive-margin effects. As we show in Appendix F, VAT and corporate income tax cuts with the same TUCC change can have different investment elasticities and differ in their fiscal effectiveness.

[61]Given that the different corporate income tax cuts fall in a straight line, this investment-to-tax-revenue elasticity is constant across the different rate cuts.

Panel B of Figure 4.7 compares the effects of a VAT cut to those of introducing an investment tax credit.[62] In contrast to Panel A, this graph shows that the effects of an investment tax credit mirror those of a VAT cut very closely. The reason for this result is that the investment tax credit also lowers the partial irreversibility of investment.[63] This result is important for settings that feature additional sources of partial irreversibility, such as those driven by imperfections in the market for used capital. This graph shows that the lessons of China's 2009 VAT reform are applicable to other countries since an investment tax credit can lessen these distortions.

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[62]We model the effect of an investment tax credit on the purchase price of capital as follows: $\text{TUCC} = \frac{(1+\nu)(1-\tau z) - ITC}{1-\tau}$. Note that an investment tax credit does not affect the book value of capital or its resale price. Similar to a VAT cut, an investment tax credit reduces the gap between the purchase and resale price of capital.

[63]The slight difference in the effectiveness of these policies is due to the fact that the VAT cut reduces the value of depreciation deductions while the investment tax credit does not.
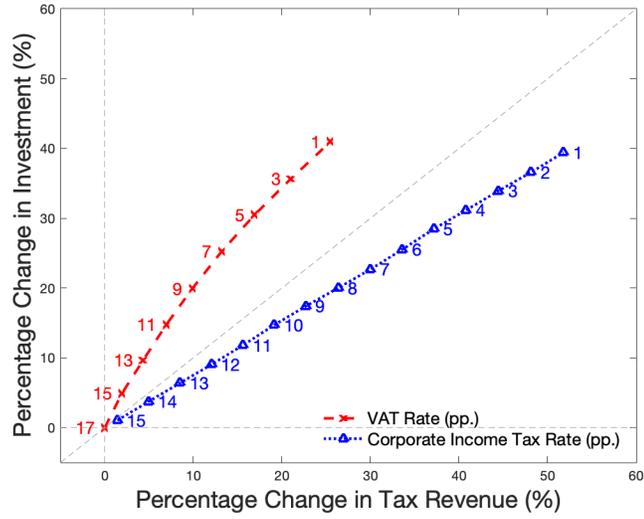
A. VAT Cuts vs. Corporate Income Tax Cuts
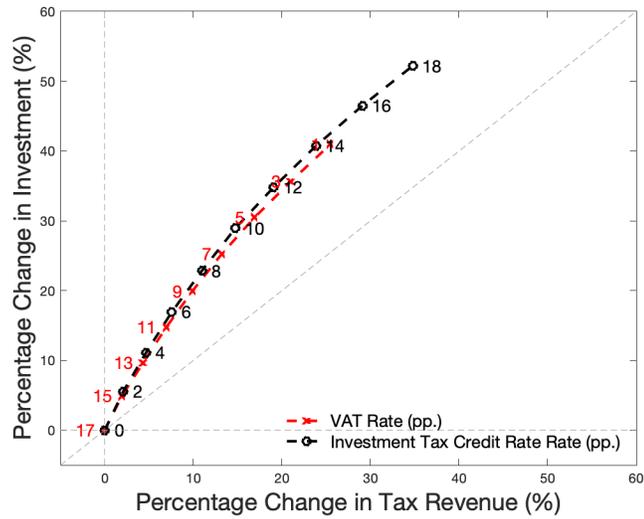
B. VAT Cuts vs. Investment Tax Credit

Figure 4.7: Simulating Alternative Tax Reforms: Elasticity of Investment to Tax Revenue

Notes: These figures plot the simulated percentage change in aggregate investment to the percentage loss in tax revenue at different rates of VAT cut, corporate income tax cut and investment tax credit policies. For each tax rate, we solve the model, simulate investment and tax revenue, and calculate the corresponding changes in each outcome. Panel A plots the percentage change in aggregate investment against the percentage change in tax revenue. The red solid curve corresponds to VAT cuts from 17% to different rates. The blue dotted line corresponds to corporate income tax cuts from 15.4% to different rates. Similarly, Panel B compares the percentage change in tax revenue from VAT cuts with that from an investment tax credit .

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4.6.2 Simulating Tax Reforms

We now build on the intuition from Figure 4.7 by studying a broader menu of policy alternatives, including ones recently enacted as part of the US tax reform. We consider the effects of the following policies:

1. the VAT reform with a 17% tax rate reduction (our baseline);

2. a corporate income tax cut from the current effective tax rate of 15.4% to 10%[64];

3. 100% bonus depreciation (expensing), which allows firms to deduct capital expenditures immediately;

4. a version of the Tax Cuts and Jobs Act (TCJA) that combines expensing with the corporate income tax cut; and

5. a 17% investment tax credit.

Table 4.9 simulates the effects of these policies on investment, firm value, and tax revenues.[65] Column (1) shows that the baseline VAT cut increased aggregate investment by 43%. We also find a relatively large increase of 10% in the fraction of firms investing and an increase of 11% in firm value. Because the VAT on equipment purchases raised a considerable amount of revenue, this simulation entails a revenue loss of 28%. To compare the fiscal effectiveness of different policies, we also report the ratios of the percentage changes in investment and firm value to the percentage change in tax revenue. In the case of the VAT reform, we find that investment increases by 1.6% for every 1% loss in tax revenue. Similarly, firm value increases by 0.41% for a 1% loss in tax revenue.

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[64]This 35% reduction in τ is comparable to the decrease in the corporate income tax following the TCJA in the US.

[65]As in Winberry (2020), firm value is the sum of the value function and the tax value of depreciation allowances. Figure F.6 compares the effects of different VAT, corporate income tax, and investment tax credit incentives on firm value.

Table 4.9: Simulating Tax Reforms

Percentage Change in	Baseline 17%	Corporate Tax Cut 15.4% to 10%	Bonus Depreciation	Tax Cuts and Jobs Act: (2)+(3)	Investment Tax Credit 17%
	(1)	(2)	(3)	(4)	(5)
Aggregate Investment	0.434	0.147	0.099	0.217	0.495
Fraction of Firms Investing	0.098	0.062	0.032	0.084	0.101
Tax Revenue	-0.279	-0.191	-0.131	-0.286	-0.319
Firm Value	0.114	0.103	0.017	0.116	0.132
Ratios of					
Investment to Tax Revenue	1.559	0.769	0.753	0.757	1.553
Firm Value to Tax Revenue	0.410	0.540	0.134	0.407	0.415

Notes: This table displays the simulated responses to five scenarios: column (1) considers a reduction of the VAT rate from 17% to zero, i.e., our baseline reform; column (2) considers a reduction of the effective corporate income tax rate from 15.4% to 10%; column (3) considers a policy that allows firms to fully depreciate capital expenses immediately, i.e., bonus depreciation; column (4) considers a combination of a corporate income tax cut and bonus depreciation, i.e., a version of the Tax Cuts and Jobs Act (TCJA); and column (5) considers a policy granting a 17% investment tax credit. We report percentage (%) changes in the outcomes of interest. For instance, our baseline 17% VAT cut increases aggregate investment by 43% over a 10-year window.

We now consider the effects of tax policies that are modeled after the recent US tax reform but that have a similar tax cost to the VAT reform. Column (2) reports the effects of a corporate income tax cut, which has smaller effects on both investment and the fraction of firms that invest in any given year. Column (3) studies the effects of a bonus depreciation policy that allows firms to immediately deduct the full cost of investment. This policy has similar effects on investment to those of the corporate income tax cut but is less effective at raising firm value. Column (4) combines the effects of a corporate income tax cut and bonus depreciation, mirroring the TCJA in the US.[66] This policy increases aggregate investment by roughly half of the effect of the VAT reform, even though the tax revenue losses from both policies are similar. This result shows that addressing distortions that generate partial irreversibility may be more important for emerging economies like China than lowering the tax cost of investment.

The last policy we consider is an investment tax credit of 17%. As shown in Figure 4.7,

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[66]Bonus depreciation has a smaller effect on firm value than a corporate income tax cut since this policy only benefits firms that invest. Our simulated TCJA raises overall investment by less than the sum of the corporate income tax cut and bonus depreciation, since the tax cut lowers the value of depreciation deductions.

this policy is very closely related to a VAT cut since it also reduces the partial irreversibility of investment. For this reason, it is no surprise that column (5) reports ratios of investment and firm value to the tax revenue loss that are comparable to those of the VAT cut. This again shows that the result that tax policy can directly affect the lumpiness of investment is applicable outside the case of China.

4.6.3 Model Robustness

We now show that our baseline simulation results are robust to a number of extensions.[67] First, we explore the general equilibrium effects of increasing capital prices or interest rates. In our baseline model, we assume that the pre-tax price of capital goods is constant. One concern is that the price of capital increases as demand goes up (e.g., Goolsbee, 1998). We relax this assumption by calibrating an upward-sloping capital supply curve at different supply elasticities that range from 2.54 to 14, where 2.54 is based on a 56% pass-through rate in Goolsbee (1998) and 14 is the upper bound elasticity estimated in House and Shapiro (2008).[68] Table F.18 shows that a smaller supply elasticity results in a smaller aggregate effect on investment. When the supply elasticity is 2.54, which is translated into a 9.52% increase in the pre-tax capital price, the aggregate investment response and investment-to-tax revenue is around two-fifths of our baseline simulation result. Nevertheless, a supply elasticity at 10 leads to similar, though slightly smaller, results compared to our baseline simulation.[69] Additionally, we also consider the possibility that borrowing rates increase as a result of the VAT cut. To allow for this possibility, we assume that interest rates have a proportional increase to the TUCC. Table F.20 simulates the effects of the VAT cut

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[67]Appendix F.1 provides additional discussion of these extensions.

[68]Using updated data over a longer period, House et al. (2017) redo the regressions in Goolsbee (1998) and find little or no equipment price increases in response to tax incentives, indicating that the supply elasticity of capital goods is larger than earlier literature suggests. The authors argue that the supply of capital goods is more elastic in an open economy where firms can purchase equipment abroad.

[69]Equilibrium effects on capital prices would likely impact both domestic and foreign firms. In Appendix F.3, we show that our simulated difference-in-differences estimates are similar when we allow for the reform to impact equipment prices.

assuming interest rate elasticities with respect to the TUCC that range from -0.05 to -0.25. We find slightly smaller effects when we allow for this mitigating effect. However, even for the largest effect of the TUCC on interest rates, the increase in investment is 80% of the baseline increase. While a full general equilibrium calculation is beyond the scope of this paper, these extensions show that our main results are not sensitive to allowing for changes in interest rates or in the price of capital goods.

As a second extension, we consider the role of imperfections in the used capital market. A potential concern is that the resale price is smaller than the purchase price, even without taxes. To explore this possibility, we increase the degree of partial irreversibility by reducing the resale price from 1 (as in the baseline model) to 0.80 (as in Cooper and Haltiwanger, 2006; Ramey and Shapiro, 2001). Column (3) of Table F.19 shows that our results are virtually unaffected by this change.

While we have shown that our empirical results in Section 4.4 are not affected by other stimulus policies, it may be important to account for aggregate productivity shocks related to the financial crisis in our counterfactual analysis. Column (4) of Table F.19 shows that our results are very similar when the reform coincides with a (permanent) one-standard-deviation drop in aggregate productivity.[70]

Finally, we address the fact that our simulations of the effects of corporate income tax cuts on investment abstracted from interactions between the corporate income tax rate and both adjustment costs and borrowing costs.[71] First, we modify our model to consider the possibility that adjustment costs are tax deductible. In this case, a corporate income tax cut directly impacts the importance of fixed and convex adjustment costs, making the pre-tax value of these costs larger. Following this intuition, Table F.21 shows that we find smaller effects following a corporate income tax cut when we assume that adjustment costs

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[70]While the effects of the VAT reform are robust to coincidental productivity shocks, we do not study whether the effectiveness of fiscal policy depends on the business cycle (Winberry, 2020) or on whether other forms of partial irreversibility endogenously respond to fiscal policy (Lanteri, 2018).

[71]Note that these assumptions do not affect our estimation or our simulation of changes to the VAT system. However, they impact the simulation of changes to the CIT.

are deductible. Second, we now consider the fact that debt is a preferred form of financing since interest payments are tax deductible (Graham, 2000). Because a corporate income tax cut reduces the value of tax-deductible financing, accounting for this effect on the after-tax cost of financing may reduce the effectiveness of corporate income tax cuts at stimulating investment. Table F.21 confirms that when a corporate income tax cut affects a firm's financing costs (through the weighted average cost of capital, WACC), it is less effective at stimulating investment. Therefore, our main result—that policies that directly impact the extensive margins of investment are more effective at stimulating investment—is only strengthened by assuming that adjustment costs or interest costs are tax deductible.

4.7   Conclusion

The universal fact that firms make lumpy investment decisions has important implications for tax policy. This paper develops this point in several ways.

First, in models with frictions that generate lumpy investment, the user cost of capital is not a sufficient statistic for how tax policy affects investment. Accounting for how tax policy interacts with investment frictions is necessary to obtain a complete picture of the effects of tax policy on investment behavior.

Second, we analyze an important tax policy change in China that reduced the after-tax cost of investment by close to 15%. We use comprehensive tax data and a difference-in-differences research design to document that, as a result of the reform, domestic Chinese firms increased investment by 36% relative to foreign firms. We also find that the majority of the increase in investment was due to extensive-margin responses, including additional investment spikes.

Finally, we estimate an empirical dynamic model of investment that embeds adjustment frictions and relevant tax parameters. We use the reduced-form estimates of the reform to show that the model can reproduce the effects of an actual tax reform. The model shows that policies that have larger extensive margin responses, such as eliminating a tax

on investment or subsidizing it through an investment tax credit, are more effective at stimulating investment than policy tools that simply lower the cost of investment, such as a corporate income tax cut. Because other policies—such as investment tax credits and sales taxes—can directly impact extensive-margin investment decisions, these results have important implications for tax policy beyond China.

By showcasing the importance of lumpy investment for tax policy, this paper also identifies important questions for future research. First, in this paper we focus on the short-term effects of tax policy changes. Accounting for how tax policy interacts with the frictions that generate lumpy investment may also impact the long-run effects of tax reform (e.g., through allocative efficiency, as in Baley and Blanco, 2021). Second, our model abstracts from capital-embodied technological change. Extending models of lumpy investment to account for this force could help evaluate the government's mission to use tax policy as a way to incentivize technology upgrading, and may explain documented effects of the reform on productivity growth (e.g., Liu and Mao, 2019).

Chapter 5

Conclusion

Recent developments in ICT have widened firms' geographic span of control, allowing them to expand production across locations. Chapter 1 and 2 provide empirical evidence and studies the efficiency gains from this technology improvement through firm geographic expansion.

First, I leverage US Census microdata with establishment-level ownership linkages, geographic locations and ICT adoption to document three facts that link firms' geographic expansion and their ICT adoption. First, I document that firms have increased their geographic span of control, especially firms with multiple production sites, i.e., multi-unit firms. Second, firms that have adopted Intranet, which reduces firms' internal communication costs, are more likely to expand geographically. To corroborate that the effect operates through the channel of internal communication, I document the third fact, namely, that firms with Intranet are more likely to communicate within the firm. To go beyond correlation and empirically show that ICT improvements help widen firms' geographic span of control, I exploit quasi-experimental variation from a milestone in the history of US Internet development: the Internet privatization in 1995, which greatly reduced ICT costs. Using a difference-in-differences approach, I find that the Internet privatization increased the number of establishments per firm by 8.5%.

Guided by these empirical findings, I propose and estimate a model of firm ICT adoption and geographic expansion. Firms choose a set of locations, instead of a single location, to set up establishments but are subject to communication costs among establishments. Firms can adopt advanced ICT to reduce these costs. I estimate the model by matching firms' geographic expansion patterns and ICT adoption observed in the data. The estimated model suggests that the Internet privatization increased aggregate efficiency by 1.1%.

Finally, the policy counterfactuals suggest that to improve local ICT access and local welfare, a policy coordinated across locations can be more effective than uncoordinated local policies. Efficiency gains from local improvements in ICT might spill over to other locations through multi-unit firms. Compared to those in an alternative trade-only model, the efficiency gains from ICT improvements are more geographically dispersed when we take into account firms' multi-unit production and geographic expansion.

In chapter 3, we show both empirically and quantitatively that investment stimuli that shift firms' inaction regions, such as value-added tax and investment tax credits, are more effective in boosting firm investment.

Appendix A

Appendix for Chapter 1

A.1   Data Appendix

A.1.1   Firm Headquarters

This appendix section outlines the procedure to identify firm headquarters and their locations and employment. Firms can be categorized into three types: 1) single-unit firms, 2) multi-unit firms with stand-alone headquarters, and 3) multi-unit firms with integrated headquarters. As single-unit firms only have one establishment, that establishment is considered as the headquarter. I obtain the location and employment of these headquarters of single-unit firms from the Longitudinal Business Database (LBD).

For the second type of firm, I augment the LBD with the Census of Auxiliary Establishments (AUX) to identify the stand-alone headquarters of multi-unit firms. According to the Census Bureau, an auxiliary establishment does not engage in the production but engaged in "performing management, supervision, general administrative functions, and supporting services for other establishments of the same enterprise, such as corporate headquarters, research, development, and testing laboratories, warehouses and so forth." The AUX is collected every five years for the census years that end with 2 and 7. I use firm headquarters' locations at the beginning of the sample period in 1987 to construct the firm's distance to the nearest NSFNET node. I follow the procedure in Aarland et al. (2007) and Giroud (2013) to identify these stand-alone headquarters of multi-unit firms. The 1987 AUX provides a detailed breakdown of employment to administrative and managerial employees, office and clerical employees, research, development, and testing employees, warehousing employees, sales employees, and so forth. An establishment is identified as a headquarter if its total employment in administrative, managerial, and clerical work is larger than employ-

ment in any of the other types of work. While many firms have one headquarter identified using this criterion, some firms have multiple establishments identified as headquarters.[1] In this case, I use the Standard Statistical Establishment Listing (SSEL) to obtain the establishment's name and consider an establishment as the headquarter if its name includes the word "headquarter." After these two rounds of selection, if a firm still has multiple headquarters identified, I choose the one with the largest payroll as the headquarter. The salaries are often higher for employees engaging in management, e.g., executive members.

The third type of firm is multi-unit firms that integrate the headquarter with manufacturing units. Similarly, I choose the establishment with the largest payroll as the headquarter for these multi-unit firms.

A.2 Reduced-Form Analysis Appendix

A.2.1 General Propensity Score

This appendix section provides details on the generalized propensity score reweighting in the robustness checks. I construct the generalized propensity score of treatment, using firm and location characteristics before the Internet privatization, and apply the inverse propensity score method to reweight observations for the difference-in-differences regression.

Denote firm by i and its covariates by X_i, the generalized propensity score is defined as the conditional distribution of the treatment, i.e., $f_{D|X}$, where treatment is the distance to the nearest NSFNET node. I assume that, conditional on the covariates, the treatment is log-normally distributed with mean as a function of the covariates; that is,

$$\text{HQDistToNode}_i \mid X_i \sim \log N(X_i\beta, \sigma^2). \tag{A.1}$$

The covariates X_i is comprised of two components: One is a vector of firm-specific characteristics, including the firm's number of establishments and the logarithm of employment.

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[1]Since 1997, headquarters are classified with NAICS code 551114.

The other is a vector of county-specific characteristics, including the logarithm of local population, the logarithm of median household income, share of population below the poverty line, share of the elderly over sixty-five years old, share of black population, and share of population with a bachelor's degree and above. I also include one-year growth rate in these covariates, as well as a full set of state dummies. The conditional distribution of treatment is

$$f_{D|X}(\text{HQDistToNode}_i \mid X_i)$$
$$= \frac{1}{\text{HQDistToNode}_i \sqrt{2\pi\sigma^2}} \exp\left(-\frac{(\log \text{HQDistToNode}_i - X_i\beta)^2}{2\sigma^2}\right). \qquad (A.2)$$

Then, we can define the weight as $w_i = f_D / f_{D|X}$, where the numerator is a required stabilizing factor equal to the marginal distribution of treatment, and the denominator is the generalized propensity score defined above (see Robins et al., 2000). I follow common approach and assume that the marginal distribution to be log-normal; that is, $\text{HQDistToNode}_i \sim \log N(\overline{\mu}, \overline{\sigma})$. Therefore, the weight is given by

$$w_i = \frac{\sigma}{\overline{\sigma}} \exp\left(\frac{(\log \text{HQDistToNode}_i - X_i\beta)^2}{2\sigma^2} - \frac{(\log \text{HQDistToNode}_i - \overline{\mu}))^2}{2\overline{\sigma}^2}\right). \qquad (A.3)$$

I use observations at the beginning of the sample period in 1987 to estimate the parameters $(\beta, \sigma, \overline{\mu}, \overline{\sigma})$ via the maximum likelihood estimator. To show that the distance measure is not correlated with firm and location characteristics before the privatization, I regress the distance on those covariates using the 1987 observations and adjust the regression by weights specified in Equation (A.3):

$$\text{HQDistToNode}_i = \alpha + X_i\beta + \alpha_i^{\text{Industry}} + \alpha_i^{\text{State}} + u_i. \qquad (A.4)$$

As industries might cluster in certain regions, I include the industry fixed effect at the 4-digit NAICS level. To account for heterogeneity across states, I include the state fixed effect. Standard errors are clustered at the county level. Figure A.3 plots the coefficients. These estimated coefficients are economically small and statistically insignificant, indicating that, after reweighting, the distance measure is not systematically correlated with firm and location characteristics before the Internet privatization.

A. All Firms   B. Multi-Unit Firms
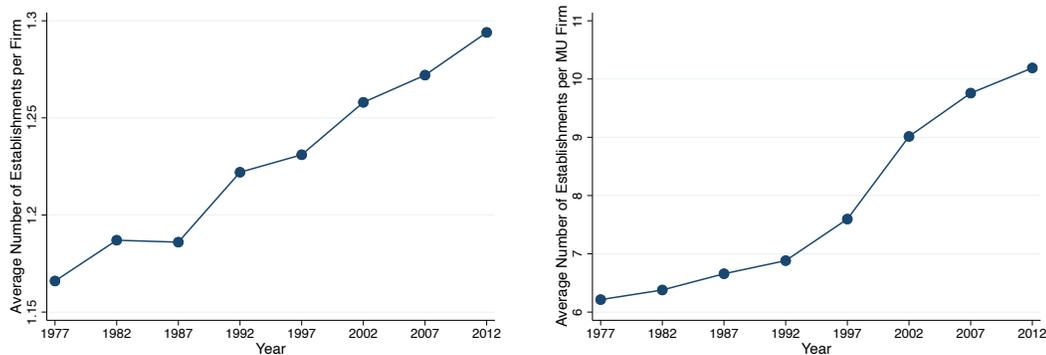
Figure A.1: Number of Establishments from 1977 to 2012, All Sectors

Notes: These figures show the number of establishments for firms from the Longitudinal Business Database in all sectors, including Utilities (22), Construction (23), Manufacturing (31-33), Wholesale trade (42), Retail trade (44-45), Transportation and warehousing (48-49), Information (51), Finance and insurance (52), Real estate and rental and leasing (53), Professional, scientific, and technical services (54), Management of Companies and enterprises (55), Administrative and support and waste management and remediation services (56), Educational services (61), Health care and social assistance (62), Arts, entertainment, and recreation (63), Accommodation and food services (72), and other services, except public administration (81). Panel A uses all firms. Panel B restricts to multi-unit firms. Each firm is a FIRMID×6-digit NAICS industry pair. Multi-unit firms are firms with more than one establishment.

A. Number of Industries   B. Number of Establishments
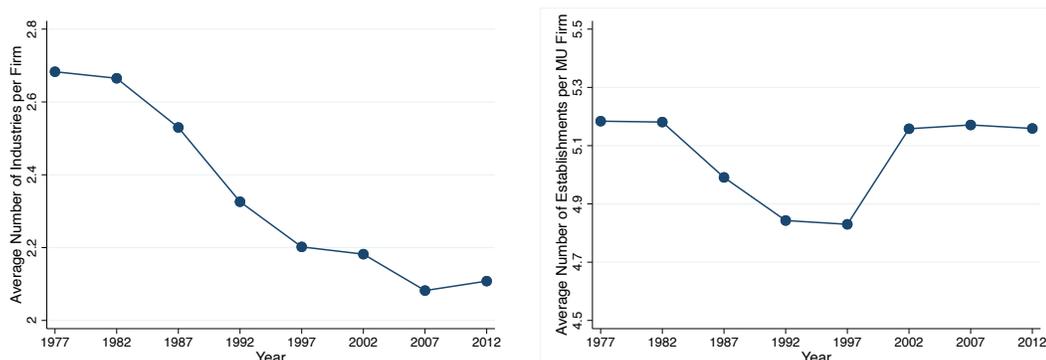
Figure A.2: Multi-Unit Firms' Span of Control, Alternative Firm Definition

Notes: These figures show firms' span of control for multi-unit firms in the manufacturing sector from the Longitudinal Business Database. Firm is defined by FIRMID. Multi-unit firms are firms with more than one establishment. Panel A plots the average number of industries of multi-unit firms. Industry is defined at the 6-digit NAICS level. Panel B plots the average number of establishments of multi-unit firms, including establishments in the multiple locations and multiple industries.

A. Level

B. One-Year Growth Rate
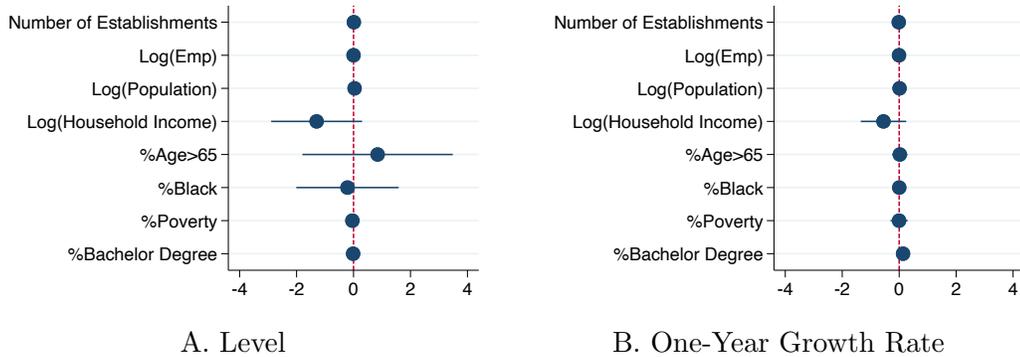
Figure A.3: Regression Estimates of Distance to the Nearest NSFNET Nodes on Firm and County Characteristics

Notes: These figures plot the estimated coefficients of the following regression using observations in 1987:

$$\text{HQDistToNode}_i = \alpha + X_i\beta + \alpha_i^{\text{Industry}} + \alpha_i^{\text{State}} + u_i,$$

where the dependent variable is the distance from a firm's headquarter to the nearest NSFNET node, X_i includes the firm's number of establishments, the logarithm of employment, the county characteristics including the logarithm of local population, the logarithm of median household income, share of population below the poverty line, share of the elderly over sixty-five years old, share of black population, and share of population with a bachelor's degree and above, as well as one-year growth rates in these covariates. $\alpha_i^{\text{Industry}}$ is 4-digit NAICS industry fixed effect, and α_i^{State} is state fixed effect. Standard errors are clustered at the county level. Panel A and B plot the estimated coefficients on the level and one-year growth rate of firm and county covariates, respectively.

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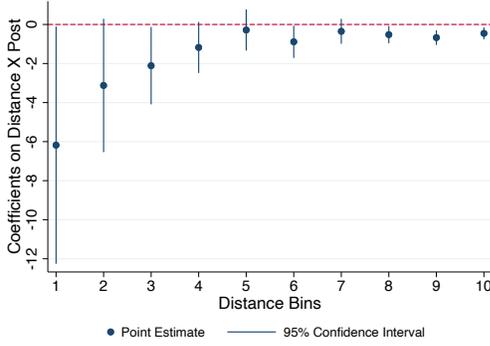
A. Estimated Coefficient for Each Distance Bin
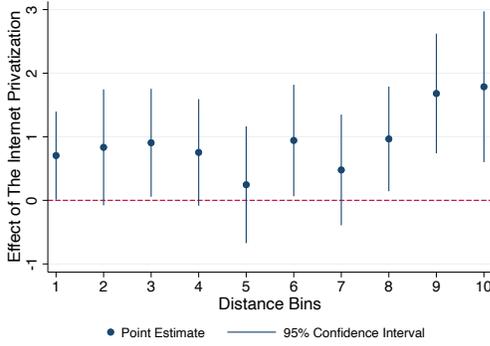
B. Estimated Effect for Each Distance Bin

Figure A.4: Estimates of the Effect of ICT on Firms' Geographic Expansion: Distance Bins

Notes: These figures show the effects of the Internet privatization on firms' geographic span of control for firms headquartered along different distances to the nearest NSFNET node, by estimating the regression:

$$Y_{it,k} = \alpha_i + \sum_{k=1}^{10} \beta_k \text{HQDistToNode}_i \times \text{Post}_t + \text{CountyControls}_{it}\gamma + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it,k},$$

where the dependent variable $Y_{it,k}$ is the number of establishment of firm i in year t, and k indicates the k'th decile of the distance distribution that the firm belongs to. α_i is firm fixed effect, HQDistToNode_i is the distance from the ZIP code firm i is headquartered to its nearest NSFNET node (in 100 miles), Post_t is an indicator set to one for years since 1995, and $\text{CountyControls}_{it}$ is a vector of county characteristics, including the logarithm of population and median household income, the share of black population and the elderly over 65 years old, and the share of adults with bachelor's degrees. $\alpha_i^{\text{Industry-Year}}$ and $\alpha_i^{\text{State-Year}}$ are industry-year and state-year fixed effects, respectively. Panel A plots the difference-in-differences coefficients on the interaction term for each decile of the distance distribution. Panel B plots the corresponding effect that is calculated by multiplying the coefficient by the average distance for firms in each decile.

Table A.1: Matching of the 1999 Longitudinal Business Database and Computer Network Use Supplement

	Matched Firms		Unmatched Firms	
	N	Mean	N	Mean
Multi-unit firm	4,600	0.466	29,000	0.027
Number of establishments	4,600	3.347	29,000	1.054
Log(employment)	4,600	5.065	29,000	2.548

Notes: This table shows summary statistics of firms in the 1987–2007 balanced panel of the Longitudinal Business Database that are matched to the 1999 Computer Network Use Supplement, and those firms that are not matched, respectively. Observations are in the year 1999. Multi-unit firm is an indicator set to one if a firm has more than one establishment.

Table A.2: Estimates of the Effect of ICT on Firms' Expansion: Intensive Margin

	Log(Emp)	Log(Emp/Establishment)	Log(Wage)
	(1)	(2)	(3)
HQDistToNode $\times$ Post	-0.019*	-0.001	-0.004
	(0.011)	(0.011)	(0.004)
N	702000	702000	702000
Avg. Dep. Var	6.123	5.090	3.383
R^2	0.973	0.957	0.837
County Controls	Y	Y	Y
Industry-Year FE	Y	Y	Y
State-Year FE	Y	Y	Y

Notes: This table estimates regressions of the form:

$$Y_{it} = \alpha_i + \beta \text{HQDistToNode}_i \times \text{Post}_t + \text{CountyControls}_{it}\gamma + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it},$$

where the dependent variable is the logarithm of employment of firm i in year t, the logarithm of employment per establishment, and the logarithm of average wage rate of the firm, respectively, for column (1)–(3). α_i is firm fixed effect, HQDistToNode_i is the distance from the ZIP code firm i is headquartered to its nearest NSFNET node (in 100 miles), Post_t is an indicator set to one for years since 1995, and $\text{CountyControls}_{it}$ is a vector of county characteristics, including the logarithm of population and median household income, the share of black population and the elderly over 65 years old, and the share of adults with bachelor's degrees. $\alpha_i^{\text{Industry-Year}}$ and $\alpha_i^{\text{State-Year}}$ are industry-year and state-year fixed effects, respectively. Regressions are weighted by the firm's employment share. Standard errors are clustered at the firm and headquarter county level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.3: Estimates of the Effect of ICT on Firms' Expansion: Location of New Establishments

	$\overline{\text{DistToNode}}^{\text{New}}$ (1)	$\overline{\text{Log(Pop)}}^{\text{New}}$ (2)	$\overline{\text{Log(HH Income)}}^{\text{New}}$ (3)	$\overline{\text{\%Poverty}}^{\text{New}}$ (4)
HQDistToNode × Post	0.315**	-0.318	-0.087***	-0.001
	(0.136)	(0.259)	(0.027)	(0.006)
N	1200	1200	1200	1200
Avg. Dep. Var	1.574	12.36	10.47	0.127
County Controls	Y	Y	Y	Y
Industry-Year FE	Y	Y	Y	Y
State-Year FE	Y	Y	Y	Y

	$\overline{\text{\%Black}}^{\text{New}}$ (5)	$\overline{\text{\%Age>65}}^{\text{New}}$ (6)	$\overline{\text{\%Bachelor's Degree}}^{\text{New}}$ (7)
HQDistToNode × Post	-0.025	0.019***	-0.019
	(0.016)	(0.005)	(0.012)
N	1200	1200	1200
Avg. Dep. Var	0.123	0.125	0.206
County Controls	Y	Y	Y
Industry-Year FE	Y	Y	Y
State-Year FE	Y	Y	Y

Notes: This table estimates regressions of the form:

$$Y_{it} = \alpha_i + \beta \text{HQDistToNode}_i \times \text{Post}_t + \text{CountyControls}_{it}\gamma + \alpha_i^{\text{Industry-Year}} + \alpha_i^{\text{State-Year}} + \varepsilon_{it},$$

where the dependent variable is a characteristic of the new establishments of firm i in year t, α_i is firm fixed effect, HQDistToNode_i is the distance from the ZIP code firm i is headquartered to its nearest NSFNET node (in 100 miles), Post_t is an indicator set to one for years since 1995, and $\text{CountyControls}_{it}$ is a vector of county characteristics, including the logarithm of population and median household income, the share of black population and the elderly over 65 years old, and the share of adults with bachelor's degrees. $\alpha_i^{\text{Industry-Year}}$ and $\alpha_i^{\text{State-Year}}$ are industry-year and state-year fixed effects, respectively. The dependent variable is the average distance from the new establishments to their nearest NSFNET node for column (1). The dependent variable for column (2)–(7) is the average population, household income, poverty rate, share of black population and the elderly over 65 years old, and the share of adults with bachelor's degrees of the counties where new establishments are located, respectively. Regressions are weighted by the firm's employment share. Standard errors are clustered at the firm and headquarter county level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Appendix B

Appendix for Chapter 2

B.1 Model Appendix

B.1.1 The Consumer's Problem

Denote firm by i and its headquarter location by o. As each firm produces a continuum of varieties ω, each product can be denoted by a firm-variety combination (i, ω). Denote the consumer's location by k, the aggregate consumption by Y_k, and the expenditure by E_k. Denote the price index by P_k such that $E_k = P_k Y_k$. In each location, given the product prices (i.e., $p_{ok}(i, \omega)$) and total expenditure (i.e., E_k), the representative consumer maximizes her utility that aggregates all varieties with constant elasticity of substitution σ. We can express the consumer's problem as: in each location k,

$$\max_{\{y_{ok}(i,\omega)\}_{\omega,i,o}} \left(\sum_{o=1}^{N} \int_{0}^{m_o} \int_{0}^{1} y_{ok}(i,\omega)^{\frac{\sigma-1}{\sigma}} d\omega di \right)^{\frac{\sigma}{\sigma-1}},$$

subject to the budget constraint $\sum_{o=1}^{N} \int_{0}^{m_o} \int_{0}^{1} p_{ok}(i,\omega) y_{ok}(i,\omega) d\omega di \leq E_k$. Lagrangian is

$$\mathcal{L} = \left(\sum_{o=1}^{N} \int_{0}^{m_o} \int_{0}^{1} y_{ok}(i,\omega)^{\frac{\sigma-1}{\sigma}} d\omega di \right)^{\frac{\sigma}{\sigma-1}} + \mu \left[E_k - \sum_{o=1}^{N} \int_{0}^{m_o} \int_{0}^{1} p_{ok}(i,\omega) y_{ok}(i,\omega) d\omega di \right]$$

The first-order condition for each product is

$$Y_k^{-1/\sigma} y_{ok}(i,\omega)^{-1/\sigma} = \mu p_{ok}(i,\omega), \tag{B.1}$$

where $Y_k \equiv \left(\sum_{o=1}^{N} \int_{0}^{m_o} \int_{0}^{1} y_{ok}(i,\omega)^{\frac{\sigma-1}{\sigma}} d\omega di \right)^{\frac{\sigma}{\sigma-1}}$. Then, we can express the expenditure on any product by the price and quantity of product ω of firm i, which is headquartered in location o; that is, $p_{ok}(i',\omega') y_{ok}(i',\omega') = p_{ok}(i,\omega) y_{ok}(i,\omega)^{1/\sigma} y_{ok}(i',\omega')^{(\sigma-1)/\sigma}$. Thus, the

total expenditure is

$$
\sum_{o=1}^{N} \int_0^{m_o} \int_0^1 p_{ok}(i', \omega') y_{ok}(i', \omega') d\omega di
$$

$$
= \sum_{o=1}^{N} \int_0^{m_o} \int_0^1 p_{ok}(i, \omega) y_{ok}(i, \omega)^{\frac{1}{\sigma}} y_{ok}(i', \omega')^{\frac{\sigma-1}{\sigma}} d\omega di
$$

$$
= p_{ok}(i, \omega) y_{ok}(i, \omega)^{\frac{1}{\sigma}} Y_k^{\frac{\sigma-1}{\sigma}} = E_k, \tag{B.2}
$$

where the last equality follows the budget constraint. By definition of the price index, we can derive the demand for each product from location k:

$$
y_{ok}(i, \omega) = E_k P_k^{\sigma-1} p_{ok}(i, \omega)^{-\sigma}. \tag{B.3}
$$

Integrating $y_{ok}(i, \omega)^{\frac{\sigma-1}{\sigma}}$ over (i, ω) and summing over the headquarter location o, we can get the price index for each location k: $P_k = \left(\sum_{o=1}^{N} \int_0^{m_o} \int_0^1 p_{ok}(i, \omega)^{1-\sigma} \right)^{1/(1-\sigma)}$.

B.1.2   The Firm's Problem Given Set of Locations and ICT

This appendix section provides more details on the derivation of the firm's sales, given a set of establishment locations and state of ICT.

Let o denote the firm's headquarter location, z the firm-specific productivity, S the set of establishment locations in which the firm has operation, and φ the ICT level. As the production function has constant returns to scale and uses labor as the only input, the firm's unit cost of producing a variety ω at establishment in location s and shipping to market k is $c_{oks}(\omega, \varphi, z) = (z\varepsilon_s(\omega))^{-1} w_s \tau_{sk} \gamma_{os}(\varphi)$, where $\varepsilon_s(\omega)$ is establishment-specific productivity that follows a Fréchet distribution and is independently and identically distributed across locations and varieties; w_s is the wage rate in location s; τ_{sk} is the shipping cost between location s and market k; and $\gamma_{os}(\varphi)$ is the communication cost between headquarter location o and establishment location s.

Each market exists a representative consumer who makes consumption decisions independently. Due to the constant-return-to-scale production function at the establishment

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level, the firm chooses the establishment with the lowest unit cost to serve each market. That is, for any variety $\omega \in [0,1]$, the actual cost to market k is $c_{ok}(\omega, S, \varphi, z) = \min_{s \in S} c_{oks}(\omega, \varphi, z)$. Let variety $\omega \in [0,1]$ be given. Since establishment productivity $\varepsilon_s(\omega)$ follows a Fréchet distribution with scale parameter T_s and shape parameter θ and is i.i.d. across locations, we can derive the distribution of the lowest unit cost for market k:

$$P(c_{ok}(\omega, S, \varphi, z) \leq c) = 1 - P(c_{ok}(\omega, S, \varphi, z) > c) = 1 - P(\min_{s \in S} c_{oks}(\omega, \varphi, z) > c)$$

$$= 1 - \prod_{s \in S} P(c_{oks}(\omega, \varphi, z) > c) = 1 - \prod_{s \in S} P((z\varepsilon_s(\omega))^{-1} w_s \tau_{sk} \gamma_{os}(\varphi) > c)$$

$$= 1 - \prod_{s \in S} P(\varepsilon_s(\omega) < (cz)^{-1} w_s \tau_{sk} \gamma_{os}(\varphi)) = 1 - \prod_{s \in S} e^{-\left((cz)^{-1} T_s^{-1} w_s \tau_{sk} \gamma_{os}(\varphi)\right)^{-\theta}}$$

$$= 1 - e^{-c^\theta z^\theta \sum_{s \in S} T_s^\theta (w_s \tau_{sk} \gamma_{os}(\varphi))^{-\theta}} \equiv 1 - e^{-c^\theta z^\theta \Phi_{ok}(S,\varphi)},$$

where we define $\Phi_{ok}(S, \varphi) \equiv \sum_{s \in S} T_s^\theta (w_s \tau_{sk} \gamma_{os}(\varphi))^{-\theta}$ as "production potential" of the firm to market k, which summarizes the states of technology, input costs, market access, and communication costs from the headquarter of all the establishment locations.

As the demand has constant elasticity of substitution, the firm charges a constant markup over the marginal cost, which is the same as the unit cost in this case, with a factor of $\sigma/(\sigma - 1)$. Thus, the distribution of the price of variety ω that the firm charges to market k (i.e., $p_{ok}(\omega, S, \varphi, z)$) has the cumulative distribution function of

$$P(p_{ok}(\omega, S, \varphi, z) \leq p) = 1 - e^{-\left(\frac{\sigma-1}{\sigma}\right)^\theta c^\theta z^\theta \Phi_{ok}(S,\varphi)}. \tag{B.4}$$

By the demand function in Equation (B.3), the sales of variety ω of the firm to market k is

$$\text{sales}_{ok}(\omega, S, \varphi, z) = p_{ok}(\omega, S, \varphi, z) y_{ok}(\omega, S, \varphi, z) = E_k P_k^{\sigma-1} p_{ok}(i, \omega)^{1-\sigma}, \forall \omega \in [0,1] \tag{B.5}$$

Therefore, the total sales of the firm to market k is

$$\text{sales}_{ok}(S, \varphi, z) = E_k P_k^{\sigma-1} \int_0^1 p_{ok}(i, \omega)^{1-\sigma} d\omega$$

$$= \Gamma\left(\frac{\theta - \sigma + 1}{\theta}\right) \left(\frac{\sigma - 1}{\sigma}\right)^{\sigma-1} z^{\sigma-1} E_k P_k^{\sigma-1} \Phi_{ok}(S, \varphi)^{\frac{\sigma-1}{\theta}}, \tag{B.6}$$

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where E_k is the consumer's expenditure and P_k is the ideal price index in location k. Here, it requires $\frac{\theta-\sigma+1}{\theta} > 0$ to have a proper definition. It is worthwhile to note that the share of sales to market k that is generated from the establishment in location $s \in S$ equals the share of varieties that get the lowest unit costs in location s. That is,

$$\zeta_{ok\leftarrow s} \equiv \frac{\text{sales}_{ok\leftarrow s}(S, \varphi, z)}{\text{sales}_{ok}(S, \varphi, z)} = \frac{T_s^\theta(\gamma_{os}(\varphi)w_s\tau_{sk})^{-\theta}}{\Phi_{ok}(S, \varphi)}. \tag{B.7}$$

B.2 Estimation Appendix

B.2.1 First-Stage Regression with Employment Share

<u>Claim:</u> Let firm i be headquartered in location o and has a set of locations denoted by S. Let s denotes the establishment location and k the market location. The employment share regression in the first-stage estimation is of the form:

$$\log \tilde{\zeta}_{ioS,s} = -\theta \log d_{ios} + \log \left(\sum_k \frac{E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-\theta-1}{\theta}}}{\sum_k E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-\theta-1}{\theta}}} \tau_{sk}^{-\theta} \right) + \xi_s + \xi_{oS}, \tag{B.8}$$

where the left-hand side variable is the logarithm of the establishment's employment share, normalized by the employment share of the headquarter. On the right-hand side, d_{ios} is the location-pair–dependent communication cost between the headquarter and establishment; E_k and P_k are the consumer's expenditure and price index, respectively, on manufacturing goods; Φ_{ioSk} is the firm's production potential for market k; τ_{sk} is the trade cost between the establishment and market; ξ_s and ξ_{oS} are fixed effects of the establishment location and the headquarter-set, respectively. θ is the shape parameter of Fréchet distributions for establishment-specific productivity. σ is the elasticity of substitution across varieties in consumer preference.

<u>Derivation:</u> Let market k be given. The firm's sales from market k is:

$$\text{sales}_{ioSk} = \frac{\sigma^{1-\sigma}}{(\sigma-1)^{1-\sigma}} \tilde{\Gamma} z_i^{\sigma-1} E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-1}{\theta}}, \tag{B.9}$$

where $\tilde{\Gamma}$ is a constant and z_i is firm-specific productivity for firm i. Following the properties of the Fréchet distributions for establishment-specific productivity, we can get that the share

of sales from market k that is generated from establishment $s \in S$ is:

$$
\begin{aligned}
\text{sales}_{ioSk \leftarrow s} &= \frac{T_s^{\theta}(w_s \tau_{sk} d_{ios})^{-\theta}}{\Phi_{ioSk}} \times \text{sales}_{ioSk} \\
&= T_s^{\theta}(w_s \tau_{sk} d_{ios})^{-\theta} \times \frac{\sigma^{1-\sigma}}{(\sigma-1)^{1-\sigma}} \tilde{\Gamma} z_i^{\sigma-1} E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-1}{\theta}-1}.
\end{aligned}
\tag{B.10}
$$

Here, T_s denotes the state of technology in location s, w_s the location's wage rate, τ_{sk} the trade cost, and d_{ios} the location-pair–dependent communication cost, respectively.

Since the production function is Cobb-Douglas with labor as the only input and firms compete monopolistically, the wages are proportional to the sales with a factor of $(\sigma-1)/\sigma$:

$$
w_s L_{ioSk \leftarrow s} = T_s^{\theta}(w_s \tau_{sk} d_{ios})^{-\theta} \times \left(\frac{\sigma-1}{\sigma}\right)^{\sigma} \tilde{\Gamma} z_i^{\sigma-1} E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-1}{\theta}-1}.
\tag{B.11}
$$

Then, we can get the total employment at the establishment in location s is:

$$
L_{ioS,s} \equiv \sum_k L_{ioSk \leftarrow s} = \left(\frac{\sigma-1}{\sigma}\right)^{\sigma} \tilde{\Gamma} z_i^{\sigma-1} T_s^{\theta} w_s^{-(\theta+1)} d_{ios}^{-\theta} \times \sum_k E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-1}{\theta}-1} \tau_{sk}^{-\theta}.
\tag{B.12}
$$

Similarly, the employment in the headquarter location is:

$$
L_{ioS,o} \equiv \sum_k L_{ioSk \leftarrow s} = \left(\frac{\sigma-1}{\sigma}\right)^{\sigma} \tilde{\Gamma} z_i^{\sigma-1} T_o^{\theta} w_o^{-(\theta+1)} \times \sum_k E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-1}{\theta}-1} \tau_{ok}^{-\theta},
\tag{B.13}
$$

where we take into account that the location-pair–dependent communication costs are zero at the headquarter.

Therefore, we can derive the logarithm of the employment share at non-establishment locations $s \in S, s \neq o$, normalized by the logarithm of the headquarter employment share, is:

$$
\begin{aligned}
\log \tilde{\zeta}_{ioS,s} &\equiv \log \zeta_{ioS,s} - \log \zeta_{ioS,o} = \log L_{ioS,s} - \log L_{ioS,o} \\
&= \underbrace{\theta \log T_s - (\theta+1)\log w_s}_{\equiv \xi_s} - \theta \log d_{ios} + \log \left(\sum_k \frac{E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-\theta-1}{\theta}}}{\sum_k E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-\theta-1}{\theta}}} \tau_{sk}^{-\theta} \right) \\
&\quad \underbrace{- \log T_o + (\theta+1)\log w_o - \log \left(\sum_k \frac{E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-\theta-1}{\theta}}}{\sum_k E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-\theta-1}{\theta}}} \tau_{ok}^{-\theta} \right)}_{\equiv \xi_{oS}}.
\end{aligned}
$$

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Here, I add and subtract a headquarter-set-specific term, i.e., $\sum_k E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-\theta-1}{\theta}}$. Reorganize the equation above, and we can get that

$$\log \tilde{\zeta}_{ioS,s} = -\theta \log d_{ios} + \log \left(\sum_k \frac{E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-\theta-1}{\theta}}}{\sum_k E_k P_k^{\sigma-1} \Phi_{ioSk}^{\frac{\sigma-\theta-1}{\theta}}} \tau_{sk}^{-\theta} \right) + \xi_s + \xi_{oS}, \tag{B.14}$$

which is of the same form as the normalized sales share.

B.3 Counterfactual Appendix

B.3.1 Decomposition of Price Index

Denote firm by i and firm headquarter location by o. In each market k, the ideal price index is defined by $P_k = \left(\sum_{o=1}^N \int_0^{m_o} p_{ok}(i)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}$, where m_o is the exogenous mass of firms headquartered in location o, and $p_{ok}(i)$ is the firm-specific price charged to market k by the firm. Depending on whether a firm is headquartered in location k (i.e., local firms versus outside firms) and whether a firm sets up an establishment in location k in the benchmark or counterfactual equilibrium, we can decompose the price index to the contribution from five types of firms:

$$P_k^{1-\sigma} = (P_k^{\text{local}})^{1-\sigma} + (P_k^{\text{out},11})^{1-\sigma} + (P_k^{\text{out},10})^{1-\sigma} + (P_k^{\text{out},01})^{1-\sigma} + (P_k^{\text{out},00})^{1-\sigma},$$

where P_k^{local} is the price index of local firms, $P_k^{\text{out},11}$ is the price index of outside firms that set up establishments in location k in both the benchmark and counterfactual equilibria, $P_k^{\text{out},10}$ is the price index of outside firms that set up establishments in the location in the benchmark equilibrium but exit in the counterfactual equilibrium, $P_k^{\text{out},01}$ is the price index of outside firms that do not set up establishments in the location in the benchmark equilibrium but enter the location in the counterfactual equilibrium, and $P_k^{\text{out},00}$ is the price index of outside firms that do not set up establishments in the location in either the benchmark or counterfactual equilibria. Particularly, these price indices are defined as follows. Let $S^0(i)$ and $S^1(i)$ the set of establishment locations of firm i in the benchmark

equilibrium and counterfactual equilibrium, respectively. Then, we can express the price index of each type of firms by:

$$P_k^{\text{local}} = \left(\int_0^{m_k} p_{kk}(i)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}$$

$$P_k^{\text{out},11} = \left(\sum_{o \neq k} \int_0^{m_o} \mathbb{1}[k \in S^0(i), k \in S^1(i)] \, p_{ok}(i)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}$$

$$P_k^{\text{out},10} = \left(\sum_{o \neq k} \int_0^{m_o} \mathbb{1}[k \in S^0(i), k \notin S^1(i)] \, p_{ok}(i)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}$$

$$P_k^{\text{out},01} = \left(\sum_{o \neq k} \int_0^{m_o} \mathbb{1}[k \notin S^0(i), k \in S^1(i)] \, p_{ok}(i)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}$$

$$P_k^{\text{out},00} = \left(\sum_{o \neq k} \int_0^{m_o} \mathbb{1}[k \notin S^0(i), k \notin S^1(i)] \, p_{ok}(i)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}.$$

Let P_k denote the price index in location k in the benchmark equilibrium and $\tilde{P}_k$ the price index in the counterfactual equilibrium. As welfare changes are captured by changes

in the inverse of price index, we can thus decompose the changes in welfare as follows:

$$\log \tilde{W}_k - \log W_k = \log 1/\tilde{P}_k - \log 1/P_k = \log P_k - \log \tilde{P}_k$$

$$= \frac{1}{1-\sigma}\Bigg[\log\Big((P_k^{\text{local}})^{1-\sigma} + (P_k^{\text{out},11})^{1-\sigma} + (P_k^{\text{out},10})^{1-\sigma} + (P_k^{\text{out},01})^{1-\sigma} + (P_k^{\text{out},00})^{1-\sigma} \Big) -$$

$$\log\Big((\tilde{P}_k^{\ \text{local}})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},11})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},10})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},01})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},00})^{1-\sigma} \Big) \Bigg]$$

$$= \frac{1}{1-\sigma}\Bigg[\log\Big((P_k^{\text{local}})^{1-\sigma} + (P_k^{\text{out},11})^{1-\sigma} + (P_k^{\text{out},10})^{1-\sigma} + (P_k^{\text{out},01})^{1-\sigma} + (P_k^{\text{out},00})^{1-\sigma} \Big) -$$

$$\log\Big((P_k^{\text{local}})^{1-\sigma} + (P_k^{\text{out},11})^{1-\sigma} + (P_k^{\text{out},10})^{1-\sigma} + (P_k^{\text{out},01})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},00})^{1-\sigma} \Big) +$$

$$\log\Big((P_k^{\text{local}})^{1-\sigma} + (P_k^{\text{out},11})^{1-\sigma} + (P_k^{\text{out},10})^{1-\sigma} + (P_k^{\text{out},01})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},00})^{1-\sigma} \Big) -$$

$$\log\Big((P_k^{\text{local}})^{1-\sigma} + (P_k^{\text{out},11})^{1-\sigma} + (P_k^{\text{out},10})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},01})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},00})^{1-\sigma} \Big) +$$

$$\log\Big((P_k^{\text{local}})^{1-\sigma} + (P_k^{\text{out},11})^{1-\sigma} + (P_k^{\text{out},10})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},01})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},00})^{1-\sigma} \Big) -$$

$$\log\Big((P_k^{\text{local}})^{1-\sigma} + (P_k^{\text{out},11})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},10})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},01})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},00})^{1-\sigma} \Big) +$$

$$\log\Big((P_k^{\text{local}})^{1-\sigma} + (P_k^{\text{out},11})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},10})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},01})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},00})^{1-\sigma} \Big) -$$

$$\log\Big((P_k^{\text{local}})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},11})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},10})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},01})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},00})^{1-\sigma} \Big) +$$

$$\log\Big((P_k^{\text{local}})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},11})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},10})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},01})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},00})^{1-\sigma} \Big) -$$

$$\log\Big((\tilde{P}_k^{\ \text{local}})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},11})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},10})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},01})^{1-\sigma} + (\tilde{P}_k^{\ \text{out},00})^{1-\sigma} \Big) \Bigg]$$

$$\equiv \Big(\Delta^{\text{out},00} + \Delta^{\text{out},01} + \Delta^{\text{out},10} + \Delta^{\text{out},11} + \Delta^{\text{local}} \Big),$$

where Δ^{local}, $\Delta^{\text{out},11}$, $\Delta^{\text{out},10}$, $\Delta^{\text{out},01}$, and $\Delta^{\text{out},00}$ represents the contribution in changes in the price index from different types of firms, respectively.

Appendix C

Appendix for Chapter 3

C.1   Model Appendix

C.1.1   Static Model

This section documents derivations of the static models following the setup of the firm problem in Section 4.1.

Partial Irreversibility

Assume the purchase price of capital is p^b and the resale price is $p^s < p^b$. The firm's problem is now:

$$
\max \left\{ \underbrace{\max_{K > K_0} (1-\tau)A^{1-\theta}K^\theta - p^b(K-K_0)}_{\text{Invest}}, \underbrace{\max_{K < K_0} (1-\tau)A^{1-\theta}K^\theta - p^s(K-K_0)}_{\text{Disinvest}}, \underbrace{(1-\tau)A^{1-\theta}K_0^\theta}_{\text{Inaction}}, \right\}
$$

The optimal capital level K is characterized as follows.

- There exists an upper threshold $\bar{A}$ such that firms invest if their productivity is sufficiently high $A > \bar{A}$. In particular, the optimal capital $K^b = A\left[\frac{(1-\tau)\theta}{p^b}\right]^{1/(1-\theta)}$ and

$$
\bar{A} = \left[\frac{p^b}{(1-\tau)\theta}\right]^{\frac{1}{1-\theta}} K_0. \tag{C.1}
$$

- There exists a lower threshold $\underline{A}$ such that firms disinvest if their productivity is sufficiently low $A < \underline{A}$. In particular, the optimal capital $K^s = A\left[\frac{(1-\tau)\theta}{p^s}\right]^{1/(1-\theta)}$ and

$$
\underline{A} = \left[\frac{p^s}{(1-\tau)\theta}\right]^{\frac{1}{1-\theta}} K_0. \tag{C.2}
$$

- Firms with productivity $A \in [\underline{A}, \bar{A}]$ remain with K_0.

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Fixed Cost

Now assume the firm needs to pay a fixed cost ξK^* to adjust capital. The firm's problem is now:

$$\max \left\{ \underbrace{\max_{K \neq K_0} (1-\tau) A^{1-\theta} K^\theta - p(K - K_0) - \xi K^*}_{\text{Adjust}}, \underbrace{(1-\tau) A^{1-\theta} K_0^\theta}_{\text{Inaction}} \right\},$$

where K^* is given by Equation 4.1. The optimal profit conditional on adjusting is:

$$(1-\tau) \left[(1-\theta) - \theta \frac{\xi}{p} \right] \left[\frac{(1-\tau)\theta}{p} \right]^{\theta/(1-\theta)} A + pK_0. \tag{C.3}$$

The fixed costs generates a region of inaction where firms would rather produce with the initial capital stock K_0 rather than adjust their capital. This region is defined by two values of productivity $\underline{A}$ and $\bar{A}$ at which the firm is indifferent between adjusting and inaction. These values are defined by comparing firm profits from adjusting and inaction:

$$\underbrace{(1-\tau) \left[(1-\theta) - \theta \frac{\xi}{p} \right] \left[\frac{(1-\tau)\theta}{p} \right]^{\theta/(1-\theta)} A + pK_0}_{\text{Profit conditional on adjusting to optimal capital } K^*} = \underbrace{(1-\tau) K_0^\theta A^{1-\theta}}_{\text{Profit using initial capital } K_0} \quad , \quad A \in \{\underline{A}, \bar{A}\}.$$

To see how tax reforms interact with the fixed cost, scale both sides by a factor of $\frac{1}{1-\tau}$ and denote $\text{UCC} = \frac{p}{1-\tau}$:

$$\underbrace{\left[\frac{(1-\theta)}{\theta} \text{UCC} - \frac{\xi}{1-\tau} \right] \left[\frac{\theta}{\text{UCC}} \right]^{1/(1-\theta)} A}_{\text{Slope}} + \underbrace{\text{UCC} K_0}_{\text{Intercept}} = K_0^\theta A^{1-\theta}. \tag{C.4}$$

Convex Adjustment Cost

In the presence of convex adjustment cost, the firm's problem is:

$$\max_K (1-\tau) A^{1-\theta} K^\theta - p(K - K_0) - D(K),$$

where $p = p_k(1 - \tau z)$ and where we assume that $D'(K) \geq 0$ and $D''(K) \geq 0$. The firm's FOC is:

$$\theta(1-\tau) A^{1-\theta} K^{\theta-1} = p + D'(K) \tag{C.5}$$

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Taking logarithms and differentiating FOC (C.5) w.r.t. p_k, we have:

$$(\theta - 1)\frac{1}{K}\frac{\partial K}{\partial p_k} = \frac{1}{p + D'(K)}\left(\frac{\partial p}{\partial p_k} + D''(K)\frac{\partial K}{\partial p_k}\right)$$

$$(\theta - 1)\varepsilon_{K,p_k} = \underbrace{\frac{p}{p + D'(K)}}_{s^p}\varepsilon_{p,p_k} + \frac{D'(K)}{p + D'(K)}\varepsilon_{K,p_k}\underbrace{\left(\frac{D''(K)K}{D'(K)}\right)}_{\alpha(K)}$$

$$(\theta - 1)\varepsilon_{K,p_k} = s^p\varepsilon_{p,p_k} + (1 - s^p)\varepsilon_{K,p_k}\alpha(K)$$

$$\varepsilon_{K,p_k} = \frac{-s^p}{1 - \theta + (1 - s^p)\alpha(K)}, \tag{C.6}$$

where the second line multiplies by p_k and arranges terms into elasticities, the third line introduces $s^p = \frac{p}{p+D'(K)}$ and $\alpha(K) = \frac{D''(K)K}{D'(K)} \geq 0$, and the last line solves for ε_{K,p_k} and uses the fact that $\varepsilon_{p,p_k} = 1$. If there are no convex adjustment costs ($s^p = 1$), ε_{K,p_k} equals the elasticity in the frictionless case.

Convex costs dampen how firms respond to changes in p_k in two ways. First, convex costs decrease the relative importance of p in the total marginal cost of investment ($s^p \leq 1$ in the numerator). Second, firms take into account the fact that larger deviations from the initial capital impact the marginal cost of investment by moving the firm into more convex regions of the function $D(K)$ ($\alpha(K) \geq 0$ in the denominator).

Similarly, taking logarithms and differentiating FOC (C.5) w.r.t $(1 - \tau)$, we have:

$$\varepsilon_{K,1-\tau} = \frac{-s^p\varepsilon_{UCC,1-\tau} + (1 - s^p)}{1 - \theta + (1 - s^p)\alpha(K)}, \tag{C.7}$$

where $\varepsilon_{K,1-\tau}$ is the elasticity of UCC with respect to $1 - \tau$.

To interpret Equations C.6 and C.7, note that s^p is the share of the price of capital in the total marginal cost of investment $(p + D'(K))$.[1] By increasing the marginal cost of investment, convex costs dampen the numerator of these elasticities. In addition, note that $\alpha(K)$ is a measure of the curvature of the adjustment cost function $D'(K)$.[2] Larger deviations of K from K_0 also increase the marginal cost of investment. This indirect effect of the convex costs also dampens the elasticities by increasing the value of the denominator.

[1]Note $s^p \in [0, 1]$ as long as $D'(K) \geq 0$.

[2]In the context of expected utility theory, $\alpha(K)$ is the Arrow-Prat measure of risk aversion, or the coefficient of relative risk aversion. Note $\alpha(K) \geq 0$ as long as $D(K)$ is convex.

Comparing Equations C.6 and C.7, we note that changes in $1 - \tau$ and p_k now have different effects on investment. To see the nature of this difference, note that changes in $1 - \tau$ change the after-tax cost of $D(K)$. These adjustment costs are thought to include halts in production. Because these costs are not tax-deductible, we model $D(K)$ as being an after-tax expense.

A particular example of $D(K)$ is the case of quadratic costs. These costs feature prominently in the literature and we use them in our dynamic model. Assuming $D(K) = \frac{\gamma}{2} \left(\frac{K}{K_0} - 1 \right)^2 K_0$ implies $\alpha(K) = \frac{1}{1 - K_0/K}$ and $s^p = \frac{p}{p + \gamma \left(\frac{K}{K_0} - 1 \right)}$. These facts imply the following elasticities:

$$\varepsilon_{K,p_k} = \frac{-1}{(1 - \theta) + \frac{\gamma}{p} \left((2 - \theta) \frac{K}{K_0} - (1 - \theta) \right)} \quad \text{and}$$

$$\varepsilon_{K,(1-\tau)} = \frac{-\varepsilon_{UCC,1-\tau} + \frac{\gamma}{p}(K/K_0 - 1)}{(1 - \theta) + \frac{\gamma}{p} \left((2 - \theta) \frac{K}{K_0} - (1 - \theta) \right)}.$$

C.1.2   Profit Function

In this section, we micro-found the profit function of the form $\Pi = (A^\Pi)^{1-\theta} K^\theta$ by a simple firm optimization problem. Assume the final good market is perfectly competitive. Firms use capital, labor and intermediate goods for production. The production function features decreasing-return-to-scale (DRTS) with the following form:

$$Y = A^{1-\eta}[(K^\alpha L^{1-\alpha})^{1-\sigma} M^\sigma]^\eta,$$

where η is the span-of-control parameter, σ is the share of intermediate goods, and α is the capital share in value added. Capital K is pre-determined while labor L and intermediate goods M are chosen contemporaneously after productivity A is realized.

Given the price of final goods p_c which is normalized to one, wage w, the price of intermediate goods p^M and corporate income tax rate τ, the firm's problem is:

$$\max_{L,M} (1 - \tau)\{A^{1-\eta} \left[(K^\alpha L^{1-\alpha})^{1-\sigma} M^\sigma \right]^\eta - wL - p^M M\}.$$

Solving the FOCs, we obtain the optimal labor and intermediate inputs:

$$L^* = \left\{ \eta \left[\frac{(1-\alpha)(1-\sigma)}{w} \right]^{1-\sigma\eta} \left[\frac{\sigma}{p^M} \right]^{\sigma\eta} A^{1-\eta} \right\}^{\frac{1}{1-\eta[(1-\alpha)(1-\sigma)+\sigma]}} K^{\frac{\alpha(1-\sigma)\eta}{1-\eta[(1-\alpha)(1-\sigma)+\sigma]}},$$

$$M^* = \frac{w}{(1-\alpha)(1-\sigma)} \frac{\sigma}{p^M} L^*.$$

Thus, the optimal revenue and profit are:

$$R^* = \left\{ \underbrace{\left[\frac{(1-\alpha)(1-\sigma)}{w} \right]^{\frac{1-\sigma\eta}{1-\eta}} \left[\frac{\sigma}{p^M} \right]^{\frac{\sigma\eta}{1-\eta}} A}_{A^R} \right\}^{1-\underbrace{\frac{\alpha(1-\sigma)\eta}{1-\eta[(1-\alpha)(1-\sigma)+\sigma]}}_{\theta}} K^{\frac{\alpha(1-\sigma)\eta}{1-\eta[(1-\alpha)(1-\sigma)+\sigma]}}$$

$$= (A^R)^{1-\theta} K^\theta,$$

$$\Pi^* = \left\{ 1 - \eta[(1-\alpha)(1-\sigma)+\sigma] \right\} R^*$$

$$= \left\{ \underbrace{(1-\tau)^{\frac{1}{1-\theta}} \left\{ 1 - \eta[(1-\alpha)(1-\sigma)+\sigma] \right\}^{\frac{1}{1-\theta}} A^R}_{A^\Pi} \right\}^{1-\theta} K^\theta = (A^\Pi)^{1-\theta} K^\theta, \qquad (\text{C.8})$$

where the parameter θ, and profit shocks A^Π are defined by:

$$\theta = \frac{\alpha(1-\sigma)\eta}{1-\eta[(1-\alpha)(1-\sigma)+\sigma]},$$

$$A^\Pi = (1-\tau)^{\frac{1}{1-\theta}} \left\{ 1 - \eta[(1-\alpha)(1-\sigma)+\sigma] \right\}^{\frac{1}{1-\theta}} \left[\frac{(1-\alpha)(1-\sigma)}{w} \right]^{\frac{1-\sigma\eta}{1-\eta}} \left[\frac{\sigma}{p^M} \right]^{\frac{\sigma\eta}{1-\eta}} A.$$

C.1.3   Value Function and Normalization

This section details the derivation of the value function.

Original Value Function

The per-period profit is $\Pi(K, A^\Pi)$, where K is pre-determined capital and A^Π is a profit shock realized at the beginning of the period. Firms pay the input VAT at rate ν on purchases of new investment, which is not allowed to be deducted from the output VAT. Firms also pay the corporate income tax at rate τ on profits. Capital depreciates at rate

δ. Besides the economic depreciation rate, we also consider a straight-line accounting depreciation rate $(\hat{\delta})$ that determines the deductibility of capital usage from the CIT.

Firms face adjustment frictions including a convex cost $(\frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K)$, a random fixed cost (ξK^*), and partial irreversibility from the non-deductible VAT on new equipment purchases.

Let D be the depreciation allowances accumulating over time. Since the accounting depreciation rate $\hat{\delta}$ differs from the economic depreciation rate δ, firms track the depreciation allowance D besides capital stock K. The firm's state variables are (K, D, A^Π, ξ). We assume that the fixed cost is i.i.d drawn from the distribution $G(\xi)$ and we define the *ex ante* value function:

$$V^0(K, D, A^\Pi) = \int_0^{\bar{\xi}} V(K, D, A^\Pi, \xi) dG(\xi). \tag{C.9}$$

The firm's problem in recursive formulation is:

$$V(K, D, A^\Pi, \xi) = \max\{V^b(K, D, A^\Pi, \xi), V^s(K, D, A^\Pi, \xi), V^i(K, D, A^\Pi, \xi)\},$$

where

$$
\begin{aligned}
V^b(K, D, A^\Pi, \xi) &= (1-\tau)\Pi(K, A^\Pi) + \tau\hat{\delta}D \\
&+ \max_{I>0}\left\{ -[1 + \nu - \tau\hat{\delta}(1+\nu)]I - \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \right. \\
&+ \left. \beta\mathbb{E}[V^0(K', D', A^{\Pi'})|A^\Pi] \right\} \\
V^s(K, D, A^\Pi, \xi) &= (1-\tau)\Pi(K, A^\Pi) + \tau\hat{\delta}D \\
&+ \max_{I<0}\left\{ -[1 + \quad -\tau\hat{\delta}(1+\nu)]I - \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \right. \\
&+ \left. \beta\mathbb{E}[V^0(K', D', A^{\Pi'})|A^\Pi] \right\} \\
V^i(K, D, A^\Pi, \xi) &= (1-\tau)\Pi(K, A^\Pi) + \tau\hat{\delta}D + \beta\mathbb{E}[V^0(K(1-\delta), D(1-\hat{\delta}), A^{\Pi'})|A^\Pi]
\end{aligned}
$$

The capital stock K and depreciation allowance D evolve according to the following laws of motion:

$$K' = (1-\delta)K + I$$

$$D' = (1-\hat{\delta})[D + (1+\nu)I].$$

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Simplification

Winberry (2020) shows that the impact of the depreciation schedule $\hat{\delta}$ on the deductibility of a unit of new capital can be summarized by the sufficient statistic z, which is defined recursively as

$$z = \hat{\delta} + (1 - \hat{\delta})\beta\mathbb{E}[z']. \tag{C.10}$$

Furthermore, the function $V(K, D, A^{\Pi}, \xi)$ has the same solution as the following value function

$$\tilde{V}(K, A^{\Pi}, \xi) = \max\{\tilde{V}^b(K, A^{\Pi}, \xi), \tilde{V}^s(K, A^{\Pi}, \xi), \tilde{V}^i(K, A^{\Pi}, \xi)\},$$

where

$$\tilde{V}^0(K, A^{\Pi}) = \int_0^{\bar{\xi}} \tilde{V}(K, A^{\Pi}, \xi)dG(\xi)$$

$$\tilde{V}^b(K, A^{\Pi}, \xi) = \max_{I>0} \ (1 - \tau)\Pi(K, A^{\Pi}) - \left[[1 + \nu - \tau z(1 + \nu)]I + \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K + \xi K^*\right]$$

$$+ \beta\mathbb{E}[\tilde{V}^0(K', A^{\Pi'})|A^{\Pi}]$$

$$\tilde{V}^s(K, A^{\Pi}, \xi) = \max_{I<0} \ (1 - \tau)\Pi(K, A^{\Pi}) - \left[[1 \quad - \tau z(1 + \nu)]I + \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K + \xi K^*\right]$$

$$+ \beta\mathbb{E}[\tilde{V}^0(K', A^{\Pi'})|A^{\Pi}]$$

$$\tilde{V}^i(K, A^{\Pi}, \xi) = (1 - \tau)\Pi(K, A^{\Pi}) + \beta\mathbb{E}[\tilde{V}^0(K(1 - \delta), A^{\Pi'})|A^{\Pi}]$$

We sketch the brief proof here. Rewrite the value function as

$$V(K, D, A, \xi) = (1 - \tau)\Pi(K, A) + \tau\hat{\delta}D$$

$$+ \max_I - \left\{[1 + \nu - \tau\hat{\delta}(1 + \nu)]\mathbb{1}_{I>0} + [1 - \tau\hat{\delta}(1 + \nu)]\mathbb{1}_{I\leq 0}\right\} I$$

$$- \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^*\mathbb{1}_{I\neq 0} + \beta\mathbb{E}[V(K', D', A', \xi')|A] \tag{C.11}$$

Consider the set of functions of the form $f(K, A, D, \xi) = g(K, A, \xi) + \tau z D$, where $z = \hat{\delta} + (1 - \hat{\delta})\mathbb{E}[z']$, and the operator T defined by the right hand side of Bellman Equation (C.11).

Claim: The operator T maps a function of the form $f(K, A, D, \xi) = g(K, A, \xi) + \tau z D$ to itself.

Proof: Applying the operator T to $f(K, A, D, \xi)$, we get that

$$
\begin{aligned}
Tf(K, A, D, \xi) = {}& (1 - \tau)\Pi(K, A) + \tau\hat{\delta}D \\
& + \max_I - \left\{ [1 + \nu - \tau\hat{\delta}(1 + \nu)]\mathbb{1}_{I>0} + [1 - \tau\hat{\delta}(1 + \nu)]\mathbb{1}_{I\leq 0} \right\} I \\
& - \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \mathbb{1}_{I\neq 0} + \beta\mathbb{E}[g(K', A', \xi') + \tau z'D'|A]
\end{aligned}
$$

By the law of motion for the depreciation allowance $D' = (1 - \hat{\delta})[D + (1 + \nu)I]$, we have that

$$
\begin{aligned}
Tf(K, A, D, \xi) = {}& (1 - \tau)\Pi(K, A) + \tau\hat{\delta}D \\
& + \max_I - \left\{ [1 + \nu - \tau\hat{\delta}(1 + \nu)]\mathbb{1}_{I>0} + [1 - \tau\hat{\delta}(1 + \nu)]\mathbb{1}_{I\leq 0} \right\} I \\
& - \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \mathbb{1}_{I\neq 0} \\
& + \beta\mathbb{E}[g(K', A', \xi')|A] + \tau(1 - \hat{\delta})\beta\mathbb{E}[z']D + \tau(1 - \hat{\delta})\beta\mathbb{E}[z'](1 + \nu)I \\
= {}& (1 - \tau)\Pi(K, A) + \tau[\hat{\delta} + (1 - \hat{\delta})\beta\mathbb{E}[z']]D + \\
& \max_I - \left\{ [1 + \nu - \tau(1 + \nu)(\hat{\delta} + (1 - \hat{\delta})\beta\mathbb{E}[z'])]\mathbb{1}_{I>0} \right. \\
& \left. + [1 - \tau(1 + \nu)(\hat{\delta} + (1 - \hat{\delta})\beta\mathbb{E}[z'])]\mathbb{1}_{I\leq 0} \right\} I \\
& - \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \mathbb{1}_{I\neq 0} + \beta\mathbb{E}[g(K', A', \xi')|A] \\
= {}& \Pi(K, A) + \tau z D \\
& + \max_I - \left\{ [1 + \nu - \tau(1 + \nu)z]\mathbb{1}_{I>0} + [1 - \tau(1 + \nu)z]\mathbb{1}_{I\leq 0} \right\} I \\
& - \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \mathbb{1}_{I\neq 0} + \beta\mathbb{E}[g(K', A', \xi')|A], \qquad \text{(C.12)}
\end{aligned}
$$

where the last equation follows the definition of $z = \hat{\delta} + (1 - \hat{\delta})\mathbb{E}[z']$. Note that the right-hand side of Equation (C.12) is also a function of the form $h(K, A, \xi) + \tau z D$. That is, the operator T maps function $f(K, A, D, \xi) = g(K, A, \xi) + \tau z D$ to itself. Since the set of

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functions $f(K, A, D, \xi)$ is a closed set, there exists a unique fixed point and the fixed point lies in the set. By the definition of value function, which is the fixed point, it follows that $V(K, A, D, \xi)$ is of the form:

$$V(K, A, D, \xi) = \tilde{V}(K, A, \xi) + \tau z D. \tag{C.13}$$

Substituting Equation (C.13) back into the original value function (Equation (C.11)) and canceling-out common terms on both sides, we have

$$\tilde{V}(K, A, \xi) = (1 - \tau)\Pi(K, A) + \max_I - \{[1 + \nu - \tau z(1 + \nu)]\mathbb{1}_{I>0} + [1 - \tau z(1 + \nu)]\mathbb{1}_{I\leq 0}\} I$$
$$- \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \mathbb{1}_{I\neq 0} + \beta\mathbb{E}[\tilde{V}(K', A', \xi')|A].$$

Further Normalization

Recall that we decompose profit shocks into three components $A_{it}^\Pi = \exp(\omega_i + b_t + \varepsilon_{it})$, where ω_i is firm-specific permanent heterogeneity, b_t is the aggregate shock, and ε_{it} is the idiosyncratic transitory shock. The state variables are then $(K, \omega, b, \varepsilon, \xi)$. Note that both the profit function and the investment cost function are homogeneous of degree one in the pair (K, A^Π), and thus in $(K, \exp(\omega))$. This implies that the value function $V(K, \omega, b, \varepsilon, \xi)$ is also homogeneous of degree one in the pair $(K, \exp(\omega))$.

We can further normalize the value function to $v(k, b, \varepsilon, \xi)$ by defining $k = K/\exp(\omega)$, where the normalized value function is given by:

$$v(k, b, \varepsilon, \xi) = \max(v^b(k, b, \varepsilon, \xi), v^s(k, b, \varepsilon, \xi), v^i(k, b, \varepsilon, \xi)),$$

where

$$v^0(k, b, \varepsilon) = \int_0^{\bar{\xi}} v(k, b, \varepsilon, \xi) dG(\xi)$$

$$v^b(k, b, \varepsilon, \xi) = \max_{i>0} \ (1-\tau)\pi(k, b, \varepsilon) - \left[[1 + \nu - \tau z(1+\nu)]i + \frac{\gamma}{2}\left(\frac{i}{k}\right)^2 k + \xi k^* \right]$$

$$+ \beta \mathbb{E}\left[v^0\left(k', b', \varepsilon'\right) | b, \varepsilon \right],$$

$$v^s(k, b, \varepsilon, \xi) = \max_{i<0} \ (1-\tau)\pi(k, b, \varepsilon) - \left[[1 - \tau z(1+\nu)]i + \frac{\gamma}{2}\left(\frac{i}{k}\right)^2 k + \xi k^* \right]$$

$$+ \beta \mathbb{E}\left[v^0\left(k', b', \varepsilon'\right) | b, \varepsilon \right],$$

$$v^i(k, b, \varepsilon, \xi) = (1-\tau)\pi(k, b, \varepsilon) + \beta \mathbb{E}\left[v^0\left(k'(1-\delta), b', \varepsilon'\right) | b, \varepsilon \right].$$

The law of motion for capital k is

$$k' = (1-\delta)k + i,$$

where investment is normalized by $i = k' - (1-\delta)k = I/exp(\omega)$.

C.2 Policy Background

This appendix section documents details of the VAT reform (Section C.2.1) and the Corporate Income Tax reform (Section C.2.2). Table C.6.1 summarizes the impact of VAT and Corporate Income Tax reforms on the tax components of the user cost of capital (TUCC).

C.2.1 VAT Reform

The VAT reform had four stages. Effective on July 1, 2004, stage I started from eight industries in four provinces and cities in Northeast China (Heilongjiang, Jilin, Liaoning, and Dalian city). The eight industries include equipment manufacturing, petrochemical, metallurgical, automotive manufacturing, shipbuilding, agricultural product processing, military manufacturing, and new- and high-tech industries.

On July 1, 2007, the reform was extended to twenty-six cities in another six provinces (Henan, Hubei, Shanxi, Anhui, and Jiangxi) with eight qualified industries including equipment manufacturing, petrochemical, metallurgical, automotive manufacturing, agricultural product processing, electricity, mining and new- and high-tech industries.

One year later, on July 1, 2008, stage III extended the reform to five cities and leagues in eastern Inner Mongolia with the same eight industries as those in Northeast China. At the same time, due to the Wenchuan earthquake, the government allowed firms in the "key earthquake devastated areas of Wenchuan" to deduct input VAT on equipment. Except for several regulated industries, all other industries were covered.[3]

On January 1, 2009, the reform was unexpectedly extended to all industries across the country. Together with the national expansion of VAT reform, the deduction method of input VAT on equipment changed as well. At the early stages of the reform, the government first collected input VAT and then returned it to firms. To alleviate tax losses, at the beginning of each year the government usually set a limit on the tax return—the increase in VAT payable from the previous year. At the end of the year, if revenue permitted, the full amount of the input VAT on fixed assets would be returned. Since 2009, however, the government switched to the tax credit accounting method so that firms deduct input VAT on equipment from total output VAT directly.

C.2.2 Corporate Income Tax Reform

In 2008, the Chinese government implemented a corporate income tax reform that harmonized the corporate income tax rate for domestic and foreign firms. This reform reduced the corporate income tax rate for domestic firms from 33% to 25% and it raised the corporate income tax rate for foreign firms from lower rates to 25% (e.g., see Chen et al. (2019)).

In spite of the changes to the corporate income tax, the effect on the user cost of capital (TUCC) was limited since the corporate income tax only distorts the capital price

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[3]The regulated industries include coke processing, electrolytic aluminum production, small-scale steel production, and small thermal power generation.

through depreciation deductions. Table C.6.1 summarizes the VAT rate, corporate income tax rate, and TUCCs for domestic and foreign firms from 2007 to 2011. We report two TUCC's—a theoretical one and the sample average. The theoretical TUCC is calculated using the statutory VAT rate as well as the corporate income tax rate ($= (1+\nu_{\text{statutory}})(1-\tau_{\text{statutory}}z)/(1-\tau_{\text{statutory}})$); the sample average TUCC is calculated using statutory VAT rate and the empirical corporate income tax rate ($= (1+\nu_{\text{statutory}})(1-\tau_{\text{empirical}}z)/(1-\tau_{\text{empirical}})$).[4] While the theoretical TUCC drops by 3.8 percentage points in 2008, we do not see a decrease in the sample average. Notably, the TUCC then drops by 18.1 percentage points following the VAT reform in 2009. The theoretical and sample average TUCC for foreign firms barely changed. This confirms that the VAT reform is the major driving force behind the user cost of capital during this period.

C.3   Data

In this section, we provide more details of the data we use and how we construct the key variables in our empirical analysis.

National Tax Survey Database

The major dataset we use is the National Tax Survey Database (hereafter "tax data") collected jointly by Ministry of Finance (MOF) and State Administration of Tax (SAT). The two ministries produce two lists of survey firms every year. The first list consists of *key* firms that are more likely to be large firms and are required to account for at least 10% of the total number of general VAT tax payers. The key firms include those that accounted for over 70% of local VAT revenue in the past year, firms with preferential tax treatment,

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[4]The statutory corporate income tax rate increased gradually since 2008 for some foreign firms, from which we abstract away. Our calculation of the theoretical UCC represents an upper bound to which the corporate income tax reform could affect foreign firms. The empirical corporate income tax rate is calculated as $\tau =$ actual corporate income tax payable/net profit. We do not observe the separate VAT paid for equipment so we use statutory VAT rate for both measures.

exporters, and publicly listed firms. The other list of firms are randomly selected from the administrative tax database, many of which are smaller firms. During our analysis period from 2007 to 2011, firms from the key list and random list account for 80% and 20% of total number of observations, respectively. Taken together, firms in the tax data contribute to over 75% of national VAT revenue. Since our main specification relies on a balanced set of firms, our results are mostly informed by firms in the first list.

The survey is distributed between March and April, covers activities for the previous year, and is usually gathered by the end of June. For instance, the 2009 survey was conducted in 2010 and reflected investment in 2009.

Measuring Investment in Equipment

One of the appealing features of tax data is that, instead of constructing investment from capital stocks, we observe investment directly in the data. Specifically, we observe total investment in fixed assets for production purpose (hereafter "total investment") and investment in structures. Following standard classification in the investment literature, we define equipment investment as the difference between total investment and investment in structures. We cross-validate this measure using data in 2007 that separately records investment in equipment. The directly reported measure matches our main measure of equipment investment very well for 2007.

For our empirical analyses, we construct three outcomes for equipment investment. First, we define a dummy variable set to 1 if a firm has positive investment in equipment. Note that, as in other studies that rely on tax data, we do not observe equipment sales. Second, we construct the investment rate as the ratio of investment in equipment to the net value of total fixed assets. Both investment and fixed assets measures are deflated using corresponding price indexes from the China Statistical Yearbook. We winsorize investment rate for the top 1% of the sample. Finally, we define an investment spike with a dummy variable set to 1 if a firm's investment rate is larger than 20% of capital.

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Foreign Direct Investment Records

The foreign direct investment records are from the Ministry of Commerce (MOC). This comprehensive database covers the universe of foreign firms in China. It contains information on firms' name, industry, approval date, and, importantly, the type of firms—whether the firm is categorized as encouraged, restricted, or whether the project is considered advantageous under the Midwest program. The public version of foreign direct investment records is available from the MOC website: `https://wzxxbg.mofcom.gov.cn/gspt/`.

We match this dataset with the National Tax Survey Database using firms' names. The matching rate is high — In our sample, i.e., firms that existed throughout 2007–2011, around 83% of foreign firms are matched to the foreign direct investment records. Appendix Table C.6.2 compares the summary statistics of major variables for foreign firms in the tax data that are matched to the foreign direct investment records and those foreign firms that are not matched. Matched firms are slightly larger than non-matched firms but are overall comparable. In particular, the investment rate of equipment is virtually the same for matched and non-matched foreign firms. Among the matched foreign firms, 32% of these firms had preferential VAT treatment for equipment purchases before the reform and are used as the control group in our empirical analysis.

Annual Survey of Manufacturing

We extend the parallel trend of investment for domestic and foreign firms by merging the tax data with the 2005–2006 Chinese Annual Survey of Manufacturing (ASM). The ASM focuses on large firms with annual sales of over 5 million RMB. We use matched observations from 2005-2006 ASM in Panel (A) and (B) of Figure 4.6 to extend the investment patterns.

Around 48% of the firms in our sample are matched to the ASM and exist in 2005 and 2006, making a balanced panel from 2005 to 2011. In particular, 42% of domestic firms are matched, and 63% of foreign firms are matched. Table C.6.3 shows that firms that are matched to the ASM are larger than those firms that are not matched, as the ASM focuses on large firms.

C.4 Additional Reduced-Form Results

In this section, we present additional reduced-form results.

C.4.1 Inverse Probability Weighting (IPW)

This appendix section documents details of the inverse probability weighting (IPW) method that we use in robustness checks. One concern of our empirical strategy is that domestic and foreign firms might not have similar observable characteristics. To address this concern, we reweight our data to match the distribution of firm characteristics between domestic and foreign firms.

We first generate propensity scores for being treated by estimating a probit model. The model takes the following form:

$$G_i = \mathbb{1}\{\alpha + X_i\beta + \Delta Y_i\gamma + u_i > 0\}, \tag{C.14}$$

where G_i is the treatment variable, X_i is a vector of firm-specific variables including whether a firm had VAT preferential treatment (and for export), whether it is an exporter, its sales and number of workers. ΔY_i includes investment growth measured by whether a firm invests or not, investment rate and IHS investment.[5] The error term u_i is independently and identically drawn from a normal distribution. We use information in the pre-reform years to conduct the analysis. That is, we use data in 2007 for all firm-specific terms and use data in 2007 and 2008 for investment growth terms. Table C.6.4 reports the estimates of the probit model.

We use the specification in column (6) to generate propensity scores for reweighting. Figure C.6.1 plots the distribution of propensity scores for domestic and foreign firms, respectively. This figure shows that the distributions of propensity scores overlap. Panel (B) of Figure C.6.2 shows that after reweighting, domestic and foreign firms are balanced

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[5]Growth in log investment is not included because of collinearity with the indicator of firm's investing.

in observable characteristics including investment, sales, fixed assets, and the number of workers.

C.4.2 Event Study Estimates

Table C.6.5 reports coefficients used in Figure 4.6 from 2007 to 2011. Particularly, we run the following regression:

$$Y_{ijt} = G_i \gamma_t + \mu_i + \varepsilon_{ijt}, \tag{C.15}$$

where G_i is an indicator that equals one for domestic firms, and μ_i is a firm fixed effect. The dependent variable Y_{ijt} is the investment measure for firm i in industry j at time t: Columns (1) to (3) report the results at the extensive margin—i.e., the fraction of firms investing; Columns (4) to (6) report the results at the intensive margin—i.e., investment rate. In columns (1) and (3) we control for industry-year fixed effects to account for industry-specific trends; in columns (2) and (5) we control for province-year fixed effects; in columns (3) and (6) we add both industry- and province-year fixed effects.

These results confirm that domestic and foreign firms had parallel trends before 2008 since the coefficients on 2007 are economically small and statistically insignificant at both the extensive and intensive margin. At the extensive margin, column (1) shows that the reform increased the fraction of domestic firms that invest in equipment by 6.9 percentage points in 2009, which equals to 14.1% of the pre-reform average fraction of domestic firms investing. Despite of slight decrease, the effects are stable in the following years. The estimates are robust when we add province-year fixed effects. Similar results hold for the investment rate.

Table C.6.6 conducts the same robustness checks performed in our difference-in-differences analysis and shows that the event study coefficients are robust across specifications. Particularly, in columns (2) and (5) we adjust the regressions with inverse probability weighting (IPW); in columns (3) and (6) we use unbalanced samples at the variable level. Despite slight variation in magnitudes, our baseline estimates are robust.

C.4.3 User-Cost-of-Capital Investment Elasticities

As a complement to the difference-in-differences analysis, in this appendix we quantify how changes in the tax component of user-cost-of-capital (TUCC) driven by the reform affected investment outcomes. In particular, we estimate the following regression

$$Y_{ijt} = \beta \log(\text{TUCC}_{ijt}) + \mu_i + \delta_{jt} + X'_{it}\gamma + \varepsilon_{ijt}, \tag{C.16}$$

where TUCC is the tax component of user cost of capital from Equation 4.6. As in Equation 4.8, we control for firm fixed effects, industry-by-year fixed effects, and we show robustness of our results to controlling for industry-by-year fixed effects and firm-level characteristics.

Two challenges prevent OLS from delivering unbiased estimates of β in Equation C.16. First, both investment and the corporate income tax rate, and thus the TUCC, might be correlated with unobserved firm characteristics. For instance, if politically connected firms have lower productivity and enjoy a lower corporate tax rate, an OLS estimation of β would bias $\hat{\beta}$ toward zero. Second, measurement error in investment and the TUCC would also bias the estimate toward zero.

To solve these problems, we use a synthetic TUCC as an instrument for the actual TUCC. In the synthetic TUCC, we allow for ν to change with the reform but we hold all other aspects of the TUCC constant. Table C.6.10 shows that this instrument is a powerful predictor of the actual TUCC since, as we discuss in Section 4.2, the VAT reform had a large effect on the cost of capital. The exclusion restriction that the synthetic tax change identifies changes in the TUCC and is not correlated with differential shocks between foreign and domestic firms is consistent with the difference-in-differences results in the previous section.

Table C.6.11 reports estimates of semi-elasticities of investment with respect to the TUCC. The coefficients on TUCC are all negative, indicating investment increases as the TUCC declines. While OLS estimates are biased toward zero, we find that IV estimates are much larger in magnitude. Columns (2)–(8) in the first panel show that cutting the TUCC by 10% leads to an increase in the fraction of firms investing by 2.4-3.1 percentage points. Similarly, cutting the TUCC by 10% would increase the investment rate by about

2%. Relative to the average investment rate of 10%, the second row of results implies an investment elasticity of -2 with respect to the user cost of capital. Indeed, the third column shows TUCC elasticities between -2.4 and -2.1 for the sample of firms with positive investment. Finally, the last row of Table C.6.11 shows larger estimates for the IHS, which arise from the larger weight the IHS places on extensive-margin responses.

Additionally, Table C.6.12 reports regressions where the independent variable is the TUCC in levels. This specification matches that of previous studies (e.g., Hassett and Hubbard, 2002; Zwick and Mahon, 2017) and allows us to compare the magnitude of our estimated effects with those in the literature. This table shows that lowering the TUCC increases the investment-to-capital ratio by 0.19, which is a smaller effect than in both seminal (Hassett and Hubbard, 2002, c.f., estimates between .5 and 1) and more recent (Zwick and Mahon, 2017, c.f., 1.6) papers.

These tables show that regardless of how we measure outcomes, how TUCC affects investment outcomes is very stable across specifications that control for different levels of fixed effects or for firm-level controls. In particular, the last column controls for corporate income tax rates, which ensures that our identifying variation only comes from changes driven by the VAT reform.

C.4.4 Heterogeneous Effects by External Finance Dependence

An important finding in recent estimates of the effects of tax policy on investment is that the effects of tax policy can interact with financing constraints. For instance, in their study of the effects of bonus depreciation, Zwick and Mahon (2017) find that firms with tighter financial constraints see larger effects on investment. However, this effect may be more important in the case of bonus depreciation, since that policy increases immediate cash flow to these firms. In contrast, while the VAT reform reduces the price of investment and the degree of partial irreversibility, it does not otherwise interact with firms' financial constraints.

To investigate interactions between the VAT reform and financing constraints, we ex-

pand our difference-in-differences analysis by including an interaction with an industry-level measure of external finance dependence from Hsu et al. (2014). As we show in Table C.6.13, we do not find that firms in industries with higher external finance dependence have larger responses to the VAT reform. If anything, we find smaller effects along the intensive margin.

C.4.5 Tax Policy and Partial Irreversibility

We now provide two pieces of evidence that the effects of the VAT reform were driven by interactions between tax policy and partial irreversibility. First, we show that firms with excess VAT credits did not experience a reduction in partial irreversibility and therefore have smaller increases in investment. Second, we explore heterogeneous effects across industries with different degrees of partial irreversibility.

Excess VAT Payments and Partial Irreversibility

While the reform allowed domestic firms to deduct VAT payments on equipment, firms with excess VAT payments did not receive refunds from the government. This feature allows for an additional test of the role of partial irreversibility, since firms with excess VAT payments that decide to invest would face a higher purchase price.[6] We define a firm to be in a positive tax position if it has a positive *potential* VAT credit, defined by an excess VAT credit ignoring the input credit from investment.[7] After the reform, 13.38% of domestic firms have a positive tax position.

Table C.6.14 reports heterogeneous effects of the reform on investment by tax position. Columns (1) and (4) show the results for all firms,[8] columns (2) and (5) for firms without

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[6]In theory, firms could carry excess credits forward. However, even if firms are able to use these credits in the future, the interest cost of carrying the credits forward impacts the partial irreversibility of investment.

[7]Specifically, the potential VAT credit equals $\text{InputVAT}_{it} - \text{OutputVAT}_{it} + \text{Credit}_{i,t-1}$ for domestic firms prior the reform. For foreign firms prior to the reform or all firms after the reform, the potential VAT credit equals $\text{InputVAT}_{it} - \text{OutputVAT}_{it} + \text{Credit}_{i,t-1} - 17\% \times I_{it}$.

[8]The numbers of observations for columns (1) and (4) are different from the baseline results in

a positive VAT credit, and columns (3) and (6) for firms with a positive VAT credit. These results show that investment responses, especially at the extensive margin, are driven by firms without excess VAT credits. Firms that will not recover the VAT payment on equipment in this period are still subject to tax-driven partial irreversibility and display much smaller investment effects.[9,10]

Heterogeneous Response by Redeployability

To further shed light on the role of irreversibility, we now explore whether the reform had heterogeneous effects depending on non-tax sources of partial irreversibility. Intuitively, firms that use assets that are specifically tailored to their needs are likely to face additional partial irreversibility. Eliminating tax-driven sources of partial irreversibility would then have smaller effects on firms in industries with high asset specificity.

To measure the importance of irreversibility, we use an industry-level index of asset redeployability developed by Kim and Kung (2017). The index takes into account the industry's asset composition as well as how each asset is used within and across industries.[11] Industries with higher redeployability are less likely to face additional (non-tax) partial irreversibility. To test this hypothesis, we add an interaction with the redeployability index

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Table 4.3 because this table restricts the sample to a balanced panel of firms with a non-missing tax position.

[9]While this is an important result for the study of tax administration (e.g., Ebrill et al., 2001), we do not model the refundability of VAT payments in our baseline structural model. We find similar effects when we include the tax position as a feature of the structural model.

[10]Xu and Zwick (2020) show that firms may use investment as a tool to minimize tax liabilities. After the reform, only 0.62% of the observations with positive *potential* VAT liabilities, the liabilities that ignore the input VAT credits from investment, end up with zero *actual* VAT liability, suggesting that firms have not fully taken advantage of tax deductions to "zero out" VAT liabilities and that our results are unlikely to be driven by the tax-minimization motives

[11]For example, printing—which relies on customized machines—has a lower redeployability index, while leather manufacturing has a higher index.

to our difference-in-differences regression. Table C.6.15 reports the results of this analysis, where we normalize the redeployability index to have a zero mean and unit standard deviation. This table shows that industries with redeployability that is one standard deviation higher than average see larger increases in the fraction of firms investing in equipment (i.e., the extensive margin), the fraction of firms replacing more than 20% of their capital stock (i.e., investment spikes), and the investment rate (i.e., the intensive margin). These results further confirm the importance of considering the interactions between tax policy and partial irreversibility.

C.5 Additional Structural Estimation Results

This appendix provides additional details on the structural estimation.

C.5.1 Productivity Estimation via System GMM

We now document details related to estimating the curvature parameter of profit function (θ) and the persistence of idiosyncratic shocks (ρ_ε) using the system GMM estimator of Blundell and Bond (2000).

Following Appendix C.1.2, we start by taking logarithms of Equation C.8:

$$r_{it} = (1 - \theta)a_{it}^R + \theta k_{it}. \tag{C.17}$$

Since we observe sales r_{it} and capital k_{it}, we can thus back out log revenue shocks a_{it}^R by $a_{it}^R = \frac{1}{1-\theta}(r_{it} - \theta k_{it})$, which differ from a_{it}^Π by a constant. Without loss of generality, we write $a_{it}^R = b_t + \omega_i + \varepsilon_{it}$, where b_t, ω_i, ε_{it} are aggregate shock, firm permanent component and firm transitory shock, respectively. Let m_{it} denote classical measure error or any other unexpected optimization errors. Then, combined with Equation (C.17), we have

$$r_{it} = \theta k_{it} + (1 - \theta)b_t + (1 - \theta)\omega_i + (1 - \theta)\varepsilon_{it} + m_{it}.$$

Recall that the firm transitory shock ε_{it} follows an AR(1) process i.e., $\varepsilon_{it} = \rho_\varepsilon \varepsilon_{i,t-1} + e_{it}$, where e_{it} is an innovation term independently and identically distributed across firms and

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over time. We exploit the AR(1) property of ε_{it} to difference out the persistent component in ε_{it}. We can then get the following revenue equation:

$$r_{it} = \rho_\varepsilon r_{i,t-1} + \theta k_{it} - \rho_\varepsilon \theta k_{i,t-1} + b_t^* + \omega_i^* + m_{i,t} - \rho_\varepsilon m_{i,t-1} + (1-\theta)e_{it}, \qquad \text{(C.18)}$$

where $b_t^* = (1-\theta)b_t - \rho_\varepsilon(1-\theta)b_{t-1}$ is year fixed effect and $\omega_i^* = (1-\theta)(1-\rho_\varepsilon)\omega_i$ is the firm fixed effect. We complement Equation (C.18) with its first-differenced (FD) equation:

$$\Delta r_{it} = \rho_\varepsilon \Delta r_{i,t-1} + \theta \Delta k_{it} - \rho_\varepsilon \theta \Delta k_{i,t-1} + \Delta b_t^* + \Delta m_{i,t} - \rho_\varepsilon \Delta m_{i,t-1} + (1-\theta)\Delta e_{it}. \quad \text{(C.19)}$$

We construct a GMM estimator using two sets of moments based on both the level Equation (C.18) and FD Equation (C.19). The first set of moments is

$$\mathbb{E}[z_{i,t-s}^D(\Delta m_{i,t} - \rho_\varepsilon \Delta m_{i,t-1} + (1-\theta)\Delta e_{it})] = 0,$$

where $z_{i,t-s}^D = [r_{i,t-s}, k_{i,t-s}]$, $s \geq 3$. Intuitively, we use lagged revenue and capital in levels (r and k) to instrument for the FD equation. The second set of moments is

$$\mathbb{E}[z_{i,t-s}^L((1-\theta)(1-\rho_\varepsilon)\omega_i + m_{i,t} - \rho_\varepsilon m_{i,t-1} + (1-\theta)e_{it})] = 0,$$

where $z_{i,t-s}^L = [\Delta r_{i,t-s}, \Delta k_{i,t-s}]$, $s \geq 2$. Here, we use the first difference of lagged revenue and capital (Δr and Δk), to instrument for the level equation.[12] In our data, we have the moment condition

$$\mathbb{E}[Z_i' U_i] = 0, \quad \forall i,$$

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[12] The identification of the *first-differenced* equation relies on the sequential exogeneity, as well as classical measurement error assumption; the identification of the *level* equation is that the changes in revenue and capital are uncorrelated to firm-specific permanent component and the measurement error.

where

$$Z_i = \begin{bmatrix} Z_i^D & \mathbf{0} \\ \mathbf{0} & Z_i^L \end{bmatrix}$$

$$= \begin{bmatrix} r_{i,07} \; k_{i,07} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & r_{i,07} \; k_{i,07} \; r_{i,08} \; k_{i,08} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \Delta r_{i,08} \; \Delta k_{i,08} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \Delta r_{i,08} \; \Delta k_{i,08} \; \Delta r_{i,09} \; \Delta k_{i,09} \end{bmatrix}$$

$$U_i = \begin{bmatrix} U_i^D \\ U_i^L \end{bmatrix}$$

$$= \begin{bmatrix} \Delta m_{i,10} - \rho_\varepsilon \Delta m_{i,09} + (1-\theta)\Delta e_{i,10} \\ \Delta m_{i,11} - \rho_\varepsilon \Delta m_{i,10} + (1-\theta)\Delta e_{i,11} \\ (1-\theta)(1-\rho_\varepsilon)\omega_i + m_{i,10} - \rho_\varepsilon m_{i,09} + (1-\theta)e_{i,10} \\ (1-\theta)(1-\rho_\varepsilon)\omega_i + m_{i,11} - \rho_\varepsilon m_{i,10} + (1-\theta)e_{i,11} \end{bmatrix}$$

We then estimate θ and ρ_ε using the GMM estimator.

C.5.2 Markup

An alternative way to obtain the revenue equation in Appendix C.1.2 is to assume that the firm has a CRTS production function and faces a CES demand function with elasticity $1/\zeta$. This simple monopolistic competitive model yields a constant markup, which maps to our estimate of θ. In this case, we can write the curvature of profit function (θ) as a function of other primitive parameters

$$\theta = \frac{\alpha(1-\sigma)(1-\zeta)}{1 - (1-\zeta)[(1-\alpha)(1-\sigma) + \sigma]}, \tag{C.20}$$

where α is the share of capital out of value added and σ is the share of materials. The gross markup equals to $1/(1-\zeta)$. To be consistent with the empirical markup calculated from data, we consider the markup excluding capital cost, which equals $1/\{(1-\zeta)[(1-\alpha)(1-\sigma) + \sigma]\}$. Using Equation (C.20) we obtain:

$$\text{markup}_{theoretical} = \frac{1}{\theta}\frac{\alpha(1-\sigma)}{(1-\alpha)(1-\sigma) + \sigma} + 1.$$

Given an estimate of θ and values of α and σ we can calculate the markup. Setting $\alpha = 1/2$ (Bai et al., 2006) and $\sigma = 0.7$ (Jones, 2011), the theoretical markup is 1.224.

In data, we calculate the markup by

$$\text{markup}_{empirical} = \frac{\text{total sales}}{\text{major business costs}}.$$

The average empirical markup is around 1.223. It is reassuring that the theoretical markup calculated from our estimate of θ is comparable to the empirical markup from data.

C.5.3 Productivity Decomposition

In this appendix we document details of the productivity decomposition we use to obtain the standard deviation of firm idiosyncratic and permanent shocks $(\sigma_\varepsilon, \sigma_\omega)$, and the persistence and standard deviation of aggregate shocks (ρ_b, σ_b).

We first construct revenue shocks using the estimate $\hat{\theta}$

$$\hat{a}_{it}^R = r_{it} - \hat{\theta} k_{it}.$$

Here we use "purified" revenue—projecting revenue on higher-order polynomials of capital and labor—to get rid of disturbances such as measurement errors. With $\hat{a}_{it}$ in hand, we exploit the AR(1) property of ε_{it} to write:

$$\hat{a}_{it} - \hat{\rho}_\varepsilon a_{it-1} = b_t - \hat{\rho}_\varepsilon b_{t-1} + (1 - \hat{\rho}_\varepsilon)\omega_i + e_{it}, \tag{C.21}$$

where e_{it} is an innovation term of ε_{it} independently and identically distributed across firms and over time. We run a regression of $\hat{a}_{it} - \hat{\rho}_\varepsilon \hat{a}_{it-1}$ on time dummies and obtain the residual: $u_{it} = (1 - \hat{\rho}_\varepsilon)\omega_i + e_{it}$.

We then calculate the variance of ω_i and ε_{it} from $var(u_{it})$ and $cov(u_{it}, u_{it-1})$ solving the following equations:

$$\sigma_\omega^2 = \frac{cov(u_{it}, u_{it-1})}{(1 - \hat{\rho}_\varepsilon)^2} \quad \text{and} \quad \sigma_\varepsilon^2 = \frac{var(u_{it}) - cov(u_{it}, u_{it-1})}{(1 - \hat{\rho}_\varepsilon^2)}.$$

Lastly, we recover (ρ_b, σ_b) using the coefficients on time dummies from the regression above. Denote the time dummy coefficients by β_t. Then ρ_b and σ_b jointly solve the following

equations:

$$var(\beta_t) = (-2\hat{\rho}_\varepsilon \rho_b + 1 + \hat{\rho}_\varepsilon{}^2)\sigma_b^2$$

$$cov(\beta_t, \beta_{t-1}) = [-\hat{\rho}_\varepsilon \rho_b^2 + (1 + \hat{\rho}_\varepsilon{}^2)\rho_b - \hat{\rho}_\varepsilon]\sigma_b^2.$$

We bootstrap this procedure 100 times to obtain standard errors for these parameters.

C.5.4 Adjustment Cost Estimation

In this appendix we report additional results for estimation using method of simulated moments (MSM). The criterion function is:

$$g(\phi) = [\hat{m} - m(\phi)]'W[\hat{m} - m(\phi)].$$

We use grid-search to find the parameter values that minimize the criterion function $g(\phi)$. Using the grid-search results as initial values, we further refine our estimates by pattern-search. To confirm our estimates minimizes the criterion function, we plot the loss function against each parameter in Figure C.6.3, holding the other two parameters at their estimated values. For example, Panel (A) plots log loss function $\log(g)$ against convex adjustment cost γ, with $\bar{\xi}$ held at its estimate $\hat{\bar{\xi}} = 0.118$ and δ held at $\hat{\delta} = 0.071$. The loss function is convex and rises steeply around our estimated value, confirming that our estimates minimize the criterion function.

C.5.5 Sensitivity Analysis

Lastly, we construct the sensitivity measures proposed by Andrews et al. (2017):

$$\Lambda = -(G'WG)^{-1}G'W \times g(m),$$

where G is the Jacobian matrix, W is the weighting matrix (identity matrix here), and $g(m)$ is a vector of moments with misspecification. Here, we consider the misspecification to be a 10% deviation from the moment value. Table C.6.16 reports the complete sensitivity matrix.

For the parameter ξ, changes in the share of investment rate below 10% and 30% have the largest effect. An increase in the share below 10%—which implies greater inaction—results in larger fixed costs. For the parameter δ, we find that moments that skew the distribution toward zero also lower the value of this parameter. For the parameter γ, an increase in serial correlation results in a lower estimate of convex costs. These results are consistent with our discussion of identification in Section 4.5.2.

C.6   Additional Simulation Results

This appendix discusses additional simulation results. First, we show that our baseline simulation results are robust to the following extensions: 1) allowing for an upward-sloping capital supply; 2) allowing for an interest rate response to the TUCC; 3) allowing the net-of-tax resale price to be less than one; 4) aggregate productivity shocks; and 5) allowing for adjustment costs to be tax deductible; and 6) allowing changes in the corporate income tax to impact the weighted average cost of capital (WACC) which is affected by corporate income tax cut. Second, we show VAT and corporate income tax cuts with the same TUCC reduction may have different effectiveness in stimulating investment. Finally, we use our estimated model to examine how alternative assumptions may impact our simulated difference-in-differences estimates. In particular, we show that our results are robust to allowing for foreign firms to differ in their prereform tax treatment and to have a difference distribution of fixed costs.

C.6.1   Robustness of Policy Simulations

This section shows that our baseline simulation results are robust to the following extensions.

Upward-sloping Capital Supply

In our baseline model we assume that capital price—net of taxes—is constant. One concern is that the capital price is endogenous and increases as the demand goes up (e.g., Goolsbee, 1998). We relax the assumption of constant capital price by incorporating an upward-sloping capital supply. We assume a functional form of capital supply, which allows us to solve for the price change from the quantity change, i.e., investment response. The capital supply has constant elasticity:

$$p^K = I^{1/\varepsilon^s},$$

where ε^s is the elasticity of capital supply with respect to pre-tax capital price. We set the elasticity ε^s to values ranging from 2.54 to 14, where 2.54 is based on a 56% pass-through rate in Goolsbee (1998) and 14 is the upper bound elasticity estimated in House and Shapiro (2008).

In our difference-in-difference analysis, we find that investment expenditure, i.e., $p^K I$, increased by 36%. This increase can be decomposed into an increase in capital price (p^K) and an increase in investment quantity (I). For any value of the capital supply elasticity ε, we can solve for the increase in capital price (Δp^K) that leads to a 36% increase in investment expenditure. For instance, an elasticity of 2.54 leads to an 9.52% increase in the capital price. Then, we feed in Δp^K to the model—both the purchase and resale price of capital—in response to the reform. In particular, the VAT reform reduces the purchase price of capital from $(1 - \tau z)(1 + 17\%)$ to $(1 + \Delta p^K) \times (1 - \tau z)$, and increases the resale price of capital from $1 - \tau z(1 + 17\%)$ to $(1 + \Delta p^K) \times (1 - \tau z)$. Table C.6.18 reports the simulation results. Even after accounting for this price response, the reform results in a substantial increase in investment. While the drop-in capital price is smaller, the decrease in partial irreversibility continues to stimulate investment.

Interest Rate Effects of TUCC

As an alternative general equilibrium response, we consider the possibility that interest rates increase following tax incentives for investment. To allow for this possibility, we assume that the interest rate has a negative elasticity with respect to the TUCC, ϵ_{TUCC}^r. In Table C.6.20, we conduct several robustness checks allowing ϵ_{TUCC}^r to vary between -0.25 and -0.05. While stronger interest rate responses lead to smaller effects on aggregate investment, even in the most responsive scenario, we find that the overall increase in investment is close to 80% of the baseline case that assumes a fixed interest rate. Therefore, the result that policies that target extensive margins of investment are more effective at stimulating investment is robust to allowing for interest rate responses to tax policy.

Resale Price

Our baseline model assumes that the net-of-tax resale price is the same as the net-of-tax purchase price of capital. One concern is that the capital market for used capital is imperfect and that the resale price is smaller than the purchase price even without taxes. To explore this possibility, we reduce the resale price from one (as in the baseline model) to 0.80 (e.g., Ramey and Shapiro, 2001; Cooper and Haltiwanger, 2006). As we show in column (3) of table C.6.19, the results do not change. Both the pre-reform static moments and simulated investment responses—i.e., the average investment rate and the fraction of firms investing— to various tax reforms are almost identical to our baseline results. This is because, even without the imperfect resale price of capital, the VAT and fixed cost generate considerable inaction. Hence, lowering the resale price has little impact on overall investment patterns.

Aggregate Productivity Shocks

Since the VAT reform took place in 2009 as one of the measures to deal with the financial crisis, the response to the reform may reflect a concomitant drop in aggregate productivity. To explore this possibility, we feed in a one standard-deviation drop in (permanent) aggregate productivity at the same time of the tax reform. Column (4) of Table C.6.19

reports the results of this simulation. Our results are robust to allowing for a concomitant productivity drop.

Deductible Adjustment Costs

Our baseline model assumes that adjustment costs, i.e., convex and fixed adjustment costs, are non-deductible from CIT. Put differently, the adjustment costs are paid by after-tax profits. It is possible that those costs are tax-deductible and thus paid by pre-tax profits. For instance, the fixed costs might represent costs of hiring workers to install equipment, where labor costs are tax-deductible. If this were the case, a change in the corporate income tax rate would impact the adjustment costs as well. To explore this possibility, we simulate the effects of a corporate income tax cut assuming that firms pay convex costs $(1 - \tau)\gamma^D$ and fixed costs $(1 - \tau)\xi^D$, where $\gamma^D = \frac{\hat{\gamma}}{(1-0.154)}$ is the tax-deductible convex cost, and similarly for ξ^D. In column (3) of Table C.6.21, we simulate the effects of corporate income tax cuts under this alternative assumption. Since the adjustment costs are paid by pre-tax profits, a reduction in the corporate income tax rate decreases the tax benefit and increases the effective adjustment costs. As a result, the investment response is smaller than in our baseline simulation of a corporate income tax cut.

Weighted Average Cost of Capital

Our model assumes that changes in the corporate income tax rate do not affect the cost of capital. Note that this assumption has no effect on our estimation. However, the effects of changes in the corporate income tax rate may be different if this rate affects the costs of capital.

Here, we extend the constant interest rate r by allowing the corporate income tax to impact the weighted average cost of capital (WACC). WACC considers two ways through which a firm raises capital—equity and debt. Because the cost of interest payments for debt financing, but not for equity financing, are deductible from the tax base of corporate income tax (CIT), changing the corporate income tax rate affects the cost of debt financing,

and thus how firms discount future profit. The WACC is defined as follows:

$$\text{WACC} = \text{Share}_{\text{debt}}(1-\tau)r + (1-\text{Share}_{\text{debt}})r_k,$$

where $\text{Share}_{\text{debt}}$ is the share of capital financed through debt and, accordingly, $(1-\text{Share}_{\text{debt}})$ is the share of capital financed through equity. r is the real interest rate and r_k is the capital return. In the simulation, we calibrate the share of debt financing to be 0.65 to match the average debt to capital ratio. To focus on how the policy—CIT rate here—we keep r and r_k constant and match baseline discount rate at 95%.

Column (4) in Table C.6.21 reports the simulation results allowing for interactions between the corporate income tax and the WACC. In particular, the discount rate $\beta = \frac{1}{1+\text{WACC}}$. The corporate income tax rate affects the cost of capital through two channels. First, as in our baseline simulation with constant WACC, it reduces the after-tax price of capital $\frac{(1+\nu)(1-\tau z)}{1-\tau}$. Additionally, it increases the expected return on capital, $\frac{1}{\beta} - (1-\delta)$, by reducing the discount rate β. Due to the second channel—increasing expected return of capital—which offsets the decreasing capital price, the response of investment rate is smaller. The tax revenue loss is larger since the investment increase is smaller with the same reduced tax rate. Similarly, the increase in firm value is smaller as well. As a result, the ratios of investment and firm value to tax revenue are also smaller.

C.6.2 TUCC Elasticities are Not Sufficient Statistics

To show that the TUCC is not a sufficient statistic, Table C.6.22 displays the investment responses at the intensive margin (i.e., average investment rate) and the extensive margin (i.e., the fraction of firms investing) to different reforms with the same TUCC reduction. We use the estimated frictions, i.e., $\gamma = 1.43$, $\bar{\xi} = 0.12$, to simulate tax cuts. Table C.6.22 shows the results with an initial VAT rate at 17% and a corporate income tax rate at 15.4%. We compare three reforms with the same reduction in TUCC: 1) a VAT reform that lowers the VAT distortion from 17% to 14.2% (i.e., 2.8% rate reduction), 2) a corporate income tax reform that lowers the rate from 15.4% to 5.4% (i.e., 10% rate reduction), and 3) a

partial bonus depreciation policy that allows for a 70% immediate write-off. The first three lines of Table C.6.22 describe how these policy changes all reduced the TUCC by 2.4%.

Table C.6.22 shows that, of these reforms, the corporate income tax cut has larger effects on investment, even when we include the effect on the WACC, as in the last section.[13] The VAT cut and the partial bonus depreciation have similar effects on investment. As we show in Figure 4.4 the VAT cut shrinks the inaction region, while bonus depreciation shifts the investment policy function to the left. Since we focus on this table on positive investment changes, these two reforms have similar effects on the intensive and extensive margins.[14] As this table shows, while these different reforms have the same effect on the TUCC, the fact that their effects on investment differ implies that TUCC elasticities are not sufficient statistics for the effects of different policies on investment.

Consider now the effects on tax revenue, including corporate income tax revenue and the VAT revenue collected on equipment purchases. While a 10% corporate income tax cut has a stronger effect on investment, it is far less effective than other reforms since the corporate income tax cut leads to larger decreases in tax revenue. One reason for this, is that even firms in the inaction region benefit from a lower corporate tax rate, while only firms that invest benefit from bonus depreciation or the VAT cut.[15] Relative to the VAT cut, bonus depreciation is more costly from a revenue perspective. This is due to the fact that corporate income tax revenue plays a much larger role in total tax revenue relative to the revenue generated from the lack of VAT deductibility.

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[13]One reason why the effect on investment from a corporate income tax is large in this simulation is that the fixed costs is non-deductible. Thus, the inaction region decreases as part of this reform. As we describe in the previous section, a corporate income tax cut is less effective when fixed costs are tax-deductible.

[14]In the simulated disinvestment margin, we see that bonus depreciation reduces disinvestment, while the VAT cut increases it. However, disinvestment plays a small role relative to overall investment.

[15]This effect is strengthened when we allow for the corporate income tax cut to impact the WACC in column 3.

C.6.3 Robustness of Simulated Difference-in-Differences Estimates

One advantage of our estimated model is that it allows us to examine how different assumptions and equilibrium impacts can influence difference-in-differences estimates. First, we show that our baseline simulated difference-in-differences estimates are robust to assuming that firms in the control group (i.e., foreign firms) are subject to a different prereform tax treatment and face fixed costs drawn from a different distribution. Second, we explore how allowing for an endogenous capital price response that impacts both control and treated firms affects our simulated difference-in-differences estimates.

Alternative Simulated Control Group

As we describe in the note of Table 4.8, we calculate the simulated difference-in-differences estimates by simulating two sets of firms that mirror the treatment and control groups. Initially, firms in the simulated control group face the same investment frictions as firms in the treatment group, including the value-added tax distortion on equipment purchases. The simulated reform removes this distortion on the treatment group, while the control group is unaffected.

One potential concern is that the actual control group in our reduced-form analysis, i.e., foreign firms, faced different investment frictions from the domestic firms in the treatment group. For instance, foreign firms have a higher propensity to invest, suggesting that they might face lower fixed costs. Additionally, foreign firms had been allowed to deduct the value-added tax on equipment purchase even before the 2009 reform.

To address this concern, we use an alternative control group in the structural analysis to calculate the simulated difference-in-difference estimates. To match the pre-reform investment patterns of foreign firms, we allow these firms to have a different fixed cost distribution. We calibrate $\bar{\xi}^F$ to a lower value of 0.017. Doing so implies that the simulated data on the fraction of firms with positive investment prior to the reform matches the actual data.

To match the fact that foreign firms were not subject to the VAT friction throughout our sample, we set the value-added tax rate ν at 0 and use $\bar{\xi}^F$ to simulate 10,000 firms over 200 periods, without any policy changes. This set of simulated firms mimics the foreign firms as a control group. In contrast, when we simulated the treated firms, we set the value-added tax rate ν at 17% and use our estimated value of $\bar{\xi} = 0.118$ to simulate 10,000 firms over 200 periods, with the reform taking place at the 100th period.

We then calculate our simulated difference-in-differences estimates. Specifically, we calculate the difference between domestic and foreign firms in the average fraction of firms investing (or investment rate) during the two periods prior to the reform (Δ_0) and during the three periods after the reform (Δ_1). The difference-in-difference coefficient is then $\Delta_1 - \Delta_0$. Table C.6.23 compares these coefficients using the alternative simulated control group to the baseline results. The coefficient is 0.037 at the extensive margin and 0.031 at the intensive margin, which is almost the same as our baseline result. This robustness check shows that the model is able to generate both the cross-sectional differences between domestic and foreign firms before the reform and our reduced-form estimates.

Upward-sloping Capital Supply

In our baseline model we assume that the (net of tax) capital price is constant. One concern is that the capital price may endogenously increase as investment goes up (e.g., Goolsbee, 1998). We now relax this assumption by allowing for the price of capital goods that both control and treatment firms face to be determined by an upward-sloping capital supply curve.

As in Section C.6.1, we consider the following constant elasticity capital (inverse) supply curve:

$$p^K = I^{1/\varepsilon^s},$$

where ε^s is the elasticity of capital supply with respect to pre-tax capital price. We set the elasticity ranging from 2.54 to 14, where 2.54 is based on a 56% pass-through rate in Goolsbee (1998) and 14 is the upper bound estimated in House and Shapiro (2008).

For a given value of ε_s, we find the price increase Δp^K that is consistent with the aggregate investment change, including both domestic and foreign firms, and the supply equation above. To simulate the effects of the reform, we assume that the policy function for treated firms adjusts to both the change in the VAT deductibility and the new price of capital goods. The policy function for control firms only adjusts to the equilibrium price change. This alternative simulated difference-in-differences estimate then incorporates the investment increase for domestic firms and a potential reduction in the investment of foreign firms.

Table C.6.24 shows the results of this simulation procedure for different values of ε^s. Relative to our baseline calculation (where $\varepsilon^s \to \infty$), we find that lower values of ε^s lead to larger simulated difference-in-differences estimates. This is driven partly by the fact that the investment of foreign firms decreases when capital goods prices are more sensitive. When $\varepsilon^s = 6$, we calculate that about 25% of the simulated difference-in-differences estimate is driven by the decrease in investment of foreign firms. These results show that our simulated difference-in-differences effects are close to our empirical estimates, even when we allow for endogenous effects on the price of investment goods.
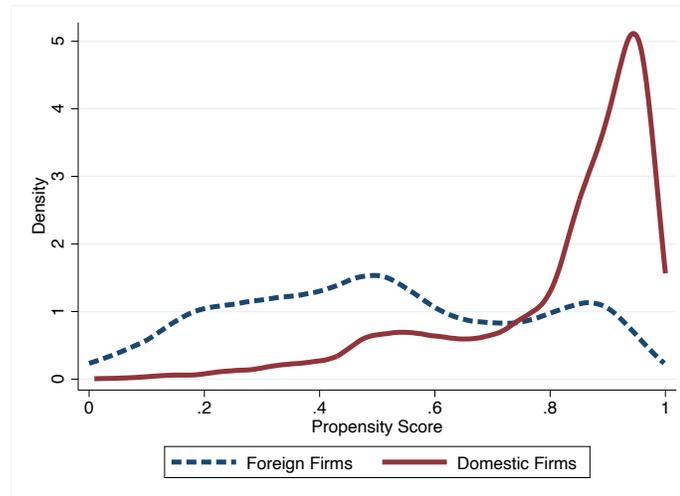
Figure C.6.1: Distribution of Propensity Score

Notes: This figure plots the distributions of estimated propensity scores for domestic firms (solid line) and foreign firms (dash line), respectively. The propensity score is estimated using a probit model (see Equation (C.14)). The estimation results are reported in column (6) in Table C.6.4. The dependent variable is an indicator $= 1$ if a firm is in the treatment group, i.e., domestic firms. The regressors include: whether a firm had VAT preferential treatment, whether a firm had export VAT preferential treatment, whether it is an exporter, sales, logarithm of the number of workers, growth in the fraction of firms investing, growth in the investment rate, growth in the log investment, and growth in the IHS measure of investment. The regression is performed using pre-reform data form 2007 and 2008. All regressions include region and industry fixed effects, and firm fixed effects.
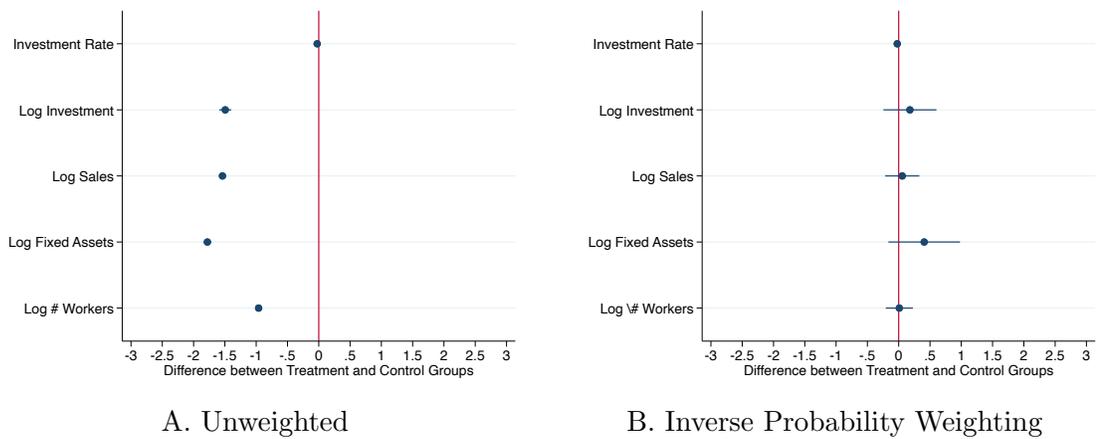
Figure C.6.2: Mean Difference between Treatment and Control Groups

Notes: This graph shows the difference in major variables between the treatment group (i.e., domestic firms) and control group (i.e., foreign firms). The left panel shows the differences before weighting; The right panel shows the differences using inverse probability weighting (IPW). The propensity score is estimated using probit model (see Equation (C.14)). The estimation results are reported in column (6) in Table C.6.4.
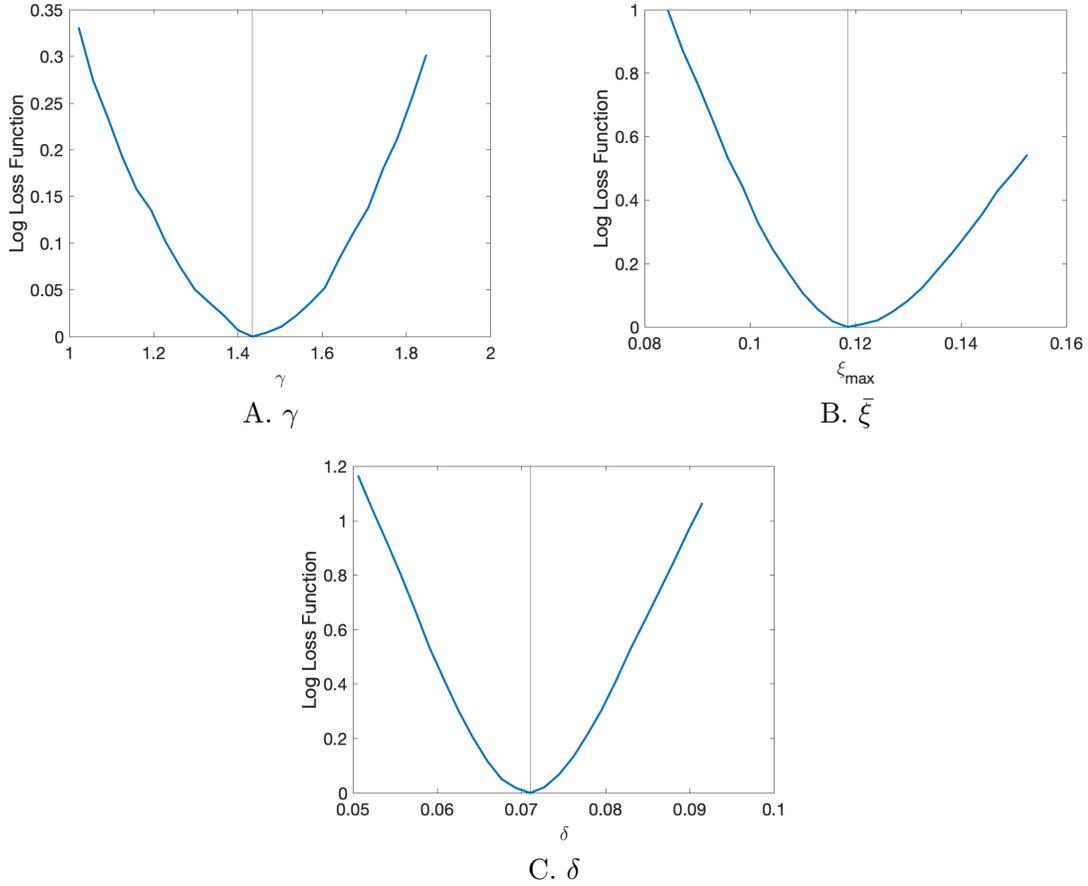
Figure C.6.3: Loss Function from Structural Estimation

Notes: This graph displays the loss function against each parameter, holding the other two parameters at optimal values. The loss function is calculated by:

$$g(\phi) = [\hat{m} - m(\phi)]'\hat{W}[\hat{m} - m(\phi)],$$

where the moments $m(\phi)$ include six pre-reform static moments, as well as two investment responses from reduced-form analysis (see Section 4.5.2). We use the identity matrix as the weighting matrix. Panel A plots log loss function against values of γ, holding $\bar{\xi}$ and δ at their optimal values. The vertical line indicates the estimated $\gamma = 1.434$. Panel B and C plot the log loss function against $\bar{\xi}$ and δ, respectively.
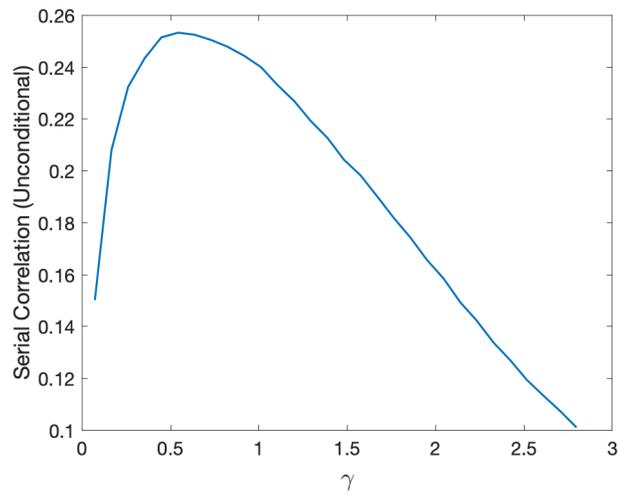
Figure C.6.4: Correlation between Serial Correlation and Convex Adjustment Cost γ

Notes: This graph plots simulated serial correlations against convex cost γ, holding the other two parameters at their estimated values, i.e., fixed cost $\bar{\xi} = 0.118$ and depreciation rate $\delta = 0.710$.

A.I Direct Tax Losses   A.II Tax Revenues from Behavioral Responses

A. VAT Cuts vs. Corporate Income Tax Cuts

B.I Direct Tax Losses   B.II Tax Revenues from Behavioral Responses

B. VAT Cuts vs. Investment Tax Credit
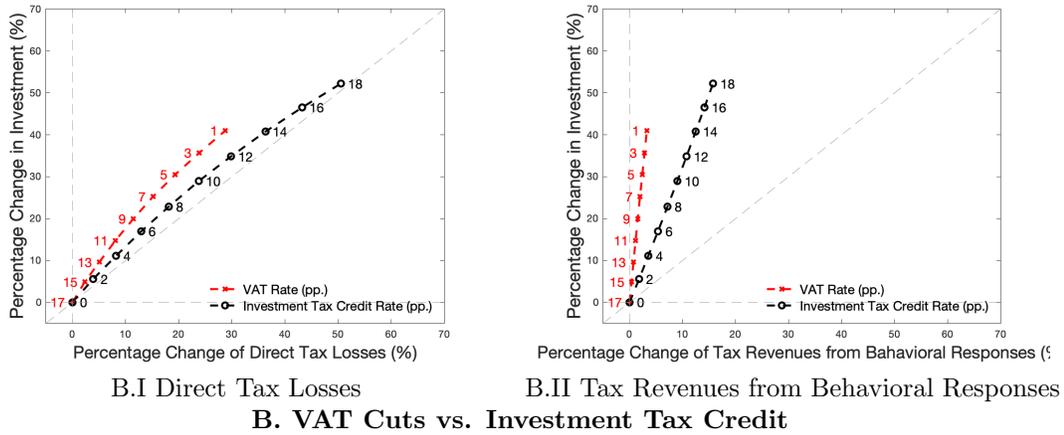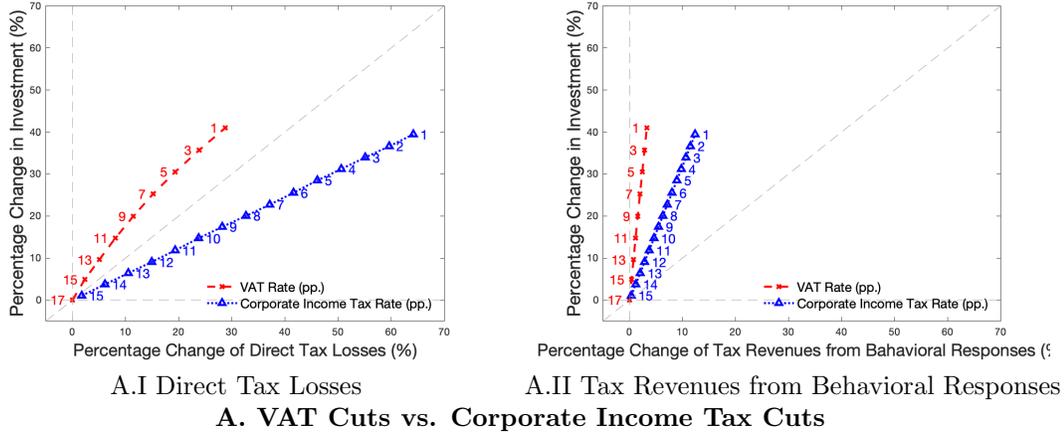
Figure C.6.5: Decomposition of Percentage Change in Tax Revenues

Notes: These figures plot the simulated percentage change in aggregate investment to the change in direct tax losses and tax revenues from additional investment at different rates of VAT cut, corporate income tax cut and investment tax credit policies. For each tax rate, we solve the model, simulate investment and tax revenue, and calculate the corresponding changes in each outcome. Panel A.I plots the percentage change in aggregate investment against the change in VAT revenue and corporate income tax revenue for VAT and corporate income tax cuts, respectively. Changes in tax revenues are scaled by total tax revenue without any policies. The red solid curve corresponds to VAT cuts from 17% to different rates. The blue dotted line corresponds to corporate income tax cuts from 15.4% to different rates. Panel A.II plots the percentage change in aggregate investment against additional corporate income tax revenue and VAT revenue tax revenue from increased investment for VAT and corporate income tax cuts, respectively. Similarly, Panel B decomposes the change in tax revenue for VAT cuts and investment tax credit policies.
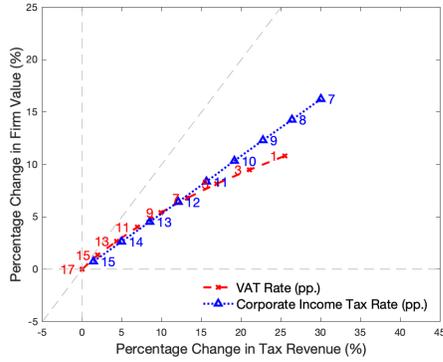
A. VAT Cuts vs. Corporate Income Tax Cuts
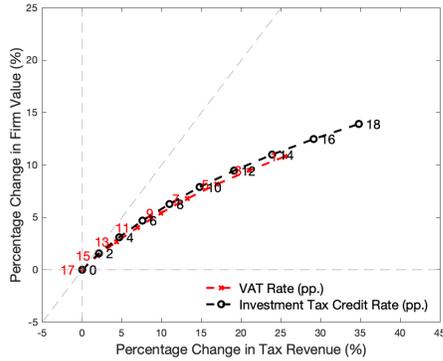
B. VAT Cuts vs. Investment Tax Credit

Figure C.6.6: Simulating Alternative Tax Reforms: Elasticity of Firm Value to Tax Revenue

Notes: These figures plot the simulated percentage change in the average firm value to the percentage loss in tax revenue at different rates of VAT cut, corporate income tax cut and investment tax credit policies. For each tax rate, we solve the model; simulate investment, tax revenue and firm value; and calculate the corresponding changes in each outcome. Panel A plots the percentage change in the average firm value against the percentage change in tax revenue. The red solid curve corresponds to VAT cuts from 17% to different rates. The blue dotted line corresponds to corporate income tax cuts from 15.4% to different rates. Similarly, Panel B compares the percentage change in tax revenue from VAT cuts with that from an investment tax credit .

Table C.6.1: Changes in Tax Rate, Theoretical and Effective User Cost of Capital

Year	Corporate Income Tax (%)	VAT (%)	User Cost of Capital		
			Theoretical	Sample Avg.	#Obs
	(1)	(2)	(3)	(4)	(5)
A. Domestic Firms					
2007	33	17	1.284	1.222	30,789
2008	25	17	1.247	1.233	44,893
2009	25	0	1.066	1.042	53,580
2010	25	0	1.066	1.037	56,579
2011	25	0	1.066	1.040	56,955
B. Foreign Firms					
2007	20	0	1.049	1.023	15,984
2008	25	0	1.066	1.038	16,842
2009	25	0	1.066	1.035	20,394
2010	25	0	1.066	1.038	20,596
2011	25	0	1.066	1.044	20,555

Notes: This table displays summary statistics of user cost of capital (TUCC) of domestic and foreign firms, respectively. TUCC is calculated by $TUCC = (1 + \nu)(1 - \tau z)/(1 - \tau)$, where ν is VAT rate, τ is the corporate income tax rate, $z = 0.803$ is discounted present value of capital depreciation schedule. Column (1) and (2) report the statutory rates of corporate income tax and VAT for domestic and foreign firms, respectively. Theoretical TUCC is calculated using statutory VAT and corporate income tax rates. Sample average refers to the average TUCC in tax data, which is calculated using statutory VAT rate but empirical corporate income tax rate. The sample average statistics are calculated using full balanced panel, i.e., firms existing for five years in the sample. Empirical corporate income tax rate is calculated by τ = actual corporate income tax payable/net profit, which is closer to the "effective" corporate income tax rate.

Table C.6.2: Matching Tax Data and Foreign Direct Investment Records

	Matched			Not Matched		
	mean	sd	count	mean	sd	count
Equipment Investment (million RMB)	6.83	19.16	58,049	5.96	17.01	12,033
Equipment Investment Rate	0.10	0.15	57,550	0.10	0.16	11,830
Log Equipment Investment	7.16	2.33	41,396	7.14	2.30	8,304
Total Investment (million RMB)	8.52	23.95	74,597	7.47	21.22	14,937
Sales (million RMB)	266.51	573.50	86,062	239.45	493.45	17,152
Fixed Assets (million RMB)	62.70	137.61	85,522	57.81	127.71	16,991
Cash Inflow (million RMB)	271.18	598.48	82,667	240.98	512.61	16,359
Debt (million RMB)	131.63	305.24	85,809	125.56	273.52	17,091

Notes: This table presents summary statistics of equipment investment and other variables for foreign firms from the tax data. The first three columns correspond to foreign firms that are matched to the foreign direct investment records. The last three columns correspond to firms that are not matched. Investment is reported in million RMB and deflated by the national price index of equipment investment. The investment rate is defined as the ratio of investment to the capital stock measured in terms of the book value of net fixed assets, unconditional on investing. Total investment includes investments in equipment, buildings and structures, and other productive capital. Sales are the total sales including domestic and export sales. Fixed assets are measured in terms of the book value, deflated by the national price index of fixed-asset investment. Cash flow is the business cash inflow from the cash-flow statement. Debt is the total debt at the end of the year. Variables are winsorized at the 1% level.

Table C.6.3: Matching Tax Data and Annual Survey of Manufacturing (ASM)

	Matched			Not Matched		
	mean	sd	count	mean	sd	count
Equipment Investment (million RMB)	5.05	15.97	132,596	2.46	11.81	139,641
Equipment Investment Rate	0.10	0.16	131,266	0.11	0.21	135,164
Log Equipment Investment	7.03	2.18	88,787	6.06	2.39	65,842
Total Investment (million RMB)	6.91	20.96	161,131	3.64	16.11	162,878
Sales (million RMB)	214.73	481.48	186,046	98.15	350.97	204,201
Fixed Assets (million RMB)	51.87	120.90	184,792	25.09	93.39	200,303
Cash Inflow (million RMB)	215.96	512.33	171,660	94.69	364.67	184,646
Debt (million RMB)	126.37	285.07	185,502	60.94	218.47	202,968

Notes: This table presents summary statistics of equipment investment and other variables from the tax data. The first three columns correspond to firms that are matched to the Annual Survey of Manufacturing (ASM). The last three columns correspond to firms that are not matched to the ASM. Investment is reported in million RMB and deflated by the national price index of equipment investment. The investment rate is defined as the ratio of investment to the capital stock measured in terms of the book value of net fixed assets, unconditional on investing. Total investment includes investments in equipment, buildings and structures, and other productive capital. Sales are the total sales including domestic and export sales. Fixed assets are measured in terms of the book value, deflated by the national price index of fixed-asset investment. Cash flow is the business cash inflow from the cash-flow statement. Debt is the total debt at the end of the year. Variables are winsorized at the 1% level.

Table C.6.4: Estimates of Probit Model of Propensity Score

	(1)	(2)	(3)	(4)	(5)	(6)
Had VAT PT	0.112***	0.106**	0.116***	0.131*	0.119***	0.107**
	(0.020)	(0.044)	(0.038)	(0.067)	(0.037)	(0.046)
Had Export VAT PT	-0.797***	-0.896***	-0.902***	-0.770***	-0.925***	-0.865***
	(0.042)	(0.094)	(0.085)	(0.130)	(0.083)	(0.097)
Exporter	-1.004***	-0.287**	-0.309***	-0.373**	-0.280***	-0.329***
	(0.250)	(0.112)	(0.100)	(0.157)	(0.098)	(0.115)
Sales	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log Workers	-0.375***	-0.545***	-0.653***	-0.356***	-0.547***	-0.652***
	(0.024)	(0.045)	(0.050)	(0.101)	(0.045)	(0.050)
% Firms Investing Growth		-0.267				3.179
		(0.346)				(2.063)
Investment Rate Growth			-0.272			-1.065**
			(0.358)			(0.496)
Log Investment Growth				-0.020		
				(0.099)		
IHS Investment Growth					0.023	0.103*
					(0.019)	(0.058)
#Obs	77,939	21,433	20,172	5,836	21,423	20,170
Industry FE	Y	Y	Y	Y	Y	Y
Region FE	Y	Y	Y	Y	Y	Y

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table displays probit regression results for the propensity score estimation in Equation (C.14). The dependent variable is an indicator $= 1$ if a firm is in the treatment group. The variables on the right hand side include: whether a firm had VAT preferential treatment, whether a firm had export VAT preferential treatment, whether it is an exporter, sales, logarithm of the number of workers, growth in the fraction of firms investing, growth in the investment rate, growth in the log investment, and growth in the IHS measure of investment. The regression is performed using pre-reform data form 2007 and 2008. All regressions include region and industry fixed effects, and firm fixed effects. Standard errors are clustered at the firm level.

<div align="center">**Table C.6.5**: Estimates of Event Study</div>

	Extensive Margin			Investment Rate		
	(1)	(2)	(3)	(4)	(5)	(6)
2007	0.006	0.004	0.011	-0.000	-0.007	-0.005
	(0.013)	(0.014)	(0.014)	(0.006)	(0.006)	(0.006)
2008	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)
2009	0.069***	0.045***	0.055***	0.044***	0.043***	0.043***
	(0.013)	(0.013)	(0.013)	(0.005)	(0.005)	(0.005)
2010	0.051***	0.047***	0.050***	0.034***	0.032***	0.035***
	(0.014)	(0.015)	(0.015)	(0.005)	(0.005)	(0.006)
2011	0.064***	0.044***	0.049***	0.029***	0.027***	0.028***
	(0.014)	(0.015)	(0.015)	(0.006)	(0.006)	(0.006)
N	86870	86870	86870	81270	81270	81270
N_{firms}	17374	17374	17374	16254	16254	16254
Industry × Year FE	Y		Y	Y		Y
Province × Year FE		Y	Y		Y	Y

Notes: This table uses tax data to estimate event study regressions of the form:

$$Y_{it} = G_i \times \gamma_t + \mu_i + \delta_{jt} + \eta_{st} + \varepsilon_{it},$$

where G_i is the treatment indicator set to 1 for domestic firms and 0 for foreign firms, μ_i is firm fixed effect, δ_{jt} and η_{st} are industry-year and province-year fixed effects, respectively. Dependent variable Y_{it} is the investment measure for firm i at time t: Column (1) to (3) report the estimated γ_t ($t = 2007, \cdots, 2011$) at the extensive margin—i.e., the fraction of firms investing; Column (4) to (6) report the results at the intensive margin—i.e., investment rate. In column (1) and (3) we control for industry-year fixed effects; in column (2) and (5) we control for province-year fixed effects; in column (3) and (6) we add both industry- and province-year fixed effects. All regressions include firm fixed effects. Standard errors are clustered at the firm level.

Table C.6.6: Event Study: Robustness Checks

	Extensive Margin			Investment Rate		
	Baseline	IPW	Unbalanced	Baseline	IPW	Unbalanced
	(1)	(2)	(3)	(4)	(5)	(6)
2007	0.006	0.044	-0.001	-0.000	0.012	-0.003
	(0.013)	(0.028)	(0.011)	(0.006)	(0.011)	(0.005)
2008	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)
2009	0.069***	0.108***	0.058***	0.044***	0.045***	0.046***
	(0.013)	(0.026)	(0.010)	(0.005)	(0.009)	(0.004)
2010	0.051***	0.092***	0.058***	0.034***	0.032***	0.039***
	(0.014)	(0.032)	(0.010)	(0.005)	(0.011)	(0.004)
2011	0.064***	0.091**	0.059***	0.029***	0.030**	0.032***
	(0.014)	(0.045)	(0.010)	(0.006)	(0.013)	(0.004)
N	86870	82785	221069	81270	79195	215813
N_{firms}	17374	16557	60870	16254	15839	60513
Industry × Year FE	Y	Y	Y	Y	Y	Y

Notes: This table uses tax data to conduct robustness checks for the event study regressions of the form:

$$Y_{it} = G_i \times \gamma_t + \mu_i + \delta_{jt} + \eta_{st} + \varepsilon_{it},$$

where G_i is the treatment indicator set to 1 for domestic firms and 0 for foreign firms, μ_i is firm fixed effect, δ_{jt} and η_{st} are industry-year and province-year fixed effects, respectively. Dependent variable Y_{it} is the investment measure for firm i at time t: Column (1) to (3) report the estimated γ_t ($t = 2007, \cdots, 2011$) at the extensive margin—i.e., the fraction of firms investing; Column (4) to (6) report the results at the intensive margin—i.e., investment rate. We report the baseline results (column (1) and (4)) In column (2) and (5) we adjust the regressions by inverse probability weighting (IPW, see Section C.4.1). In column (3) and (6) we use the unbalanced sample for the analysis (i.e., unbalanced at the variable level but balanced at the firm level). All regressions include industry-year fixed effects and firm fixed effects. Standard errors are clustered at the firm level.

Table C.6.7: Estimates of Difference-in-Difference Regressions:Robustness To 4 Trillion Yuan Package

	Extensive Margin: % Firms			Intensive Margin: Investment Rate		
	Baseline	Food and Textile-related Industries	Exclude Sichuan Province	Baseline	Food and Textile-related Industries	Exclude Sichuan Province
	(1)	(2)	(3)	(4)	(5)	(6)
Domestic × Post	0.046***	0.071***	0.045***	0.038***	0.030***	0.038***
	(0.010)	(0.025)	(0.010)	(0.004)	(0.008)	(0.004)
N	86870	16469	85140	81270	15452	79650
Industry × Year FE	Y	Y	Y	Y	Y	Y
Province × Year FE	Y	Y	Y	Y	Y	Y

Notes: This table estimate regressions of the form:

$$Y_{it} = \gamma G_i \times Post_t + \mu_i + \delta_{jt} + \eta_{st}\varepsilon_{it},$$

where Y_{it} is equipment investment, G_i is an indicator set to 1 for domestic firms and 0 to foreign firms, respectively, and $Post_t$ is the post-reform indicator set to 1 for years since 2009. μ_i is firm fixed effect, δ_{jt} and η_{st} are industry-year and province-year fixed effects, respectively. The dependent variable for column (1)–(3) is a dummy variable set to 1 if a firm makes positive investment. The dependent variable for column (4)–(6) is firm's investment rate. For comparison, Column (1) and (4) report the baseline estimates from difference-in-difference regressions. We split the sample by firms' exposure to the 4 trillion yuan package. Column (2) and (5) estimate the regressions for firms in industries whose demand were less affected by the package, including Food processing (13), Food manufacturing (14), Drink manufacturing (15), Tobacco manufacturing (16), Textile (17), Textile clothes, shoes and hats manufacturing (18), Leather, fur, feather and their product manufacturing (19). Column (3) and (6) estimate the regressions excluding firms in Sichuan province where Wenchuan earthquake took place. All regressions include firm fixed effects. Standard errors are clustered at the firm level.

Table C.6.8: Robustness Check: Investment Including Leasing

	Extensive Margin			Investment Rate		
	(1)	(2)	(3)	(4)	(5)	(6)
Domestic × Post	0.059***	0.044***	0.046***	0.036***	0.038***	0.039***
	(0.010)	(0.010)	(0.010)	(0.004)	(0.004)	(0.004)
N	86870	86870	86870	81270	81270	81270
N_{firm}	17374	17374	17374	16254	16254	16254
Industry × Year FE	Y		Y	Y		Y
Province × Year FE		Y	Y		Y	Y

Notes: This table uses tax data to estimate difference-in-difference regressions of the form:

$$Y_{it} = \gamma G_i \times Post_t + \mu_i + \delta_{jt} + +\eta_{st} + \varepsilon_{it},$$

where Y_{it} is a measure of investment including leasing, G_i is an indicator set to 1 for domestic firms and 0 for foreign firms, and $Post_t$ is the post-reform indicator set to 1 for years since 2009. μ_i is firm fixed effect, δ_{jt} and η_{st} are industry-year and province-year fixed effects, respectively. We construct an alternative investment measure to include leased equipment. The dependent variable for column (1) to (3) is a dummy variable set to 1 if the leasing-included investment rate is positive. The dependent variable for column (4) to (6) is leasing-included investment rate. Column (1) and (4) control for industry-year fixed effects. Column (2) and (5) control for province-year fixed effects. Column (3) and (6) include both fixed effects. All regressions include firm fixed effects. Standard errors are clustered at the firm level.

Table C.6.9: Extensive Margin Responses of Investment in Structures

	% Firms Investing with Investment Rate			
	$\geq 1\%$	$\geq 2\%$	$\geq 3\%$	$\geq 20\%$
	(1)	(2)	(3)	(4)
Domestic $\times$ Post	0.028**	0.020*	0.017	0.001
	(0.011)	(0.011)	(0.010)	(0.007)
Domestic $\times$ Equipment $\times$ Post	0.036**	0.056***	0.077***	0.065***
	(0.015)	(0.015)	(0.015)	(0.011)
N	162540	162540	162540	162540
N_{firm}	16254	16254	16254	16254
Industry $\times$ Year FE	Y	Y	Y	Y
Province $\times$ Year FE	Y	Y	Y	Y

Notes: This table uses tax data to estimate triple-differences regressions of the form:

$$Y_{kit} = \gamma_1 G_i \times Post_t + \gamma_2 A_k \times Post_t + \gamma_3 G_i \times A_k \times Post_t + \gamma_4 G_i \times A_k + \mu_i + \delta_{jt} + \eta_{st} + \varepsilon_{ijt},$$

where k denotes the type of investment, i.e. equipment and structures. A_k is an indicator set to 1 for investment in equipment and 0 for investment in structures. Y_{it} is a dummy variable that is set to 1 if the investment rate is larger than a certain threshold specified in the column header. For instance, the dependent variable for column (2) is a dummy variable set to 1 if the investment rate is larger than 0.5%, i.e. $D_{ik} = \mathbb{1}\{IK_{it} \geq 0.005\}$, where IK_{it} is the investment rate of firm i at time t. G_i is an indicator set to 1 for domestic firms and 0 for foreign firms, and $Post_t$ is the post-reform indicator set to 1 for years since 2009. All regressions include firm fixed effects, industry-year and province-year fixed effects. Standard errors are clustered at the firm level.

Table C.6.10: Estimates of Difference-in-Difference Regressions: TUCC

	TUCC			Log TUCC		
	(1)	(2)	(3)	(4)	(5)	(6)
Domestic × Post	-0.193***	-0.194***	-0.194***	-0.171***	-0.171***	-0.171***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
N	77677	77677	77677	77677	77677	77677
N_{firm}	17371	17371	17371	17371	17371	17371
Industry × Year FE	Y			Y	Y		Y
Province × Year FE		Y	Y		Y	Y

Notes: This table estimates difference-in-difference regressions of the form:

$$Y_{it} = \gamma G_i \times Post_t + \mu_i + \delta_{jt} + \eta_{st} + \varepsilon_{ijt},$$

where Y_{it} is the user cost of capital (TUCC), G_i is the treatment indicator set to 1 for domestic firms and 0 for foreign firms, and $Post_t$ is the post-reform indicator set to 1 for years since 2009. μ_i is firm fixed effect, δ_{jt} and η_{st} are industry-year and province-year fixed effects, respectively. Particularly, the dependent variable for column (1) to (3) is $TUCC = (1 + \nu)(1 - \tau z)/(1 - \tau)$ where ν is the statutory VAT rate, τ is the empirical corporate income tax rate, and z is the discounted present value of capital depreciation schedule. The dependent variable for column (4) to (6) is the logarithm of TUCC. Column (1) and (4) control for industry-year fixed effects. Column (2) and (5) control for province-year fixed effects. Column (3) and (6) include both fixed effects. All regressions include firm fixed effects. Standard errors are clustered at the firm level.

Table C.6.11: TUCC Semi-Elasticity Regressions Results

	OLS	IV						
	Year FE	Year FE	Industry-Year FE	Province-Year FE	Both FE	Cash Flow	Firm Controls	Corporate Rate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Dependent Variable: Dummy Variable if Firms Investing								
log TUCC	-0.055*	-0.317***	-0.318***	-0.262***	-0.266***	-0.238***	-0.260***	-0.292***
	(0.031)	(0.058)	(0.060)	(0.061)	(0.063)	(0.064)	(0.063)	(0.085)
N	77677	77661	77661	77661	77661	74959	77265	77661
Panel B. Dependent Variable: Investment Rate								
log TUCC	-0.056***	-0.197***	-0.207***	-0.213***	-0.218***	-0.215***	-0.199***	-0.235***
	(0.013)	(0.023)	(0.023)	(0.024)	(0.025)	(0.025)	(0.025)	(0.035)
N	73115	73102	73102	73102	73102	71731	72743	73102
Panel C. Dependent Variable: Log Investment								
log TUCC	-0.945***	-2.399***	-2.399***	-2.191***	-2.223***	-2.231***	-2.129***	-2.155***
	(0.193)	(0.291)	(0.302)	(0.314)	(0.322)	(0.329)	(0.319)	(0.465)
N	19607	19607	19606	19604	19603	19164	19594	19603
Panel D. Dependent Variable: IHS Investment								
log TUCC	-0.883***	-4.145***	-4.185***	-3.876***	-3.913***	-3.710***	-3.750***	-3.415***
	(0.232)	(0.498)	(0.511)	(0.523)	(0.532)	(0.539)	(0.530)	(0.715)
N	77677	77661	77661	77661	77661	74959	77265	77661

Notes: This table uses tax data to estimate (semi-)elasticity regression of the form:

$$Y_{it} = \beta \log(\text{TUCC}_{it}) + \mu_i + \delta_{jt} + X'_{it}\gamma + \varepsilon_{it},$$

where TUCC_{it} is the user cost of capital of firm i at time t. The dependent variables are an indicator of positive investment, investment rate, log investment and IHS measure of investment that are reported in Panel A to D, respectively. Column (1) uses OLS estimator. Column (2) to (8) uses theoretical TUCC as instrument, where theoretical TUCC is calculated by statutory tax rates. Column (1) and (2) controls for year fixed effects. Column (2) controls for industry-year fixed effects. Column (4) controls for province-year fixed effects. Column (5) to (8) add both industry- and province-year fixed effects. Column (6) controls for firm's cash flow (scaled by fixed assets). Column (7) controls for fourth-order polynomials of sales, profit margin (=profit/revenue) and age. Column (8) controls for statutory corporate income tax rate. All regressions include firm fixed effects. Standard errors are clustered at the firm level.

Table C.6.12: TUCC Regressions Results

	OLS	IV						
	Year FE	Year FE	Industry-Year FE	Province-Year FE	Both FE	Cash Flow	Firm Controls	Corporate Rate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Dependent Variable: Dummy Variable if Firms Investing								
TUCC	-0.048*	-0.281***	-0.281***	-0.232***	-0.235***	-0.210***	-0.230***	-0.257***
	(0.026)	(0.051)	(0.053)	(0.054)	(0.056)	(0.057)	(0.056)	(0.075)
N	77677	77661	77661	77661	77661	74959	77265	77661
Panel B. Dependent Variable: Investment Rate								
TUCC	-0.047***	-0.174***	-0.183***	-0.188***	-0.193***	-0.190***	-0.176***	-0.207***
	(0.011)	(0.020)	(0.021)	(0.021)	(0.022)	(0.022)	(0.022)	(0.031)
N	73115	73102	73102	73102	73102	71731	72743	73102
Panel C. Dependent Variable: Log Investment								
TUCC	-0.800***	-2.117***	-2.116***	-1.933***	-1.960***	-1.968***	-1.878***	-1.890***
	(0.164)	(0.257)	(0.266)	(0.276)	(0.284)	(0.290)	(0.281)	(0.407)
N	19607	19607	19606	19604	19603	19164	19594	19603
Panel D. Dependent Variable: IHS Investment								
TUCC	-0.754***	-3.678***	-3.710***	-3.433***	-3.464***	-3.286***	-3.319***	-3.003***
	(0.192)	(0.442)	(0.454)	(0.463)	(0.471)	(0.477)	(0.469)	(0.627)
N	77677	77661	77661	77661	77661	74959	77265	77661

Notes: This table uses tax data to estimate regressions of the form:

$$Y_{it} = \beta \text{TUCC}_{it} + \mu_i + \delta_{jt} + X'_{it}\gamma + \varepsilon_{it},$$

where TUCC_{it} is the user cost of capital of firm i at time t. The dependent variables are an indicator of positive investment, investment rate, log investment and IHS measure of investment that are reported in Panel A to D, respectively. Column (1) uses OLS estimator. Column (2) to (8) uses theoretical TUCC as instrument, where theoretical TUCC is calculated by statutory tax rates. Column (1) and (2) controls for year fixed effects. Column (2) controls for industry-year fixed effects. Column (4) controls for province-year fixed effects. Column (5) to (8) add both industry- and province-year fixed effects. Column (6) controls for firm's cash flow (scaled by fixed assets). Column (7) controls for fourth-order polynomials of sales, profit margin (=profit/revenue) and age. Column (8) controls for statutory corporate income tax rate. All regressions include firm fixed effects. Standard errors are clustered at the firm level.

Table C.6.13: Estimates of Difference-in-Difference Regressions: External Finance Dependence

	Extensive Margin		Investment Spikes		Intensive Margin	
	(1)	(2)	(3)	(4)	(5)	(6)
Domestic × Post	0.044***	0.044***	0.071***	0.070***	0.037***	0.037***
	(0.010)	(0.010)	(0.009)	(0.010)	(0.004)	(0.004)
Domestic × Post × EFD		0.005		-0.002		-0.004***
		(0.003)		(0.003)		(0.002)
N	86870	86870	81270	81270	81270	81270
Industry × Year FE						
Province × Year FE	Y	Y	Y	Y	Y	Y

Notes: This table shows the heterogeneous responses by industry's external finance dependence, by using tax data to estimate regressions of the form:

$$Y_{it} = \gamma_1 G_i \times Post_t + \gamma_2 G_i \times Post_t \times EFD_j + \mu_i + \eta_{st}\varepsilon_{it},$$

where Y_{it} is equipment investment, G_i is an indicator set to 1 for domestic firms and 0 to foreign firms, respectively, and $Post_t$ is the post-reform indicator set to 1 for years since 2009. EFD_j is the external finance dependence index of industry j from Hsu et al. (2014) that measures the industry-level dependence on external finance. μ_i is firm fixed effect, and η_{st} is province-year fixed effect. For comparison, Column (1), (3) and (5) report the baseline estimates from difference-in-difference regressions. The dependent variable for column (1) and (2) is a dummy variable set to 1 if a firm makes positive investment. The dependent variable for column (3) and (4) is a dummy variable set to 1 if the investment rate is larger than 0.2. The dependent variable for column (5) and (6) is firm's investment rate. All regressions include firm fixed effects. Standard errors are clustered at the firm level.

Table C.6.14: Estimates of Difference-in-Difference Regressions: VAT Refundability

	Extensive Margin: % Firms Investing			Intensive Margin: Investment Rate		
	All Firms	No VAT Credit	Positive VAT Credit	All Firms	No VAT Credit	Positive VAT Credit
	(1)	(2)	(3)	(4)	(5)	(6)
Domestic × Post	0.043***	0.065***	-0.009	0.034***	0.040***	0.019**
	(0.010)	(0.013)	(0.024)	(0.004)	(0.006)	(0.008)
N	82880	66309	11145	79098	63142	10781
P-val of difference			0.00			0.00
Firm Controls	Y	Y	Y	Y	Y	Y
Industry × Year FE	Y	Y	Y	Y	Y	Y
Province × Year FE	Y	Y	Y	Y	Y	Y

Notes: This table uses tax data to estimate difference-in-difference regressions of the form:

$$Y_{it} = \gamma G_i \times Post_t + \mu_i + \delta_{jt} + \eta_{st} + X'_{it}\beta + \varepsilon_{ijt},$$

where Y_{it} is equipment investment, G_i is the treatment indicator set to 1 for domestic firms and 0 for foreign firms, and $Post_t$ is the post-reform indicator set to 1 for years since 2009. μ_i is the firm fixed effect. δ_{jt} and η_{st} are industry-year and province-year fixed effects, respectively. We conduct the analysis separately for three sets of firms depending on their tax position. A firm is said to be in a positive tax position if it has a positive potential VAT credit. Particularly, the VAT credit of firm i at time $t =$ InputVAT$_{it}$ − OutputVAT$_{it}$ + Credit$_{i,t-1}$ for domestic firms prior the reform and = InputVAT$_{it}$ − OutputVAT$_{it}$ + Credit$_{i,t-1}$ − 17% × I_{it} otherwise (i.e., foreign firms prior the reform or all firms after the reform). We report results in columns (1) and (4) using all firms; in columns (2) and (5) using firms with no VAT credit; and in columns (3) and (6) using firms with positive VAT credits. The dependent variable for columns (1)–(3) is a dummy variable set to 1 if a firm makes a positive investment, i.e., $D_{it} = \mathbb{1}\{IK_{it} > 0\}$, where IK_{it} is the investment rate of firm i at time t. The dependent variable for columns (4) to (6) is the investment rate IK_{it}. All regressions include firm controls (i.e., net cash flow scaled by capital stock and quadratics in sales, profit margin, and age), firm fixed effects, and industry-year and province-year fixed effects. Standard errors are clustered at the firm level.

Table C.6.15: Estimates of Difference-in-Difference Regressions: Redeployability

	Extensive Margin		Investment Spikes		Intensive Margin	
	(1)	(2)	(3)	(4)	(5)	(6)
Domestic × Post	0.044***	0.044***	0.071***	0.071***	0.037***	0.037***
	(0.010)	(0.010)	(0.009)	(0.009)	(0.004)	(0.004)
Domestic × Post × Redeployability		0.005		0.005*		0.003**
		(0.003)		(0.003)		(0.001)
N	86870	86870	81270	81270	81270	81270
Province × Year FE	Y	Y	Y	Y	Y	Y

Notes: This table shows the heterogeneous responses according to industry irreversibility. We use tax data to estimate regressions of the form:

$$Y_{it} = \gamma_1 G_i \times Post_t + \gamma_2 G_i \times Post_t \times Redeployability_j + \mu_i + \eta_{st} + \varepsilon_{ijt},$$

where Y_{it} is equipment investment, G_i is the treatment indicator set to 1 for domestic firms and 0 for foreign firms, and $Post_t$ is the post-reform indicator set to 1 for years since 2009. $Redeployability_j$ is the redeployability index of industry j from Kim and Kung (2017), which measures industry-level irreversibility. μ_i is the firm fixed effect, and η_{st} is the province-year fixed effect. For comparison, columns (1), (3) and (5) report the baseline estimates from difference-in-difference regressions. The dependent variable for columns (1) and (2) is a dummy variable set to 1 if a firm makes a positive investment. The dependent variable for columns (3) and (4) is a dummy variable set to 1 if the investment rate is larger than 0.2. The dependent variable for columns (5) and (6) is the firm's investment rate. All regressions include firm fixed effects. Standard errors are clustered at the firm level.

Table C.6.16: Sensitivity Analysis of Structural Moments

Moments	10% Change		
	γ	$\bar{\xi}$	δ
Pre-Reform Static Moments			
Avg. Investment Rate	-0.0060	0.0007	0.0005
Share<0.1	-0.5459	0.0213	-0.0064
Share<0.2	-0.1469	-0.0015	-0.0098
Share<0.3	0.4908	-0.0324	-0.0109
Serial Correlation	-0.0591	-0.0057	0.0002
SD. Investment Rate	-0.0722	0.0047	0.0013
Reduced-Form Investment Responses			
Extensive DID	-0.0192	-0.0000	-0.0001
Intensive DID	-0.0106	0.0002	0.0000

Notes: This table displays sensitivity matrix:

$$\Lambda = -(G'WG)^{-1}G'W \times g(m),$$

where G is the Jacobian matrix, W is the weighting matrix (identity matrix here), and $g(m)$ is a vector of moments with misspecification. Here, we consider the misspecification to be a 10% deviation from the moment value.

Table C.6.17: Structural Estimation and Reduced-Form Moments of Investment Spikes

	Extensive Margin % Firms Investing with $IK > 0.2$ (1)	Intensive Margin Spike Investment Rate (2)
Data	0.073	0.035
Model	0.058	0.033

Notes: This table displays additional reduced-form moments regarding investment spike, complementing Table 4.8. The first row reports difference-in-difference estimates of investment spike responses (column (3) and (6) in Table 4.6). The extensive margin refers to the fraction of firms whose investment rate is larger than 0.2, i.e., $\mathbb{1}\{IK_{it} \geq 0.2\}$ where IK_{it} is the investment rate of firm i at time t. The intensive margin refers to the spike investment rate, i.e., $IK_{it}^{spike} = IK_{it} \times \mathbb{1}\{IK_{it} \geq 0.2\}$. The second row reports model simulated responses of investment spikes. We use the estimated frictions, i.e., $\gamma = 1.434$, $\bar{\xi} = 0.118$, for the simulation.

Table C.6.18: Robustness of Simulating 17% VAT Cut: Upward-Sloping Capital Supply

Percentage Change in	Elasticity of Capital Supply				
	Infinity (Baseline) (1)	2.54 (2)	6 (3)	10 (4)	14 (5)
Capital Price	0	0.095	0.049	0.032	0.023
Aggregate Investment	0.434	0.187	0.308	0.352	0.375
Fraction of Firms Investing	0.098	0.063	0.084	0.090	0.093
Tax Revenue	-0.279	-0.280	-0.279	-0.279	-0.279
Firm Value	0.114	0.050	0.082	0.093	0.099
Ratio of Investment to Tax Revenue	1.559	0.666	1.104	1.262	1.346
Ratio of Firm Value to Tax Revenue	0.410	0.178	0.293	0.335	0.356

Notes: This table displays simulation results for the baseline policy reform—17% VAT cut—assuming the capital supply is upward sloping with the functional form of $p^K = I^{1/\varepsilon^s}$. We vary the elasticity of capital supply with respect to price at 2.54, 6, 10, and 14, respectively. For instance, column (1) assumes the elasticity of capital supply with respect to pre-tax capital price ε^s is 2.54, which is translated into a 9.52% increase in the pre-tax purchase price of capital.

Table C.6.19: Robustness of Simulating 17% VAT Cut

Percentage Change in	Baseline (1)	Resale Price $p_s = 0.80$ (2)	Aggregate Productivity Drop (3)
Aggregate Investment	0.434	0.430	0.439
Fraction of Firms Investing	0.098	0.097	0.102
Tax Revenue	-0.279	-0.279	-0.277
Firm Value	0.114	0.114	0.114
Ratio of Investment to Tax Revenue	1.559	1.543	1.586
Ratio of Firm Value to Tax Revenue	0.410	0.407	0.413

Notes: This table displays simulation results for the baseline policy reform—17% VAT cut—with the following extensions. Column (1) is the baseline simulation results. Column (2) assumes the net-of-tax resale price to be 0.8. In column (3), we feed in a one standard deviation permanent drop of aggregate productivity.

Table C.6.20: Robustness of Simulating 17% VAT Cut: Varying Interest Rate

	Elasticity of interest rate w.r.t TUCC				
Percentage Change in	0 (Baseline) (1)	-0.05 (2)	-0.1 (3)	-0.2 (4)	-0.25 (5)
TUCC	-0.145	-0.145	-0.145	-0.145	-0.145
Aggregate Investment	0.434	0.416	0.399	0.365	0.348
Fraction of Firms Investing	0.098	0.093	0.088	0.077	0.072
Tax Revenue	-0.279	-0.280	-0.281	-0.284	-0.286
Firm Value	0.114	0.104	0.094	0.074	0.065
Ratio of Investment to Tax Revenue	1.559	1.485	1.417	1.282	1.218
Ratio of Firm Value to Tax Revenue	0.410	0.371	0.334	0.261	0.227

Notes: This table displays simulation results for the baseline policy reform—17% VAT cut—with elasticity of interest rate with respect to TUCC at -0.05, -0.1, -0.2 and -0.25, respectively. For instance, column (1) assumes the elasticity of interest rate with respect to TUCC at -0.05, leading to a 0.73% increase in interest rate. In our baseline model, we fix the discount factor at 0.95 and thus the interest rate at $0.0526 = 1/\beta - 1$.

Table C.6.21: Simulating Corporate Income Tax Cuts with Deductible Adjustment Costs and Weighted Average Cost of Capital (WACC)

| | 17% VAT Cut | Corporate Rate Cut 15.4% to 10% | | |
| | | Baseline | Ded. Costs | Varying WACC |
Percentage Change in	(1)	(2)	(3)	(4)
Aggregate Investment	0.434	0.147	0.038	0.062
Fraction of Firms Investing	0.098	0.062	0.013	0.025
Tax Revenue	-0.279	-0.191	-0.172	-0.225
Firm Value	0.114	0.103	0.066	0.049
Ratio of Investment to Tax Revenue	1.559	0.769	0.222	0.276
Ratio of Firm Value to Tax Revenue	0.410	0.540	0.380	0.218

Notes: This table displays simulation results for corporate income tax cut from 15.4% to 10%. Column (2) reports the baseline results. Column (3) shows the simulated results when adjustment costs (i.e., convex and fixed adjustment costs) are tax deductible. Column (4) shows the simulated results when the corporate income tax cut changes weighted average cost of capital (WACC), and thus discount rate $\beta = \frac{1}{1+\text{WACC}}$. WACC is calculated as

$$\text{WACC} = \text{Share}_{\text{debt}}(1 - \tau)r + (1 - \text{Share}_{\text{debt}})r_k,$$

where $\text{Share}_{\text{debt}}$ is the share of capital financed through debt and, accordingly, $(1 - \text{Share}_{\text{debt}})$ is the share of capital financed through equity. We calibrate the share of debt financing to be 0.65 to match the average debt to capital ratio. We keep real interest rate r and capital return r_k constant to match baseline discount rate.

Table C.6.22: Tax Cuts with Same TUCC Reduction

Percentage Change in	VAT Cut	Corporate Rate Cut		Bonus Depreciation
		Constant WACC	Varying WACC	
	(1)	(2)	(3)	(4)
Tax Rate (pp.)	-2.8	-10.0	-10.0	0
Immediate Depreciation Write-off	0	0	0	70%
TUCC	-0.024	-0.024	-0.024	-0.024
Aggregate Investment	0.068	0.273	0.107	0.069
Fraction of Firms Investing	0.023	0.111	0.043	0.023
Tax Revenue	-0.029	-0.357	-0.419	-0.084
Ratio of Investment to Tax Revenue	2.367	0.764	0.256	0.823

Notes: The table shows the results with an initial VAT rate at 17% and a corporate income tax rate at 15.4%. We compare three reforms with the same reduction in TUCC: 1) VAT reform cuts VAT from 17% to 14.2% (i.e., 2.8% rate reduction), 2) corporate income tax reform cuts this rate from 15.4% to 5.4% (i.e., 10% rate reduction), and 3) bonus depreciation allows a 70% immediate write-off rate. Those three reforms have the same impacts on TUCC, reducing TUCC by 2.4%. We use the estimated frictions, i.e., $\gamma = 1.43$, $\bar{\xi} = 0.12$, to simulate tax cuts. In column (2) we simulate a corporate income tax cut with fixed interest rate. In column (3) we use weighted-average cost of capital (WACC) for simulation. WACC is calculated as

$$\text{WACC} = \text{Share}_{\text{debt}}(1 - \tau)r + (1 - \text{Share}_{\text{debt}})r_k,$$

where $\text{Share}_{\text{debt}}$ is the share of capital financed through debt and, accordingly, $(1 - \text{Share}_{\text{debt}})$ is the share of capital financed through equity. We calibrate the share of debt financing to be 0.65 to match the average debt to capital ratio. We keep real interest rate r and capital return r_k constant to match baseline discount rate. Ratio of investment rate to tax revenue is calculated by dividing the percentage change in average investment rate by the percentage change in tax revenue.

Table C.6.23: Robustness of Simulated Difference-in-Differences Estimates

	Baseline (1)	Alternative Control Group (2)
DID. Extensive	0.036	0.037
DID. Intensive	0.030	0.031

Notes: This table displays the simulated difference-in-differences estimates using alternative simulated control group, complementing Table 4.8. To calculate these estimates, we simulate 10,000 firms over 200 periods, with the reform taking place at the 100th period. Meanwhile, we simulate another counterfactual economy where the reform does not take place as the control group. The difference-in-difference estimates are calculated by taking the difference between the two simulated economies. Column (1) shows the benchmark simulation where the treatment and control groups face the same convex adjustment cost $\gamma = 1.43$, an upper bound of fixed cost $\bar{\xi} = 0.12$, and a value-added tax rate at 17% on equipment purchase. Column (2) shows the results using an alternative set of firms as the control group. To match the cross-sectional difference between domestic and foreign firms in the fraction of firms investing before the reform, we calibrate the upper bound of fixed costs to $\xi^F = 0.017$. Firms in the alternative control group are not subject to the value-added tax throughout the simulation.

Table C.6.24: Robustness of Simulated Difference-in-Differences Estimates: Upward-Sloping Capital Supply

	Elasticity of Capital Supply				
	Infinity (Baseline) (1)	2.54 (2)	6 (3)	10 (4)	14 (5)
%Change in Capital Price	0	0.063	0.038	0.026	0.020
DID. Extensive ($\Delta_1^{Ext} - \Delta_0^{Ext}$)	0.036	0.050	0.045	0.042	0.040
Difference of Domestic Firms (Δ_1^{Ext})	0.036	0.027	0.032	0.033	0.034
Difference of Foreign Firms (Δ_0^{Ext})	0	-0.023	-0.013	-0.009	-0.006
DID. Intensive ($\Delta_1^{Ext} - \Delta_0^{Ext}$)	0.030	0.032	0.031	0.031	0.031
Difference of Domestic Firms (Δ_1^{Int})	0.030	0.019	0.024	0.026	0.027
Difference of Foreign Firms (Δ_0^{Int})	0	-0.013	-0.008	-0.005	-0.004

Notes: This table displays simulated difference-in-differences estimates for the baseline policy reform—17% VAT cut—assuming the capital supply is upward sloping with the functional form of $p^K = I^{1/\varepsilon^s}$. We vary the elasticity of capital supply with respect to price at 2.54, 6, 10, and 14, respectively. For instance, column (1) assumes the elasticity of capital supply with respect to pre-tax capital price ε^s is 2.54, which is translated into a 6.3% increase in the pre-tax purchase price of capital.

Bibliography

Aarland, K., J. C. Davis, J. V. Henderson, and Y. Ono (2007). Spatial organization of firms: The decision to split production and administration. *The RAND Journal of Economics 38*(2), 480–494.

Abadie, A. (2005). Semiparametric difference-in-differences estimators. *The Review of Economic Studies 72*(1), 1–19.

Abel, A. B. (1980). Empirical investment equations: An integrative framework. *Carnegie-Rochester Conference Series on Public Policy 12*, 39 – 91.

Akerman, A., I. Gaarder, and M. Mogstad (2015). The skill complementarity of broadband internet. *The Quarterly Journal of Economics 130*(4), 1781–1824.

Andrews, I., M. Gentzkow, and J. M. Shapiro (2017). Measuring the sensitivity of parameter estimates to estimation moments. *The Quarterly Journal of Economics 132*(4), 1553–1592.

Antras, P., T. C. Fort, and F. Tintelnot (2017). The margins of global sourcing: Theory and evidence from us firms. *American Economic Review 107*(9), 2514–64.

Arellano, C., Y. Bai, and J. Zhang (2012). Firm dynamics and financial development. *Journal of Monetary Economics 59*(6), 533 – 549.

Arkolakis, C., F. Eckert, and R. Shi (2021). Combinatorial discrete choice.

Atalay, E., A. Hortaçsu, and C. Syverson (2014). Vertical integration and input flows. *American Economic Review 104*(4), 1120–48.

Auerbach, A. J. (1986). The dynamic effects of tax law asymmetries. *The Rreview of economic studies 53*(2), 205–225.

Auerbach, A. J. (1989). Tax reform and adjustment costs: The impact on investment and market value. *International Economic Review 30*(4), 939–962.

Auerbach, A. J. and J. R. Hines (1988). Investment tax incentives and frequent tax reforms. *American Economic Review 78*(2), 211–216.

Autor, D., D. Dorn, L. F. Katz, C. Patterson, and J. Van Reenen (2020). The fall of the labor share and the rise of superstar firms. *The Quarterly Journal of Economics 135*(2), 645–709.

Bachmann, R., R. J. Caballero, and E. M. R. A. Engel (2013, October). Aggregate implications of lumpy investment: New evidence and a dsge model. *American Economic Journal: Macroeconomics 5*(4), 29–67.

Bai, C.-E., C.-T. Hsieh, Y. Qian, et al. (2006). The return to capital in china. Technical report, National Bureau of Economic Research, Inc.

Bai, C.-E., C.-T. Hsieh, and Z. Song (2016). The long shadow of a fiscal expansion. *Brookings Papers on Economic Activity*, 15–16.

Baley, I. and A. Blanco (2019). Aggregate dynamics in lumpy economies. Technical report, Working Paper.

Baley, I. and A. Blanco (2021). The macroeconomic effects of corporate tax reforms. Technical report, Working Paper.

Barnatchez, K., L. D. Crane, and R. Decker (2017). An assessment of the national establishment time series (nets) database.

Barro, R. J. and J. Furman (2018). Macroeconomic Effects of the 2017 Tax Reform. *Brookings Papers on Economic Activity 49*(1 (Spring), 257–345.

Bernard, A. B. and J. B. Jensen (2007). Firm structure, multinationals, and manufacturing plant deaths. *The Review of Economics and Statistics 89*(2), 193–204.

Bils, M. and P. J. Klenow (2000). Does schooling cause growth? *American economic review 90*(5), 1160–1183.

Bloom, N., L. Garicano, R. Sadun, and J. Van Reenen (2014). The distinct effects of information technology and communication technology on firm organization. *Management Science 60*(12), 2859–2885.

Bloom, N., R. Sadun, and J. Van Reenen (2010). Recent advances in the empirics of organizational economics. *Annu. Rev. Econ. 2*(1), 105–137.

Blundell, R. and S. Bond (2000). Gmm estimation with persistent panel data: an application to production functions. *Econometric reviews 19*(3), 321–340.

Bresnahan, T. (2010). General purpose technologies. In *Handbook of the Economics of Innovation*, Volume 2, pp. 761–791. Elsevier.

Caballero, R. J. and E. M. Engel (1999). Explaining investment dynamics in us manufacturing: a generalized (s, s) approach. *Econometrica 67*(4), 783–826.

Cai, J. and A. Harrison (2016). Industrial policy in china: Some unintended consequences? *Working Paper*.

Cao, D., H. R. Hyatt, T. Mukoyama, and E. Sager (2019). Firm growth through new establishments. *Available at SSRN*.

Chen, X., H. Hong, and A. Tarozzi (2008). Semiparametric efficiency in gmm models with auxiliary data. *The Annals of Statistics 36*(2), 808–843.

Chen, Y., Z. He, and L. Zhang (2016). The effect of investment tax incentives: Evidence from china's value-added tax reform. *Working Paper, Peking University.*.

Chen, Z., Z. Liu, J. C. Suárez Serrato, and D. Y. Xu (2019). Notching r&d investment with corporate income tax cuts in china. Technical report, mimeo, Duke University.

Chirinko, R. S. and D. J. Wilson (2008). State investment tax incentives: A zero-sum game? *Journal of Public Economics 92*(12), 2362 – 2384. New Directions in Fiscal Federalism.

Clementi, G. L. and B. Palazzo (2016). Entry, exit, firm dynamics, and aggregate fluctuations. *American Economic Journal: Macroeconomics 8*(3), 1–41.

Cline, R., J. Mikesell, T. Neubig, and A. Phillips (2005). Sales taxation of business inputs existing tax distortions and the consequences of extending the sales tax to business services. Technical report, Council on State Taxation.

Cong, L. W., H. Gao, J. Ponticelli, and X. Yang (2019). Credit allocation under economic stimulus: Evidence from china. *The Review of Financial Studies 32*(9), 3412–3460.

Cooper, R. W. and J. C. Haltiwanger (2006). On the nature of capital adjustment costs. *The Review of Economic Studies 73*(3), 611–633.

Cummins, J. G., K. A. Hassett, and R. G. Hubbard (1994). A reconsideration of investment behavior using tax reforms as natural experiments. *Brookings papers on economic activity 1994*(2), 1–74.

David, J. M. and V. Venkateswaran (2019, July). The sources of capital misallocation. *American Economic Review 109*(7), 2531–67.

Desai, M. A., C. Foley, and J. R. Hines (2004). Foreign direct investment in a world of multiple taxes. *Journal of Public Economics 88*(12), 2727 – 2744.

DiNardo, J., N. M. Fortin, and T. Lemieux (1996). Labor market institutions and the distribution of wages, 1973-1992: A semiparametric approach. *Econometrica 64*(5), 1001–1044.

Disdier, A.-C. and K. Head (2008). The puzzling persistence of the distance effect on bilateral trade. *The Review of Economics and statistics 90*(1), 37–48.

Eaton, J. and S. Kortum (2002). Technology, geography, and trade. *Econometrica 70*(5), 1741–1779.

Ebrill, L., M. Keen, J.-P. Bodin, and V. Summers (2001). *The Modern VAT*. International Monetary Fund.

EY (2017). Managing indirect tax refunds. Technical report, Ernst & Young.

Fajgelbaum, P. D., E. Morales, J. C. Suárez Serrato, and O. Zidar (2019). State taxes and spatial misallocation. *The Review of Economic Studies 86*(1), 333–376.

Forman, C., A. Goldfarb, and S. Greenstein (2003). The geographic dispersion of commercial internet use. *Rethinking rights and regulations: Institutional responses to new communication technologies*, 113–45.

Forman, C., A. Goldfarb, and S. Greenstein (2012). The internet and local wages: A puzzle. *American Economic Review 102*(1), 556–75.

Fort, T. C. (2017). Technology and production fragmentation: Domestic versus foreign sourcing. *The Review of Economic Studies 84*(2), 650–687.

Fort, T. C. and S. D. Klimek (2018, June). The Effects of Industry Classification Changes on US Employment Composition. Working Papers 18-28, Center for Economic Studies, U.S. Census Bureau.

Giroud, X. (2013). Proximity and investment: Evidence from plant-level data. *The Quarterly Journal of Economics 128*(2), 861–915.

Goldfarb, A. and C. Tucker (2019). Digital economics. *Journal of Economic Literature 57*(1), 3–43.

Goolsbee, A. (1998). Investment tax incentives, prices, and the supply of capital goods. *Quarterly Journal of Economics* (113), 121–148.

Gourio, F. and A. K. Kashyap (2007, September). Investment spikes: New facts and a general equilibrium exploration. *Journal of Monetary Economics 54*(Supplemen), 1–22.

Graham, J. R. (2000). How big are the tax benefits of debt? *The Journal of Finance 55*(5), 1901–1941.

Greenstein, S. (2015). *How the internet became commercial: Innovation, privatization, and the birth of a new network*. Princeton University Press.

Greenstein, S. (2020). The basic economics of internet infrastructure. *Journal of Economic Perspectives 34*(2), 192–214.

Guner, N., G. Ventura, and Y. Xu (2008). Macroeconomic implications of size-dependent policies. *Review of Economic Dynamics 11*(4), 721–744.

Hassett, K. A. and R. G. Hubbard (2002). Tax policy and business investment. In *Handbook of public economics*, Volume 3, pp. 1293–1343. Elsevier.

Hayashi, F. (1982). Tobin's marginal q and average q: A neoclassical interpretation. *Econometrica: Journal of the Econometric Society*, 213–224.

Head, K. and T. Mayer (2014). Gravity equations: Workhorse, toolkit, and cookbook. In *Handbook of international economics*, Volume 4, pp. 131–195. Elsevier.

Hennesy, C. A. and T. M. Whited (2007). How costly is external financing? evidence from a structural estimation. *The Journal of Finance 62*(4), 1705–1745.

Hirano, K. and G. W. Imbens (2004). The propensity score with continuous treatments. *Applied Bayesian modeling and causal inference from incomplete-data perspectives 226164*, 73–84.

Hjort, J. and J. Poulsen (2019). The arrival of fast internet and employment in africa. *American Economic Review 109*(3), 1032–79.

House, C. L., A.-M. Mocanu, and M. D. Shapiro (2017). Stimulus effects of investment tax incentives: Production versus purchases. Technical report, National Bureau of Economic Research.

House, C. L. and M. D. Shapiro (2008). Temporary investment tax incentives: Theory with evidence from bonus depreciation. *The American Economic Review 98*(3), 737–768.

Hsieh, C.-T. and E. Rossi-Hansberg (2019, June). The industrial revolution in services. Working Paper 25968, National Bureau of Economic Research.

Hsu, P.-H., X. Tian, and Y. Xu (2014). Financial development and innovation: Cross-country evidence. *Journal of Financial Economics 112*(1), 116–135.

Hu, K. and R. Shi (2019). Solving combinatorial discrete choice problems in heterogeneous agent models.

Jia, P. (2008). What happens when wal-mart comes to town: An empirical analysis of the discount retailing industry. *Econometrica 76*(6), 1263–1316.

Jiao, Y. and L. Tian (2019). Geographic fragmentation in a knowledge economy. Technical report, Working Paper.

Jones, C. I. (2011). Intermediate goods and weak links in the theory of economic development. *American Economic Journal: Macroeconomics 3*(2), 1–28.

Jorgenson, D. and R. Hall (1967). Tax policy and investment behavior. *American Economic Review 57*(3), 391–414. Reprinted in Bobbs-Merrill Reprint Series in Economics , Econ-130. Investment 2, ch. 1, pp 1-26.

Juhász, R. and C. Steinwender (2018). Spinning the web: Codifiability, information frictions and trade. *NBER working paper*.

Khan, A. and J. K. Thomas (2008). Idiosyncratic shocks and the role of nonconvexities in plant and aggregate investment dynamics. *Econometrica 76*(2), 395–436.

Kim, H. and H. Kung (2017). The asset redeployability channel: How uncertainty affects corporate investment. *The Review of Financial Studies 30*(1), 245–280.

Lanteri, A. (2018, September). The market for used capital: Endogenous irreversibility and reallocation over the business cycle. *American Economic Review 108*(9), 2383–2419.

Levinsohn, J. and A. Petrin (2003, 04). Estimating Production Functions Using Inputs to Control for Unobservables. *The Review of Economic Studies 70*(2), 317–341.

Liu, Y. and J. Mao (2019, August). How do tax incentives affect investment and productivity? firm-level evidence from china. *American Economic Journal: Economic Policy 11*(3), 261–91.

Maffini, G., J. Xing, and M. P. Devereux (2016). The impact of investment incentives: evidence from uk corporation tax returns. *American Economic Journal: Economic Policy*.

McKnight, L. W. and J. P. Bailey (1998). *Internet economics*. Mit Press.

Ministry of Finance (2019). Announcement on deepening vat reform.

Moon, T. S. (2019). Capital gains taxes and real corporate investment. *Job Market Paper, Princeton University*.

NBS China (2018). China statistical yearbook. *National Bureau of Statistics of China*.

Oberfield, E., E. Rossi-Hansberg, P.-D. Sarte, and N. Trachter (2020). Plants in space. Technical report, National Bureau of Economic Research.

Ohrn, E. (2018a, May). The effect of corporate taxation on investment and financial policy: Evidence from the dpad. *American Economic Journal: Economic Policy 10*(2), 272–301.

Ohrn, E. (2018b, February). The effect of tax incentives on u.s. manufacturing: Evidence from state accelerated depreciation policies. *Working Paper*.

Ottonello, P. and T. Winberry (2019). Financial heterogeneity and the investment channel of monetary policy.

Ramey, V. A. and M. D. Shapiro (2001). Displaced capital: A study of aerospace plant closings. *Journal of Political Economy 109*(5), 958–992.

Ramondo, N. and A. Rodríguez-Clare (2013). Trade, multinational production, and the gains from openness. *Journal of Political Economy 121*(2), 273–322.

Rao, N. (2016). Do tax credits stimulate r&d spending? the effect of the r&d tax credit in its first decade. *Journal of Public Economics 140*, 1–12.

Robins, J. M., M. A. Hernan, and B. Brumback (2000). Marginal structural models and causal inference in epidemiology. *Epidemiology 11*(5), 550–560.

Rossi-Hansberg, E., P.-D. Sarte, and N. Trachter (2021). Diverging trends in national and local concentration. *NBER Macroeconomics Annual 35*, 115–150.

Salinger, M. A. and L. H. Summers (1981, September). Tax reform and corporate investment: A microeconometric simulation study. Working Paper 757, National Bureau of Economic Research.

Steinwender, C. (2018). Real effects of information frictions: When the states and the kingdom became united. *American Economic Review 108*(3), 657–96.

Summers, L. H. (1981). Taxation and corporate investment: A q-theory approach. *Brookings Papers on Economic Activity 1981*(1), 67–140.

Tintelnot, F. (2017). Global production with export platforms. *The Quarterly Journal of Economics 132*(1), 157–209.

Wilson, D. J. (2009). Beggar thy neighbor? the in-state, out-of-state, and aggregate effects of r&d tax credits. *The Review of Economics and Statistics 91*(2), 431–436.

Winberry, T. (2020). Lumpy investment, business cycles, and stimulus policy. *forthcoming, American Economic Review*.

Xu, Q. and E. Zwick (2020). Tax policy and abnormal investment behavior. Technical report, National Bureau of Economic Research.

Yagan, D. (2015). Capital tax reform and the real economy: The effects of the 2003 dividend tax cut. *The American Economic Review 105*(12), 3531–3563.

Zwick, E. and J. Mahon (2017). Tax policy and heterogeneous investment behavior. *The American Economic Review 107*(1), 217–248.

Biography

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