Tax Policy and Lumpy Investment Behavior: Evidence from China's VAT Reform*

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Abstract

A universal fact of firm-level data is that investment is lumpy: firms either replace a considerable fraction of their existing capital (spike) or do not invest at all (inaction). This paper incorporates the lumpy nature of investment into the study of how tax policy affects investment behavior. We show that tax policy can directly impact the lumpiness of investment and that the effectiveness of tax incentives in stimulating investment depends crucially on interactions with investment frictions. We illustrate these results by studying one of the largest tax incentives for investment in recent history: China's 2009 VAT reform. Using administrative tax data and a difference-in-differences design, we document that the reform increased investment by 36% and that this effect is driven by additional investment spikes. We then simulate the fiscal cost of stimulating investment through different tax policies using a dynamic investment model that is consistent with the reduced-form effects of the reform. Policies that directly reduce the likelihood of firm inaction (e.g., investment tax credits) are more effective at stimulating investment than policies that only reduce the tax cost of investment (e.g., corporate income tax cuts).

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This paper improves our understanding of how tax policy affects investment behavior by incorporating the lumpy nature of investment. 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. Lumpy investment behavior is evident in most microdata, since firms either replace a considerable fraction of their existing capital (spike) or do not invest at all (inaction). We show that the fiscal cost of stimulating investment depends crucially on interactions between tax policy and the frictions that generate lumpy investment.

We illustrate theoretically, empirically, and quantitatively that tax policy impacts the lumpiness of investment. We first model how different tax policies interact with adjustment frictions. Tax policies such as input taxes and tax credits directly impact the partial irreversibility of investment. Other policies, such as income taxes and depreciation deductions, indirectly affect lumpiness by changing the after-tax value of fixed disruption costs. Notably, different tax incentives have distinct effects on the after-tax cost of investment and on the frictions that generate inaction. As a result, policies that change the user cost of capital by the same degree can have different implications for firm investment. We then show quantitatively that the effects of tax policies on firm inaction are crucial determinants of the fiscal costs of stimulating 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. 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 1—investment in China has long surpassed investment levels in the United States and the European Union. 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 partial irreversibility of investment.[1] We use administrative tax data to shed light on this stimulus program and to develop insights into how tax policy interacts with frictions that generate lumpy investment.

We show that lumpy investment matters for tax policy using two sets of empirical analyses. We first use a difference-in-differences research design to document the effects of China's 2009 VAT reform. We find that affected firms increased investment relative to control firms by 36% and that the majority of this increase was driven by additional investment spikes. Second, we estimate a dynamic investment model that quantifies the interactions between investment frictions and tax policy. The model matches the reduced-form effects of the reform as well as the surge in investment spikes. We use the model to compare alternative tax policies and find that

[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). 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.

policies that reduce the likelihood of firm inaction are more effective at stimulating investment. In our empirical example, the VAT reform was more effective at stimulating investment than an income tax cut since the reduction in partial irreversibility decreased the likelihood of firm inaction. This lesson is relevant for tax policy in other countries that rely on sales taxes, VATs, and investment tax credits since they directly impact the lumpiness of investment.

We develop these insights in four steps. We start by embedding important tax policies in China—income tax, VAT, depreciation policies—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 (CIT) cut does not affect partial irreversibility, it lowers the after-tax cost of capital and affects the after-tax value of adjustment costs—thereby influencing which firms respond to tax and productivity shocks. Overall, 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 uses a novel dataset of administrative tax records from the Chinese State Administration of Tax and a difference-in-differences identification strategy to study how firms respond to the VAT reform. Since foreign firms with preferential treatment were able to deduct input VAT on equipment prior to the reform, our research design uses foreign firms as a control group for domestic firms. We find substantial effects of the reform on firm investment. On the extensive margin, the fraction of firms investing in equipment increased by 5 percentage points, or a 10% increase. On the intensive margin, investment increases by 3.6% of the existing capital stock, for a 36% increase in investment.[2] Finally, we find that the majority of the investment response was due to additional spikes in investment.

The validity of this research design rests on the assumption that, absent the reform, domestic firms would have had the same investment patterns 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, to further validate this assumption, we conduct placebo tests using domestic and foreign firms that

[2]Relative to the change in the user cost of capital (15%), the results imply an investment-to-cost-of-capital elasticity of 2.4. For comparison, Zwick and Mahon (2017) estimate an elasticity of 7.2 in the United States.

were included in a pilot program allowing firms to deduct input VAT from new investments starting in 2004. We find no evidence that the reform had differential effects on firms in the pilot program, suggesting that domestic and foreign firms were not subject to time-varying shocks that would confound our estimates. 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.

We estimate a dynamic model of investment in the third step of our analysis. 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. This approach matches simulated data from our model with observed moments that include both reduced-form estimates of the effects of the reform and prereform statistics on investment patterns, such as measures of lumpiness and the autocorrelation of investment. We validate canonical models of investment by showing that they can match the reduced-form effects of an actual reform. In contrast, we find that investment-to-cost-of-capital elasticities vary considerably across tax policies, a finding that highlights the value of combining reduced-form estimates with a model that accounts for how tax policy interacts with adjustment frictions.

The fourth and final step of our analysis uses the estimated model to simulate the effects of alternative tax policies on investment, tax revenue, and firm value. We measure the effectiveness of a given policy by comparing the tax revenue cost to the change in investment. 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 contrast, introducing an investment tax credit (ITC) is just as effective as lowering the VAT. This equivalence is driven by the fact that both an ITC and the VAT reform lower the degree of partial irreversibility. 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]

This paper is related to a long line of research in public finance dating to Hall and Jorgenson (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, Xing and Devereux, 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

[3]Our quantitative results are robust to alternative assumptions regarding the supply of capital goods, concomitant aggregate productivity shocks, additional sources of partial irreversibility, and interactions between income taxes and interest costs.

[4]Our paper is also related to classic papers that follows a model-centric estimation approach. For instance, Abel (1980), Salinger and Summers (1981), Summers (1981), and Hayashi (1982) relied 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).

(2016), Liu and Mao (2018), Chen, He and Zhang (2016), and Chen, Liu, Suárez Serrato and Xu (2019).[5] We contribute to this literature by measuring the effects of a large natural experiment using administrative tax data, documenting the importance of investment spikes in understanding the effects of tax reforms, and by studying how the administration of VAT systems can generate partial irreversibility. In addition, we improve our understanding of previous research by providing a coherent interpretation to the intensive- and extensive-margin responses to tax incentives that have been documented using quasi-experimental variation.

By investigating real-world tax reforms in a lumpy investment model, we also contribute to the investment literature (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, 2018).[6] Winberry (2018) simulates tax policy changes through their effects on the after-tax cost of investment. Our framework further shows that the effectiveness of different policy tools depends on how tax policies impact the frictions that generate lumpy investment.

Investment frictions are often identified by matching investment patterns in a stationary environment. As argued by Cummins, Hassett and Hubbard (1994), tax reforms generate large and plausibly exogenous shifts in economic fundamentals and are useful in uncovering the nature of investment frictions. By incorporating quasi-experimental estimates of the effects of tax reform in our estimation of adjustment costs, we validate and improve the estimation of dynamic models of investment. Our unified approach is therefore well suited for simulating the effects of potential tax reforms and for comparing their effectiveness at stimulating investment.[7]

The results of this paper have implications beyond China. First, policymakers should avoid generating 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, Foley and Hines, 2004). In the United States, Cline, Mikesell, Neubig and Phillips (2005) document that businesses pay over $100 billion in state sales taxes on inputs, including investment purchases. Second, VATs can generate partial irreversibility when credits

[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 (2018) use tax data to study the effects of the rollout of the reform from 2004 to 2009. Relative to Liu and Mao (2018), this paper contributes to the literature by uncovering the importance of lumpy responses to the tax reform and by clarifying how tax policies interact with investment frictions. Nonetheless, while their identification strategy uses small-scale taxpayers as a control group, we find similar increases in investment on the intensive margin.

[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, Caballero and Engel, 2013; Winberry, 2018) have clarified conditions under which micro-level investment frictions have aggregate implications in general equilibrium. In particular, Winberry (2018) shows that lumpy investments have aggregate implications when interest rate dynamics match the observed covariance with productivity.

[7]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, Bai and Zhang (2012); Ottonello and Winberry (2019).

are not refundable. Our reduced-form results show that firms with excess VAT credits are subject to partial irreversibility after the reform. While China started refunding excess VAT credits in 2019 (Ministry of Finance, 2019), excess credits are not refundable in 24 other countries (EY, 2017). 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 credit (e.g., Chirinko and Wilson, 2008), are simultaneously used to lower the price gap between new and used capital.

The paper is organized as follows. Section 1 develops the intuition for how tax policies interact with firm frictions and culminates by detailing an empirical model of investment. Section 2 discusses China's 2009 VAT reform. Section 3 describes the administrative tax data, and Section 4 documents the reduced-form effects of the reform. Section 5 estimates the model, Section 6 simulates the effects of potential tax reforms, and Section 7 concludes.

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 these frictions 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.

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 $p = p_k(1 - \tau p_v)$, where p_k is the capital goods price and $p_v \leq 1$ is the discounted present value of depreciation deductions.[8] Absent additional frictions, the firm solves the problem:

$$\max_{K} \; (1-\tau)A^{1-\theta}K^{\theta} - p(K - K_0) \implies K^* = A\left[\frac{1}{\theta}\underbrace{\frac{p_k(1-\tau p_v)}{(1-\tau)}}_{\text{UCC}}\right]^{\frac{-1}{1-\theta}}. \tag{1}$$

[8] p_v is determined by the depreciation schedule of capital. We provide more details of how the depreciation schedule maps into p_v in the dynamic model.

Equation 1 implies 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.[9] The user cost of capital (UCC) is given by $\frac{p_k(1-\tau p_v)}{(1-\tau)}$. The symmetric effect of p_k and the tax term $\frac{(1-\tau p_v)}{(1-\tau)}$ 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 $\frac{-1}{1-\theta}$.[10]

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 $p^b = p_k(1+\nu-\tau(1+\nu)p_v)$ and the sales price is $p^s = p_k(1-\tau(1+\nu)p_v)$.[11]

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 MPK of their existing capital falls in the range $[p^s, p^b]$. The dashed line in Panel A of Figure 2 shows how the MPK increases with productivity. The two horizontal lines denote p^b and p^s. The inaction region is the range of productivity where the MPK 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 2 shows how p^b, p^s, and the inaction region affect the firm's policy function—the relation between productivity and capital.

[9]By an extensive-margin response, we refer to a firm's decision to invest in a given year relative to a counterfactual of not investing. Our empirical analysis focuses on a balanced panel of existing firms, and we do not study firm entry as part of a broader extensive-margin response.

[10]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 $\frac{-1}{1-\theta} = 4$.

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

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

$$\ln(\bar{A}) - \ln(\underline{A}) = \frac{1}{1-\theta}\left[\ln(1-\tau p_v) - \ln\left(\frac{1}{1+\nu} - \tau p_v\right)\right].$$

China's VAT reform directly reduced the region of inaction by reducing ν. In addition, changes in τ and p_v also affect the inaction region, and these effects depend on interactions with ν.[12] However, while policies that directly influence p_k shift both p^b and p^s, they do not influence the inaction region. For this reason, different policy changes can have the same effect on the UCC but different effects on the inaction region.

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. A firm decides to adjust its capital if profits after adjusting, $(1-\tau)A^{1-\theta}K^{*\theta} - p(K^* - K_0) - \xi K^*$, 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:

$$\overbrace{\underbrace{\left[\frac{(1-\theta)}{\theta}\mathrm{UCC} - \frac{\xi}{1-\tau}\right]\left[\frac{\theta}{\mathrm{UCC}}\right]^{1/(1-\theta)}}_{\text{Slope}} A + \underbrace{\mathrm{UCC}K_0}_{\text{Intercept}}}^{\text{Profit conditional on adjusting to optimal capital } K^*} = \overbrace{K_0^{\theta}A^{1-\theta}}^{\text{Profit using initial capital } K_0}. \tag{2}$$

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 3 plots the after-tax profit in the case of no adjustment costs. The fixed cost ξ decreases the magnitude of 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 2 can be used to illustrate the dual effects of tax policy on the cost of capital and adjustment frictions. For instance, consider a reform that lowers the corporate income tax τ but that leaves UCC unaffected through a simultaneous change in p_v.[13] This reform would rotate the

[12] Sales taxes or an investment tax credit would also influence this region if they differentially affect p^b and p^s.

[13] For example, the Tax Reform Act of 1986 in the US lowered τ from 46% to 34%, but the repeal of the

dot-dashed line counterclockwise, which would decrease the inaction region. Intuitively, when firms can keep a larger fraction of their profits, the relative importance of the fixed cost decreases. This discussion implies that two different reforms that have the same effect on the UCC may have different implications for the lumpiness of investment depending on the degree to which each reform interacts with the value of the fixed adjustment cost.

Convex Costs

We now introduce convex adjustment costs and show how they help dampen the response of investment to changes in tax policy. We assume that firms have to pay a non-tax-deductible convex cost, $D(K)$, to adjust their capital. The firm's optimal capital level is now:

$$K^* = A\left[\frac{1}{\theta}\left(UCC + \frac{D'(K)}{1-\tau}\right)\right]^{\frac{-1}{1-\theta}},$$

where the total marginal cost of investment is the UCC plus the marginal convex cost, $\frac{D'(K)}{1-\tau}$. Since τ enters separately from the UCC in this expression, the latter is not a sufficient statistic for the effects of tax policy on investment.[14]

The capital elasticity with respect to p_k is now:

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

where $s^p = \frac{p}{p+D'(K)} \in [0,1]$ is the share of the price of capital relative to the total marginal cost of investment and $\alpha(K) = \frac{D''(K)K}{D'(K)} \geq 0$ is a measure of the convexity of adjustment costs. 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).[15]

These simple models yield two insights. First, the models clarify how investment frictions

investment credit and changes to depreciation deductions offset the rate cut (Auerbach and Slemrod, 1997).

[14] Note that, while the UCC is a sufficient statistic in the extreme case where $D(K)$ is fully tax deductible, the case where $D(K)$ is not fully deductible is the relevant empirical case.

[15] In Appendix A.1, we derive the capital elasticity with respect to $1-\tau$, which is subject to the same dampening effects and further shows that the UCC is not a sufficient statistic for tax policy. A central example in the literature is the case of quadratic costs. Assuming $D(K) = \frac{\gamma}{2}\left(\frac{K-K_0}{K_0}\right)^2 K_0$ implies $\varepsilon_{K,p_k} = \frac{-1}{(1-\theta)+\frac{\gamma}{p}\left((2-\theta)\frac{K}{K_0}-(1-\theta)\right)}$ and $\varepsilon_{K,(1-\tau)} = \frac{-\varepsilon_{UCC,1-\tau}+\frac{\gamma}{p}(K/K_0-1)}{(1-\theta)+\frac{\gamma}{p}\left((2-\theta)\frac{K}{K_0}-(1-\theta)\right)}$.

help match empirical investment patterns. Convex costs help match the sluggish response of investment to tax changes. Fixed costs and partial irreversibility generate lumpy investment. Together, these frictions yield coherent interpretations of the intensive- and extensive-margin investment responses to tax changes that have been documented in empirical studies.

Second, these models show that accounting for interactions between tax policies and the frictions that generate lumpy investment are crucial to characterizing the effects of tax policy on investment. In particular, changes in the UCC are not sufficient statistics for tax policy. The fact that tax policy can directly influence firm inaction should be taken into account when modeling the effects of tax policy changes.

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 that is rich enough to characterize our empirical setting.

Profit Function

Firms have a profit function given by:

$$\Pi(K, A^{\Pi}) = (A^{\Pi})^{1-\theta} K^{\theta}, \tag{3}$$

where K is the predetermined capital stock and A^{Π} is a profit shock that is realized at the beginning of the period.[16] $a_{it} \equiv \log(A^{\Pi}_{it})$ denotes a firm's log profitability, which has three components:

$$a_{it} = b_t + \omega_i + \varepsilon_{it}, \tag{4}$$

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

[16] 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.

Taxes

As in the static model, 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 VAT. Firms pay the CIT 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 p_v: the present discounted value of depreciation deductions.[17] The depreciation schedule interacts with both the CIT and the VAT since depreciation is deductible from the CIT 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 nondeductible VAT on equipment purchases, so the resale price is set to one.[18] 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 $G(\xi)$.[19] 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, which reduces the state space to (k, b, ε, ξ) by defining $k = K/\exp(\omega)$.[20] In any given period, the firm's value is the maximum of the value from buying capital, selling capital, or inaction:

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

[17]By abstracting from the depreciation schedule, this assumption allows us to study the firm's problem recursively. $p_v = \hat{\delta} + (1 - \hat{\delta})\beta\mathbb{E}[p'_v]$. Assuming a fixed and exogenous real interest rate r, $\beta\mathbb{E}[p'_v] = \frac{p_v}{1+r}$. This formulation builds on arguments in Winberry (2018). We show this result holds in our setting in Appendix A.3.2.

[18]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 6 shows our results are robust to allowing for additional sources of partial irreversibility.

[19]We represent the units of the fixed disruption cost in terms of the "desired capital level" K^* to make it proportional to the firm's profitability. In our empirical implementation, ξ is either fixed or drawn from a uniform distribution over the interval $[0, \bar{\xi}]$.

[20]This follows from the fact that the profit function (Equation (3)) and the costs 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.

where

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

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

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

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 the VAT-inclusive price of capital $(1+\nu)$ and depreciation deductions $\tau p_v(1+\nu)$, as well as convex and fixed costs. 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 profit.

Implications for Policy Reform

While it is not possible to analytically characterize the effects of tax policy in the dynamic model, we can solve the model numerically. This allows us 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.[21]

Figure 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 prereform 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 plots the optimal policy in the presence of all investment frictions. Both the partial irreversibility generated from the VAT and the fixed investment cost generate an inaction region where firms do not respond to small productivity shocks. When the productivity

[21] These simulations are based on model estimates in Table 6 that match the empirical setting. We discuss model parameters in detail in Section 5. The qualitative features of the model are robust to alternative parametrizations.

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.

The red solid line in Panel B of Figure 4 shows how the VAT reform impacts the policy function.[22] The VAT reform eliminates the large asymmetry between the purchase and sale price of capital. This change substantially 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 region. In addition to changing which firms respond to productivity shocks, the VAT reform directly reduces the purchase price of new investment. The joint effects of reducing the purchase price and narrowing the inaction region are key building blocks for understanding the effectiveness of the VAT reform on investment.

In Panel C, we report the policy function following a CIT cut. A CIT cut increases the after-tax marginal benefit of new capital but decreases the value of depreciation deductions. In our simulation, these countervailing forces almost perfectly cancel out for firms with low productivity shocks. In contrast, the rise in the after-tax value of new capital leads firms with large productivity shocks to increase their investment. We also see a small narrowing of the inaction region. Note, however, that a large fraction of firms are inframarginal to a CIT cut, since they will receive a productivity shock that leaves them in the inaction region.

Panel D reports the effects of a policy of bonus depreciation—which accelerates the timing of depreciation deductions and increases the value of p_v. By shifting the red line to the left, this reform affects the investment decisions of firms with low and high productivity shocks. However, the inaction region does not narrow considerably, and a significant fraction of firms do not respond to this incentive.

Figure 4 shows that different tax reforms have distinct interactions with adjustment costs. These interactions are the source of the different intensive- and extensive-margin responses documented in empirical studies.[23] In Section 5, we estimate an empirical version of this model that is consistent with the reduced-form effects of the reform in order to quantitatively compare the effects of alternative tax policies.

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

[23]In Appendix F.2, we show numerically that VAT and CIT changes with the same effect on the UCC have different effects on the intensive and extensive margins of investment.

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.[24]

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, Keen, Bodin and Summers, 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. The 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.

The Chinese government experimented with this transition starting in 2004. The reform was first piloted on firms in selected industries in Northeastern China.[25] As with most other reforms in China, the reform was designed to follow a slow rollout to allow for trial and error. However, the reform was unexpectedly extended *nationwide* in 2009. Starting on January 1, 2009, all firms were able to deduct the input VAT on equipment from the VAT on sales.[26]

The reform was an unexpected and permanent change to firms' after-tax cost of investment. Because the reform was unexpected, it is unlikely that firms retimed their investment plans. In addition, because the reform eliminated an undesirable aspect of the VAT system, firms did not

[24] 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.

[25] The initial provinces included Heilongjiang, Jilin, Liaoning, and the city of Dalian. From 2004-2008, 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.

[26] 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.

expect a reversal of the policy.

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.[27] Our research strategy uses foreign firms in encouraged 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. To bolster this assumption, we conduct a "placebo" test using domestic firms that were part of the 2004 pilot. We find that the 2009 reform did not have differential effects on the investment of foreign and domestic pilot firms. We provide more details behind this identifying variation in Section 4, where we also discuss different strategies that support the assumption that foreign firms' investment is a suitable counterfactual for domestic firms' investment.[28]

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 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 984 RMB.[29] 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 investment drops to 797.3 RMB. In total,

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

[28] 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, 2018). 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.

[29] 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.

the reform lowered the after-tax cost of investment by close to 15%.[30]

The results of Table 1 can also be expressed by extending the UCC of Hall and Jorgenson (1967) to include the effect of the VAT:

$$\text{UCC} = (1+\nu)\frac{1-\tau p_v}{1-\tau}, \tag{5}$$

where ν is the VAT rate, τ is the CIT rate, and p_v is the present value of depreciation deductions. As in Table 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, $(1+\nu)\tau p_v$.

While Equation 5 is not a sufficient statistic for tax policy, we can use it to compare the VAT reform to potential policies and recent reforms. One approach to lowering the UCC is to accelerate the depreciation schedule with the goal of increasing p_v. However, setting $p_v = 1$ through a policy of expensing (or 100% bonus depreciation) only lowers the UCC by 6%. Recent bonus depreciation policies in the US decreased the UCC by 2.4%–3.8% (Zwick and Mahon, 2017). Alternatively, consider the effects of changing the corporate income tax cut. To increase the UCC by 15%, one would need to increase τ from 25% to 54%, and eliminating the income tax would only lower the UCC by 6%. By way of comparison, Barro and Furman (2018) calibrate that the recent US tax reform reduced the average UCC by 4%. Finally, consider that undoing the effect of the VAT distortion on the UCC would require an investment tax credit (ITC) of 13.6%. This rate is greater than the last federal ITC in the US (the 8% ITC was eliminated in 1986, Cummins et al., 1994) as well as current state-level ITCs (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 UCC of foreign and domestic firms. We observe almost no change in the UCC of foreign and domestic firms before 2008. In 2009, we see that the VAT reform lowered the UCC of domestic firms by 15%.[31] The fact that the UCC is not affected by the CIT reform is reassuring for our analysis focused on the VAT reform. In addition, we report robustness checks

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

[31] Table F.1 shows these calculations by year and ownership. We implement Equation 5 using firms' effective tax rates. We also assume $r = 5.26\%$, which implies $p_v = 80\%$. The UCC for foreign firms increases from 1.023 to 1.035 between 2007 and 2009, a 1% difference. In contrast, the UCC of domestic firms drops from 1.22 to 1.042.

that control for firms' CIT rates in our empirical analysis.

Finally, we note that these calculations ignore a practical and important aspect of how the VAT is administered. Specifically, countries differ in how they process excess VAT credits. Ideally, tax authorities would automatically refund excess credits to firms. In China, as in many other countries (EY, 2017), firms can carry over credits to future tax periods. The degree to which firms are able to claim these credits varies in practice, however, and firms may view excess credits as completely foregone. For this reason, firms with excess VAT credits may still view investment as partially irreversible even after the reform. In our empirical analysis in Section 4, we test whether the lack of refundability of excess VAT payments hampers the effects of the reform.

3 Administrative Data from Corporate Tax Returns

The main data we use are the administrative tax records from the Chinese State Administration of Tax (SAT) from 2007 to 2011. This dataset contains detailed information on VAT payments and investment in fixed assets. 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.

We complement these data with two additional datasets. First, we use data on foreign direct investment records from the Ministry of Commerce (MOC). This dataset 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 extend our tax return data by merging the tax records with survey responses from the Chinese Annual Survey of Manufacturing (ASM) from 2005 to 2007. This merge provides an extended period of analysis.

We restrict our analysis to firms with nonnegative values of fixed assets for production and to firms that do not change ownership type in our sample. Our analysis relies on a balanced panel of firms that stay in the data for all five years. Our baseline specifications also require that the dependent variable is not missing for all years in our sample.

Table 2 reports summary statistics of firms in our sample. Our sample includes data on close to 315,000 firm-year observations. The sampling of this dataset ensures that large firms are included every year and that smaller firms are included on a rotating basis. Since our baseline sample requires firms to have investment data in all years, the number of observations used in our estimations is smaller. However, we show in robustness checks that we obtain similar estimates when we rely on an unbalanced sample.

In our data, 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 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.

As in many other countries, investment data in China is lumpy. Panel A of Figure 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%.[32]

Panel B of Figure 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.

Table 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) in 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, Fortin and Lemieux (1996). As we show in Figure F.3, this inverse probability weighting (IPW) method ensures that our treatment and control groups are comparable.[33]

Finally, we discuss the role of state-owned enterprises (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.

[32]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 as opposed to plant-level data, the statistics from Zwick and Mahon (2017) are more comparable to our setting.

[33]We describe this procedure in more detail in Appendix D.1.

4 Reduced-Form Effects of China's VAT Reform

We now estimate the reduced-form effects of the reform on investment. Our difference-in-differences research strategy exploits the different policy treatments of domestic and foreign firms prior to the reform. As detailed in Section 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 investment cost for domestic firms, but it did not affect foreign firms.

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

$$Y_{ijt} = G_i \gamma_t + \mu_i + \delta_{jt} + X'_{it}\beta + \varepsilon_{ijt}, \tag{6}$$

where Y_{ijt} is a firm-level measure of investment for firm i in industry j in year t. 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 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, which rule out the concern that differential growth rates across provinces 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 6 plots investment trends from 2005 to 2011. Panel A plots the fraction of firms investing in any given year and shows that domestic and foreign firms 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 6 and show that the parallel trends observed in Panels A and B result in statistically insignificant estimates before

[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, we normalize investment outcomes to domestic levels in 2008.

2009. These parallel trends are consistent with our assumption that domestic and foreign firms would have had the same investment patterns absent the reform. After the reform, however, we see that domestic firms are more likely to invest (Panels A and C) and that their overall investment rate is also higher (Panels B and D).[36]

To quantify the effects of the reform, Table 3 provides estimates of the following difference-in-differences regression:

$$Y_{ijt} = \gamma G_i \times Post_t + \mu_i + \delta_{jt} + X'_{it}\beta + \varepsilon_{ijt}. \tag{7}$$

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. This result lines up very well with the visual evidence in Figure 6. Relative to a base participation of 50%, this increase represents a 10% increase in the fraction of firms with positive investment. 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. To interpret this result, we transform this coefficient into a per-unit change in the UCC by dividing the effect of the reform on the UCC. As we report in Table F.5, the reform decreased the UCC by 0.2, which implies that a unit decrease in the UCC increased the investment rate by 0.19.[37] This estimate is significantly lower than the recent estimate of 1.6 for the US (Zwick and Mahon, 2017) and is also lower than the range of $[0.5, 1]$ used by Hassett and Hubbard (2002) to summarize previous studies. Relative to an average investment rate of 10%, the estimate from Table 3 represents a 36% increase in investment and implies a user-cost elasticity of $2.4(\approx \frac{36\%}{15\%})$.

Panel B of Table 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.[38] The remaining columns of Panel B show that our results are robust to using an unbalanced panel or to using all foreign firms (and not just those in preferential industries) as controls.

Panel C of Table 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

[36] We report the coefficients in Figure 6 in Table F.3. Table F.4 shows these results are robust to the same robustness checks performed in our difference-in-differences analysis.

[37] We formalize this comparison in Appendix D, where we use the reform as an instrument for the change in the user cost of capital. We obtain similar results.

[38] We describe this inverse-probability weighting (IPW) strategy in Section 3. See Appendix D.1 for more details.

that our results are robust to controlling for changes in the corporate income tax rate. As we discuss in Section 2, while a 2008 reform changed the statutory CIT 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.[39] 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.

To further explore the identifying assumption that foreign and domestic firms did not face differential shocks at the time of the reform, we now conduct a placebo test that compares foreign firms to 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 affect their investment decisions. Panel D in Table 3 reports 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 the estimates from Panel A. These results support our identifying assumption that foreign and domestic firms did not face differential shocks that would affect investment during this time period.

The last panel in Table 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 and imply 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 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

[39] This result is also visible in Figure 6, since there is no change in investment patterns in 2008.

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. Table F.6 reports the results of these estimates and finds similar estimates to those of Panel A of Table 3. This result suggests that evasion and avoidance are not important concerns when interpreting our reduced-form results.

Investment Spikes

We now 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 a 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 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 nonspike investment rate, i.e., $IK_{it}^{non-spike} = IK_{it} \times \mathbb{1}\{IK_{it} < 0.2\}$.

Table 4 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 nonspike investment rate. Algebraically, the sum of the effects on the spike and nonspike investment rates add up to the total effect in Panel A of Table 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.

The Refundability of Excess VAT Payments and Partial Irreversibility

While the reform allowed domestic firms to deduct VAT payments on equipment, firms with excess VAT payments were not refunded by the government. This feature presents 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.[40] We define a firm to be in a positive tax position if it

[40] 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.

has a positive *potential* VAT credit, defined by an excessive VAT credit ignoring the input credit from investment.[41] After the reform, 13.38% of domestic firms have a positive tax position.

Table 5 reports heterogeneous effects of the reform on investment by tax position. Columns (1) and (4) show the results for all firms;[42] columns (2) and (5) for firms without 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 still view the VAT as a tax on investment.[43]

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 1 suggest that the estimated effects are not sufficient to evaluate the effects of other reforms.

5 Estimating a Dynamic Investment Model

To study the fiscal effectiveness of alternative policy tools, we now estimate the dynamic model of investment outlined in Section 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 prereform investment statistics as well as the reduced-form effects estimated in Section 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.

[41] 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 $\text{InputVAT}_{it} - \text{OutputVAT}_{it} + \text{Credit}_{i,t-1} - 17\% \times I_{it}$.

[42] The numbers of observations for columns (1) and (4) are different from the baseline results in Table 3 because this table restricts the sample to a balanced panel of firms with a nonmissing tax position.

[43] 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 tax position as a feature of the structural model.

5.1 Estimating the Profit Function and Decomposing Productivity

Recall that our model of firm profit (Equations 3–4) implies:

$$\pi_{it} = \theta k_{it} + (1-\theta)a_{it} = \theta k_{it} + (1-\theta)(b_t + \omega_i + \varepsilon_{it}), \tag{8}$$

where π_{it} is log profit, k_{it} is log capital, b_t is the aggregate shock, ω_i captures firm-specific permanent heterogeneity, and ε_{it} is the idiosyncratic transitory shock. 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 (8) directly. First, it is hard to measure economic profit using accounting data. To avoid this problem, we make the standard assumption in the investment literature that profits are proportional to revenue.[44]

A second set of concerns with Equation (8) 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 (8) 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:

$$r_{it} = \rho_\varepsilon r_{i,t-1} + \theta k_{it} - \rho_\varepsilon \theta k_{i,t-1} + b_t^* + \omega_i^* + m_{i,t} - \rho_\varepsilon m_{i,t-1} + (1-\theta)e_{it}, \tag{9}$$

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.[45] We can then write this equation in first differences to obtain:

$$\Delta r_{it} = \rho_\varepsilon \Delta r_{i,t-1} + \theta \Delta k_{it} - \rho_\varepsilon \theta \Delta k_{i,t-1} + \Delta b_t^* + \Delta m_{i,t} - \rho_\varepsilon \Delta m_{i,t-1} + (1-\theta)\Delta e_{it}. \tag{10}$$

To avoid problems arising from endogenous capital, we instrument this equation using lagged

[44] Appendix A.2 gives examples where this assumption holds either with a DRTS production 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 taking logarithms, the profit and revenue shocks differ by a constant, which implies that a_{it}^R and a_{it} have the same persistence and variance.

[45] This follows from writing Equation (8) 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.

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) that jointly estimates Equation (9) using changes in lagged revenue Δr_{it-s} and capital Δk_{it-s}, $s \geq 2$ as additional instruments.[46]

Panel B of Table 6 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.[47] 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.[48] We then recover the distributions of b_t, ω_i, and ε_{it} by decomposing the variance of the estimated productivity $\hat{a}_{it}$.[49] 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. Due to the short panel nature of our data, aggregate shocks play a relatively small role once we account for persistent idiosyncratic shocks. 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 productivity comes from permanent heterogeneity across firms. However, despite the fact that the distributions of capital stock and firm size depend on permanent heterogeneity, investment dynamics are mostly determined by transitory shocks.

5.2 Estimating Adjustment Costs

We now estimate 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 1 subject to the profit function and productivity shocks estimated in the previous section. We simulate the growth of these firms until the firm size distribution stabilizes. 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.[50] Finally, the estimated adjustment cost parameters are those that best

[46] 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.

[47] 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 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, Hsieh, Qian 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.

[48] Cooper and Haltiwanger (2006) estimate a value of 0.85, and Winberry (2018) fixes this parameter at 0.9.

[49] See Appendix E.3 for more details.

[50] We simulate two sets of firms for the simulated difference-in-differences: a set of treatment firms that pay a VAT rate of $\nu = 17\%$ before the reform and a set of control firms unaffected by the reform.

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 CIT 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 p_v to 0.803.[51]

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 (2018). 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 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 prereform stationary moments (as in Figure 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.[52]

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

[51] 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.

[52] For example, among other moments, Cooper and Haltiwanger (2006) use the spike rate and the autocorrelation coefficient; Winberry (2018) uses the standard deviation of the investment rate and the spike rate; and Clementi and Palazzo (2016) use the standard deviation and the 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.[53]

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 effects of γ and $\bar{\xi}$ on the simulated moments are connected. Consider the convex adjustment cost γ. A higher convex adjustment cost motivates firms to smooth investment over time, and it also decreases the lumpiness of investment. That is, a higher γ decreases both the likelihood of inaction and the likelihood of an investment spike. 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.

The effect of γ on the serial correlation of investment combines two channels. First, a higher γ increases the serial correlation of investment by incentivizing firms to smooth investment over time. Second, a higher γ reduces the serial correlation of investment through an indirect effect on the desired capital level, which increases the relative importance of the fixed cost $\bar{\xi}$. Which channel dominates the other depends on the value of γ, as we show in Figure F.5.

We then use the reduced-form moments m^B to validate the estimated models and as potentially overidentifying moments. As we discuss in Section 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.

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, Gentzkow and Shapiro (2017).

[53]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.

Estimates of Adjustment Costs

Table 7 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 prereform 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 investment 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 7 reports estimates of a model that only targets prereform stationary statistics m^A and that allows ξ to be distributed 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 between 10%–30% (relative to 17% in the data).[54] 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.

The fourth row of Table 7 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.[55] The model predicts an increase of 4.2 percentage points in the fraction of firms investing and an increase of 3.3 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, the majority of the increase in the investment rate following the reform was due to additional investment spikes. We use the effect of the reform on investment

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

[55] Figure F.4 shows that the criterion function is concave and rises sharply around the estimated parameters.

spike as an additional overidentifying moment. Table F.9 reports that the model predicts a 6.4-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 3.6 percentage points (relative to a measured 3.5 percentage points).

Finally, we now consider the economic magnitude of the estimated adjustment costs. The estimated convex cost parameter $\hat{\gamma}$ is 1.432. Given the model's average investment rate of 8%, the convex adjustment cost at the average investment rate would amount to $0.45\%(=\frac{1.432}{2}\times(0.08)^2)$ of capital. To grasp the magnitude of the fixed adjustment, note that the estimated upper bound of 0.119 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 6 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 that the estimated model provides a solid foundation to compare the effects of alternative tax policies.

6 Simulating Alternative Tax Reforms

As we show in Section 1, the effectiveness of different types of tax incentives at stimulating investment depends on how tax policies interact with investment frictions. We now use the estimated dynamic model of investment to quantify which policies are more effective at stimulating investment and firm value relative to their total fiscal cost. To build intuition for the effects of different policies, we first simulate how changing the degree of partial irreversibility in the VAT, changing the CIT rate, or introducing an ITC at different rates affects investment. We then compare the effects of other policies that are closely modeled on the recent US tax reform. Throughout these simulations, we calculate the effects of permanent changes to tax policy over a 10-year window, which matches common tax planning horizons. In addition, we measure firm value as the discounted present value of future after-tax profits.

Panel A of Figure 7 compares the effects of a CIT cut versus those of a VAT cut. The solid blue line reports the effects of reducing the CIT rate from 15.4% to 1%. Each marker in the line represents the simulated effects of reducing the CIT rate to a given level. For example, the x-axis shows that reducing the CIT rate to 10% results in a tax revenue loss of 20% (which includes VAT and CIT revenue). The y-axis shows that this reform results in an increase in investment of 10%. Therefore, this reform implies an investment-to-tax-revenue elasticity of close to 0.5.[56]

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

Consider now the effects of a VAT cut. The dashed red line in Panel A of Figure 7 reports the effects of different cuts in the VAT rate. Because this line is always above the 45-degree line, the investment-to-tax-revenue elasticity is always greater than one. One way to view this graph is as a menu for government officials who want to stimulate investment. This graph allows a government official to compare reforms that result in a similar loss of tax revenue. For instance, cutting the VAT rate to 3% would result in the same 20% revenue loss as the CIT cut discussed above, but would result in an increase in investment of more than 20%. This graph shows that a VAT cut is more effective at stimulating investment for a given revenue cost than a CIT cut. Following the intuition from Figure 4 in Section 1, the effectiveness of the VAT reform is likely due to the decrease in partial irreversibility.

Panel B of Figure 7 compares the effects of a VAT cut to those of introducing an investment tax credit (ITC).[57] 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 ITC also lowers the partial irreversibility of investment. 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 ITC does not. Importantly, this graph shows that the lessons of China's 2009 VAT reform are applicable to other countries or states that already have or that can enact an ITC.

Panels A and B of Figure 8 compare the effects of different VAT, CIT, and ITC incentives on firm value. In contrast to the effects on investment, we find that the loss in revenue from these policies is capitalized into firm value at very similarly rates. One reason for this result is that the fiscal cost is reflected in the present discounted value of future firm profits.

We now build on the intuition from Figure 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 CIT cut from the current effective tax rate of 15.4% to 10%;[58]

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 CIT cut; and

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

[58]This 35% reduction in τ is comparable to the decrease in the CIT following the TCJA in the US.

5. a 17% investment tax credit.

Table 8 uses our dynamic model with adjustment costs to simulate the effects of these policies on investment, firm value, and tax revenues. Column (1) shows that the baseline VAT cut increased the investment rate by 30%. We find a similar effect when we study the average rate across firms and the aggregate investment rate in the economy. Note that, while this number is slightly lower than our reduced-form estimate, the simulated value measures the effects over a decade, while the reduced-form effect corresponds to a three-year period. 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% for every 1% loss in tax revenue. Similarly, firm value increases by 0.41% for a 1% loss in tax revenue.

Consider now the effects of a CIT cut reported in column (2). The CIT cut has a smaller effect on both investment and the fraction of firms that invest in any given year. While this reform also results in a smaller loss in tax revenue, comparing the lost revenue with the investment increase shows that this policy is less effective at stimulating investment than the VAT cut. Figure 4 provides intuition for this result. The policy function in Panel C shows a considerable amount of inaction. This implies that a large fraction of firms will be inframarginal to the tax cut—they will pay less in taxes but will not increase their investment. This is the reason the investment-to-tax-revenue ratio is smaller than in column (1). However, because the inframarginal firms benefit from paying less in taxes, we see that this reform is slightly more effective at stimulating firm value.

Column (3) studies the effects of a bonus depreciation policy that increases the present discounted value of depreciation deductions. This policy has similar effects on investment to the CIT cut but is less effective at raising firm value. This follows from the fact that only firms that invest benefit from the policy. Column (4) combines the effects of a CIT cut and bonus depreciation, mirroring the TCJA in the US. This policy has a similar revenue loss as the VAT reform but raises overall investment by less than the sum of the CIT cut and bonus depreciation, since the tax cut decreases the value of depreciation deductions. When we compare the investment increase to the loss of tax revenue, we find that this policy is just as effective at stimulating investment as the CIT cut or as bonus depreciation. The effectiveness of the policy at raising firm value, however, is closer to the average of these two policies.

The last policy we consider is an investment tax credit of 17%. As shown in Figure 7, 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. Finally, note that the effects we report in Table 8 correspond to average effects of the policy. The concave shape of the VAT and ITC lines in Figure 7 suggests that smaller policies are initially more effective at raising investment relative to the fiscal cost and that this effectiveness decreases with the size of these policies.

Appendix F.1 shows that our baseline simulation results are robust to the following extensions. First, we explore the general equilibrium effect of an increasing capital price. In our baseline model, we assume that capital price—net of taxes—is constant. One concern is that the price of capital increases as the demand goes up (e.g., Goolsbee, 1998). We relax this assumption by calibrating an upward-sloping capital supply curve based on the results of House and Shapiro (2008). Column (2) of Table F.10 shows that this change results in a slightly smaller aggregate effect on investment and an investment-to-tax-revenue elasticity of 0.84. The main result that policies that reduce partial irreversibility are more effective stimulus tools is not affected by allowing for an upward-sloping capital supply curve. A second concern is that the 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 increase the degree of partial irreversibility by reducing the resale price from 1 (as in the baseline model) to 0.95 (as in Cooper and Haltiwanger, 2006). Column (3) of Table F.10 shows our results are virtually unaffected by this change. Third, since the VAT reform took place in 2009 in response to the financial crisis, investment might have been affected by an aggregate productivity drop. Column (4) of Table F.10 shows our results are very similar when the reform coincides with a (permanent) one-standard-deviation drop in aggregate productivity.[59] Finally, our simulations of the effects of CIT cuts on investment abstracted from the fact that debt is a preferred form of financing since interest payments are tax deductible (Graham, 2000). This assumption does not affect our estimation or our simulation of changes to the VAT system. However, since a CIT cut reduces the value of tax-deductible financing, accounting for this effect on the after-tax cost of financing may reduce the effectiveness of CIT cuts at stimulating investment. Table F.11 confirms that when a CIT cut affects a firm's financing costs (through the weighted average cost of capital, WACC), the effectiveness of a CIT cut decreases.

[59]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, 2018) or whether other forms of partial irreversibility that can endogenously respond to fiscal policy (Lanteri, 2018).

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, the paper shows that models of investment with partial irreversibility or fixed costs of adjustment are required to generate extensive-margin responses to tax policy changes. In these models, 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 show that this reform directly affected the likelihood of firm inaction by reducing the degree to which partial irreversibility leads firms to delay adjusting their capital stock. We use administrative 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, and that the nonrefundability of excess VAT credits can also generate partial irreversibility.

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 limit partial irreversibility, 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.

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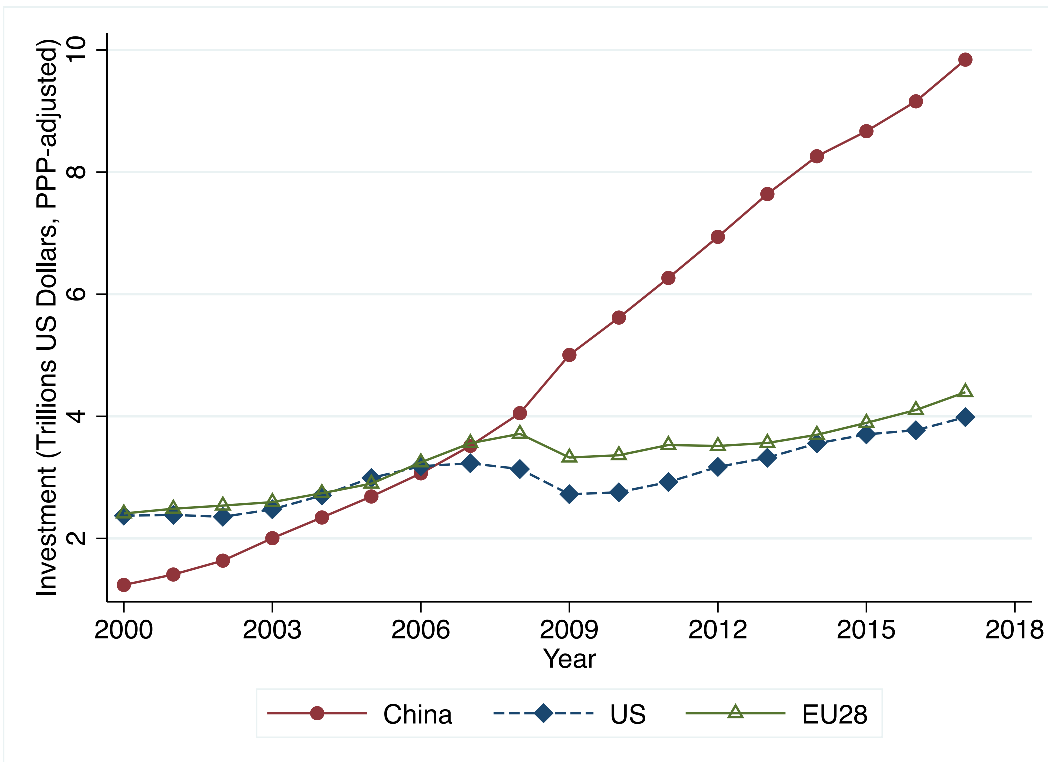
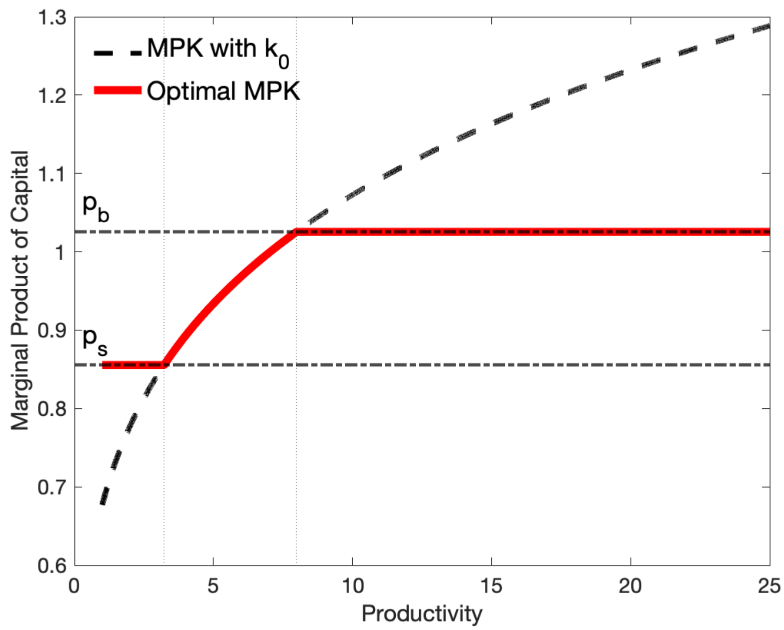
Figure 1: Cross-Country Comparison of Investment



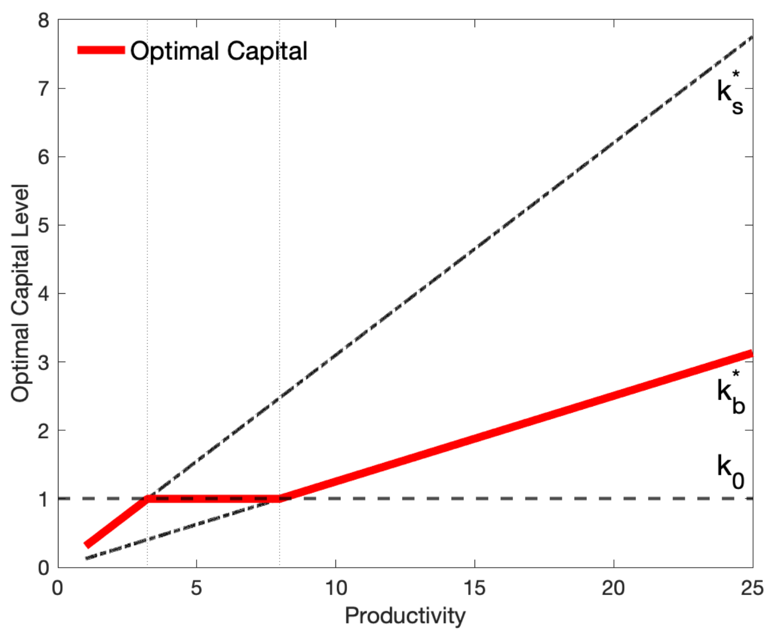
Notes: This figure displays investment in the United States, the European Union, and China from 2000 to 2017 as reported by the OECD. The figure shows that investment in China has long surpassed investment levels in the US and the European Union and that is has increased drastically since 2000.

Figure 2: Effects of Partial Irreversibility

A. Marginal Product of Capital



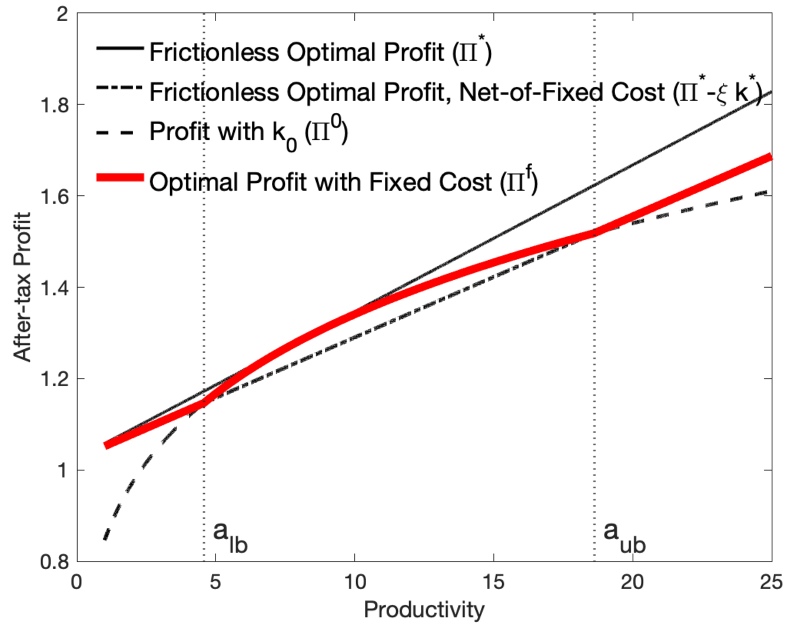
B. Optimal Capital



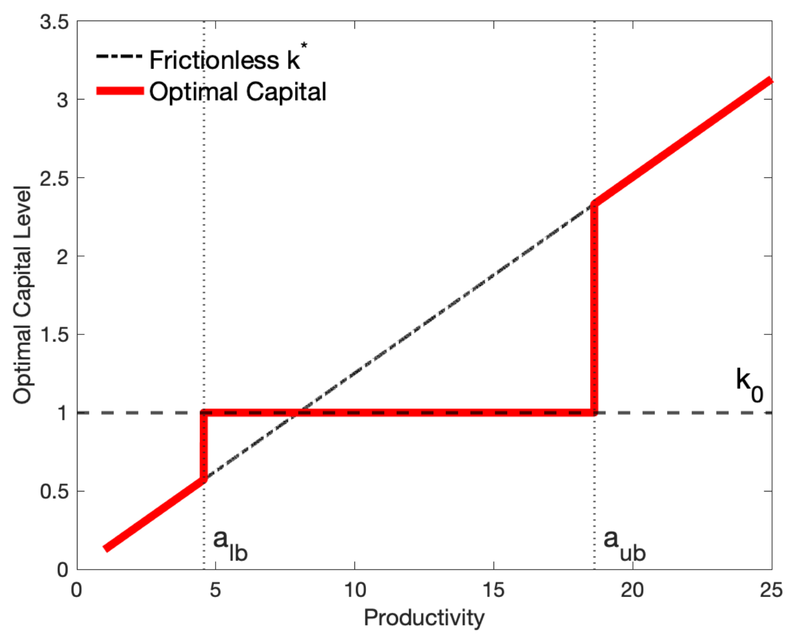
Notes: These figures plot the marginal product of capital and the optimal capital against productivity in a simple static model with only partial irreversibility, i.e., the resale price (p^s) is smaller than the purchase price (p^b). Panel A plots the marginal product of capital (MPK) against productivity. 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.

Figure 3: Effects of Fixed Costs

A. Optimal Profit

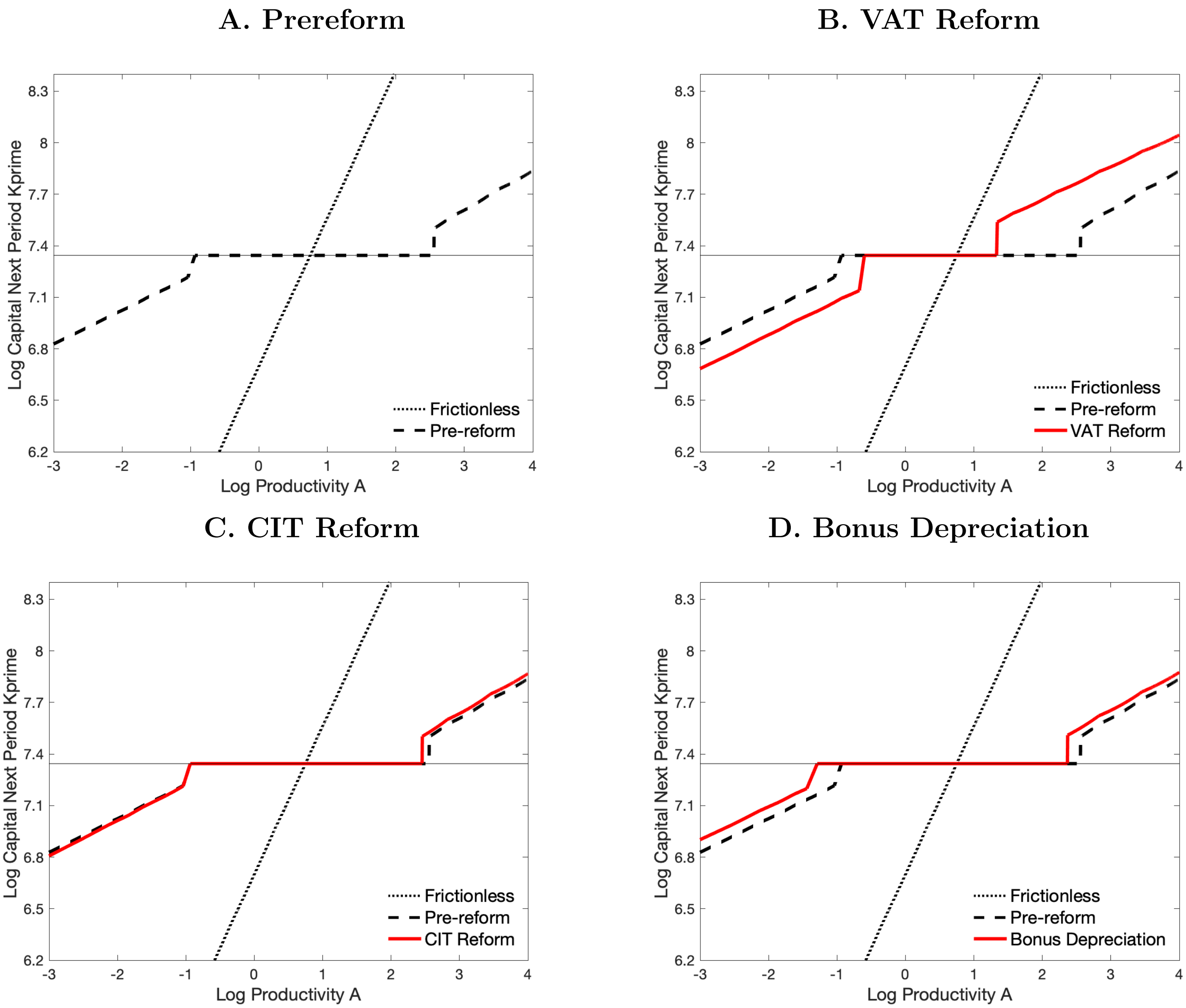


B. Optimal Capital



Notes: These figures plot the optimal profit and capital against productivity in a simple static model with only fixed cost. 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 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 cost. 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 cost.

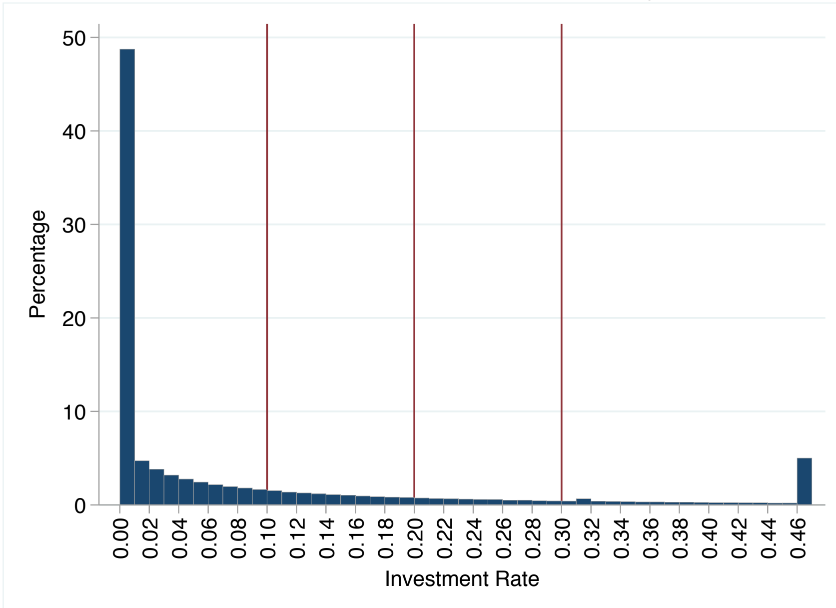
Figure 4: Effects of Tax Policy and Investment Frictions on Policy Functions



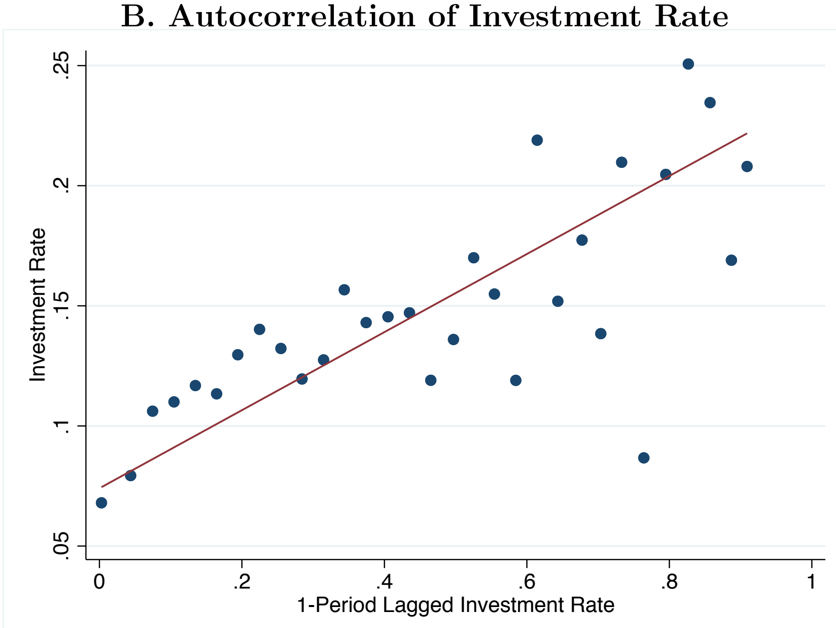
Notes: These figures display the policy functions against productivity in a dynamic investment model before the reform and after VAT reform, CIT reform and bonus depreciation, respectively. In Panel A, the dotted straight line indicates the optimal policy (the logarithm of capital stock in the next period 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 cost, fixed cost and partial irreversibility. Panel B adds the policy function (the red line) after a 17% VAT cut; Panel C plots the policy function after reducing the CIT rate from 15.4% to 10%; Panel D plots the policy function after bonus depreciation that fully accelerates the timing of depreciation deductions.

Figure 5: Distribution of Investment Rate and Autocorrelation

A. Distribution of Investment Rate

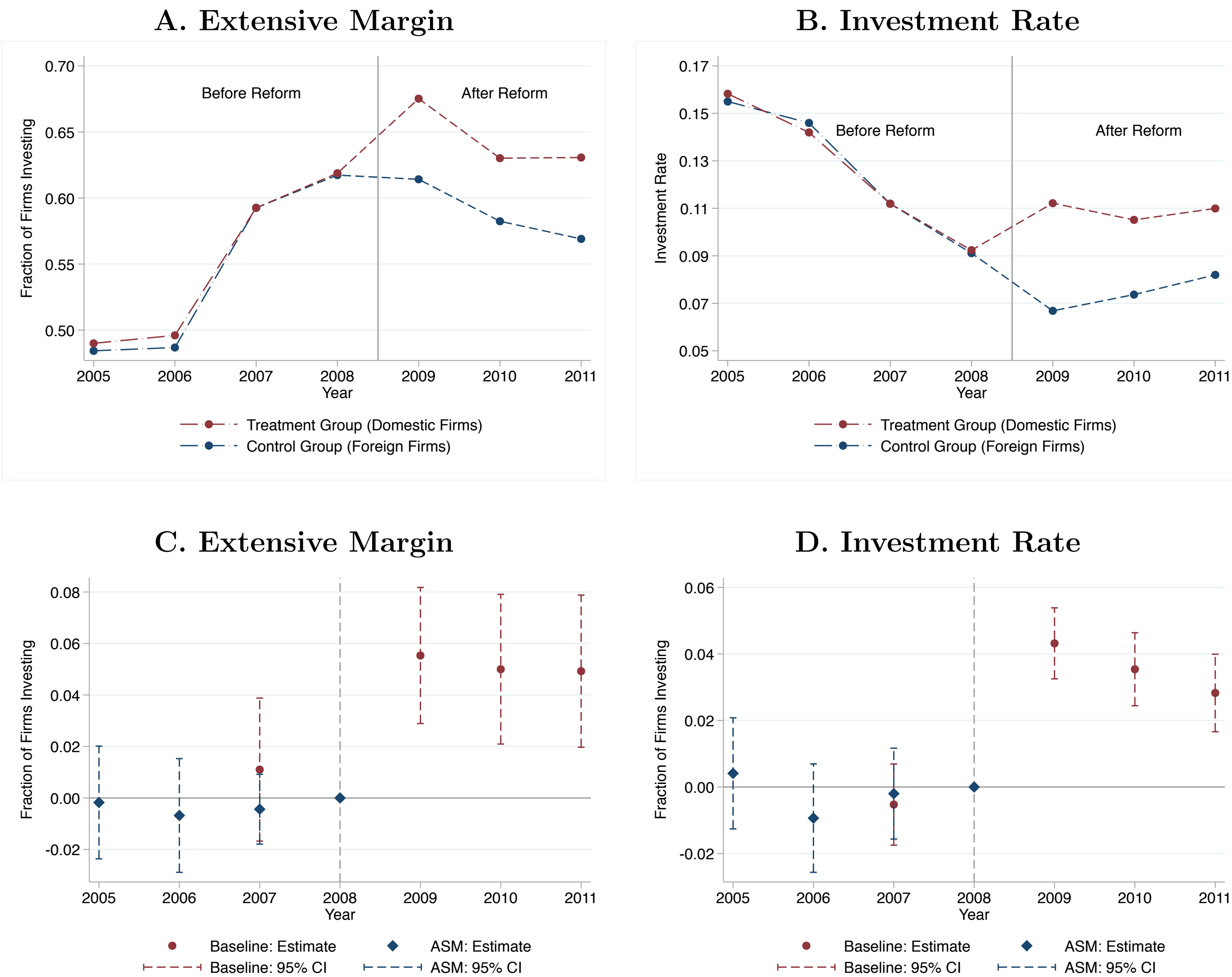


B. Autocorrelation of Investment Rate



Notes: These figures display notable features of the investment data. Panel A plots the distribution of the investment rate of domestic firms before the reform. We winsorize 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.

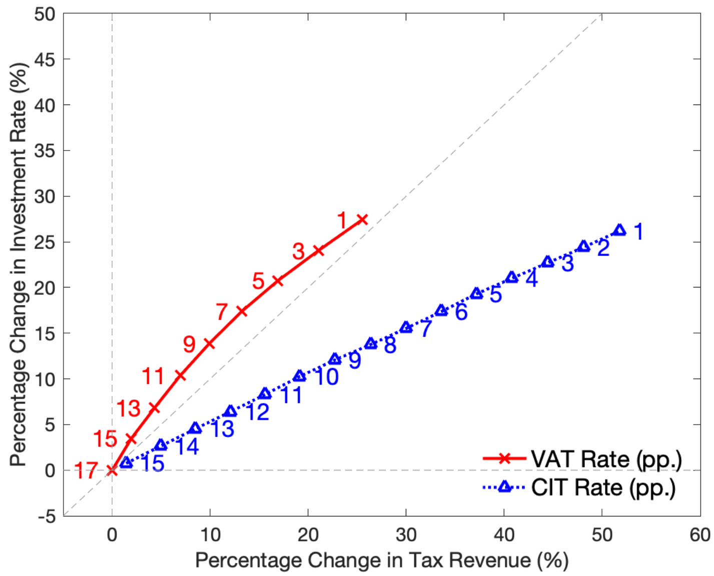
Figure 6: Reduced-Form Effects of China's 2009 VAT Reform



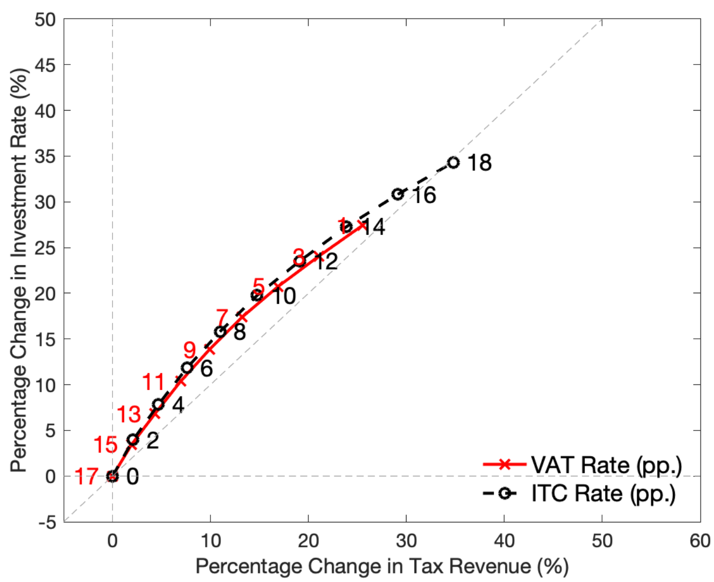
Notes: These figures show the effects of the VAT reform on the investment of domestic and foreign firms. To construct these figures, we first use tax data to calculate the average investment rate of equipment for each year from 2007 to 2011 for domestic firms (the treatment group) and foreign firms (the control group). For easier comparison, we set 2008 as the base year and align the investment rate of equipment for domestic and foreign firms to the pooled average rate in 2008. In addition, we complement the tax data with Chinese Annual Survey of Manufacturing (ASM) data. That is, we merge 2005-2006 ASM with the 2007-2008 tax data; calculate the average rate of total investment for each year from 2005 to 2008 for domestic and foreign firms. Similarly, we align the rates of total investment of the two groups to the pooled average investment rate of equipment in 2008. To do so, we subtract the average rate of total investment in 2008 from each average rate and add the pooled average investment rate of equipment that we obtained from the tax data.

Figure 7: Simulating Alternative Tax Reforms: Elasticity of Investment Rate to Tax Revenue

A. VAT Cuts vs. CIT Cuts



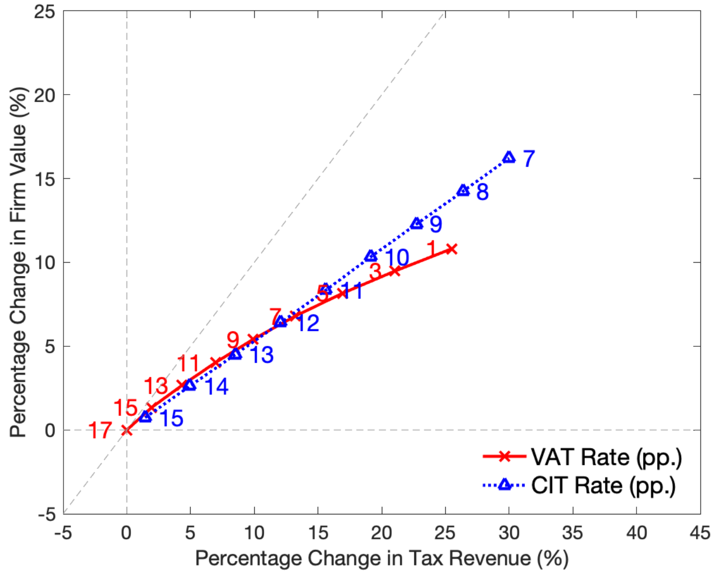
B. VAT Cuts vs. ITC



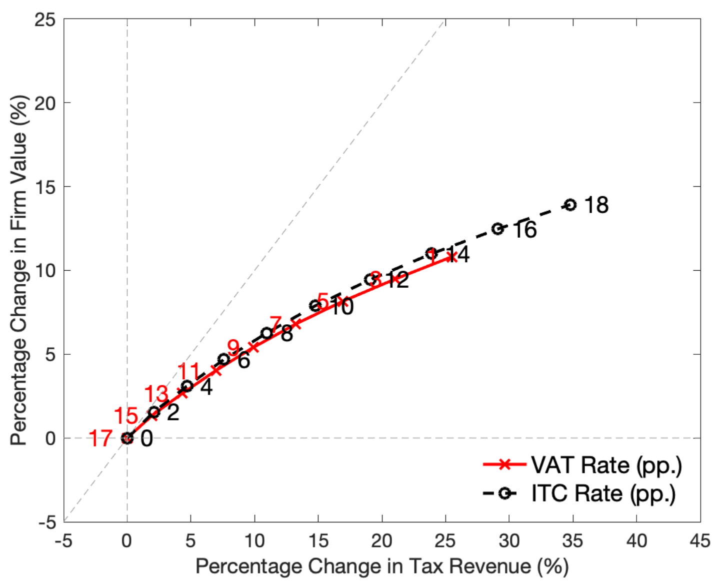
Notes: These figures plot the simulated percentage change in the aggregate investment rate to the percentage loss in tax revenue at different rates of VAT cut, CIT cut and investment tax credit (ITC) policies. For each tax rate, we solve the model; simulate investment, tax revenue; and calculate the corresponding changes in each outcome. Panel A plots the percentage change in the aggregate investment rate 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 CIT cuts from 15.4% to different rates. Similarly, Panel B compares the percentage change in tax revenue from VAT cuts with that from an ITC.

**Figure 8: Simulating Alternative Tax Reforms:
Elasticity of Firm Value to Tax Revenue**

C. VAT Cuts vs. CIT Cuts



D. VAT Cuts vs. ITC



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, CIT cut and investment tax credit (ITC) 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 CIT cuts from 15.4% to different rates. Similarly, Panel B compares the percentage change in tax revenue from VAT cuts with that from an ITC.

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

	Prereform	Postreform	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 CIT	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.

Table 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 measures and variables 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 capital stock measured in book value of net fixed assets. Total investment includes investments in equipment, buildings and structures, and other productive capital. Fixed assets are measured in 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 cash flow statement. Debt is the total debt at the end of year. Variables are winsorized at the 1% level.

Table 3: Estimates of Difference-in-Difference Regressions

	Extensive Margin: % Firms			Intensive Margin: Investment Rate		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel 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
Panel B. Robustness Checks						
	IPW	Unbalanced	All Foreign	IPW	Unbalanced	All Foreign
Domestic × Post	0.075***	0.059***	0.055***	0.030***	0.041***	0.034***
	(0.024)	(0.007)	(0.006)	(0.008)	(0.003)	(0.002)
N	82785	221069	107255	79195	215813	100980
Industry × Year FE	Y	Y	Y	Y	Y	Y
Panel C. Additional Firm-Level Controls						
	CF	Firm Controls	CIT	CF	Firm Controls	CIT
Domestic × Post	0.055***	0.060***	0.061***	0.036***	0.037***	0.036***
	(0.010)	(0.010)	(0.011)	(0.004)	(0.004)	(0.005)
N	83418	86284	86870	79547	80823	81270
Industry × Year FE	Y	Y	Y	Y	Y	Y
Firm Controls		Y			Y	
Panel D. Placebo Test						
Domestic × Post	-0.011	-0.018	-0.010	0.016	0.012	0.017
	(0.030)	(0.031)	(0.032)	(0.013)	(0.013)	(0.013)
N	13940	13940	13940	12350	12350	12350
Industry × Year FE	Y		Y	Y		Y
Province × Year FE		Y	Y		Y	Y
Panel E. Alternative Investment Measures						
	Log Investment			IHS Investment		
Domestic × Post	0.449***	0.404***	0.414***	0.716***	0.633***	0.653***
	(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 estimates 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, and $Post_t$ is the post-reform indicator. Panel A reports the baseline results. The dependent variable for column (1)-(3) is a dummy variable set to 1 if a firm makes investment; the dependent variable for column (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 augments the regression with additional controls. Column (1) controls for firms' net cash flow scaled by capital stock. Column (2) adds quadratics in sales, profit margin, and age. Column (3) adds statutory CIT rate. Panel D reports the placebo test with the same specification as Panel A but using domestic and foreign firms in the pilot project. 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: 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 estimates 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 a measure regarding investment spikes, G_i is the treatment indicator, and $Post_t$ is the postreform indicator. The dependent variable for columns (1) to (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) to (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) to (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.

Table 5: 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	0.041***	0.051***	-0.007	0.040***	0.046***	0.016***
	(0.012)	(0.012)	(0.014)	(0.005)	(0.005)	(0.006)
N	72815	61183	11632	67765	56712	11053
P-val of difference			0.00			0.00
Industry × Year FE	Y	Y	Y	Y	Y	Y
Province × Year FE	Y	Y	Y	Y	Y	Y

Notes: This table estimates difference-in-difference regressions of the form:

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

where Y_{it} is equipment investment, G_i is the treatment indicator, and $Post_t$ is the postreform indicator. We conduct 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 positive potential VAT credit. Particularly, the VAT credit of firm i at time $t = \text{InputVAT}_{it} - \text{OutputVAT}_{it} + \text{Credit}_{i,t-1}$ for domestic firms prior the reform and $= \text{InputVAT}_{it} - \text{OutputVAT}_{it} + \text{Credit}_{i,t-1} - 17\% \times I_{it}$ 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) to (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 fixed effects. Standard errors are clustered at the firm level.

Table 6: 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	p_v	0.803
Panel B. Parameters Estimated via System GMM		
Profit curvature	θ	0.734 (0.030)
Persistence firm transitory shocks	ρ_ε	0.860 (0.012)
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	1.432 (0.061)
Upper bound of fixed cost	$\bar{\xi}$	0.119 (0.004)
Economic depreciation rate	δ	0.071 (0.001)

Notes: This table summarizes parameters in Section 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 the 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 5.1). 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 5.2). Standard errors of those parameters (i.e., γ, $\bar{\xi}$, and δ) are calculated from 100 bootstrap samples.

Table 7: 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	0.892	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	0.092	0.861	0.861	0.863	0.271	0.228	0.149	0.151
(A)	(0.141)	(0.012)	(0.001)								
Uniform	1.594	0.118	0.071	0.080	0.742	0.793	0.879	0.198	0.137	0.030	0.028
(A)	(0.090)	(0.003)	(0.001)								
Uniform	1.432	0.119	0.071	0.081	0.748	0.795	0.875	0.208	0.140	0.042	0.033
(A+B)	(0.061)	(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) to (11) show the simulated moments: 1) Set A includes prereform static moments—the average investment rate; fraction of firms with investment rate smaller than 0.1, 0.2 and 0.3; 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 prereform static moments. Meanwhile, we simulate another counterfactual economy where the reform does not take place. 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 nonrandom, and uses prereform 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 prereform static moments for estimation. The fourth row uses both prereform 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. Standard errors of estimates are reported in parentheses below the point estimates.

Table 8: Simulating Tax Reforms

	Baseline 17%	CIT Cut 15.4% to 10%	Bonus Depreciation	TCJA: BD+CIT	ITC 17%
Percentage Change in	(1)	(2)	(3)	(4)	(5)
Average Investment Rate	0.29	0.09	0.07	0.14	0.33
Aggregate Investment Rate	0.29	0.10	0.07	0.15	0.33
Fraction of Firms Investing	0.10	0.06	0.03	0.08	0.10
Tax Revenue	-0.28	-0.19	-0.13	-0.29	-0.32
Firm Value	0.11	0.10	0.02	0.12	0.13
Ratio of Investment to Tax Revenue	1.04	0.54	0.53	0.52	1.03
Ratio of Firm Value to Tax Revenue	0.41	0.54	0.13	0.41	0.41

Notes: This table displays the simulated responses to five scenarios: column (1) considers reducing the VAT rate from 17% to zero, i.e., our baseline reform; column (2) considers reducing the effective CIT rate from 15.4% to 10%; column (3) allows firms to fully depreciate capital expenses immediately, i.e., bonus depreciation; column (4) combines a CIT cut and bonus depreciation, i.e., a version of the Tax Cuts and Jobs Act (TCJA); column (5) grants a 17% investment tax credit (ITC). We report percentage (%) changes in the outcomes of interest. For instance, our baseline 17% VAT cut increases the average investment rate by 29% over a 10-year window.

Online Appendix: Not for Publication

This appendix includes supplemental information and additional analyses. Appendix A provides detailed derivations of the model. Appendix B describes additional policy details. Appendix C describes the data sources. Additional results of reduced-form analysis, structural estimation and simulations are reported in Appendix D, E and F, respectively.

A Model Appendix

A.1 Static Model

This section documents derivations of the static models following the setup of the firm problem in Section 1.

A.1.1 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

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

- 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

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

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

A.1.2 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 1. The optimal profit conditional on adjusting is:

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

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:

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

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

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

A.1.3 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 $p = p_k(1 - \tau p_v)$ and where we assume that $D'(K) \geq 0$ and $D''(K) \geq 0$. The firm's FOC is:

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

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

$$\begin{aligned}
(\theta-1)\frac{1}{K}\frac{\partial K}{\partial p_k} &= \frac{1}{p+D'(K)}\left(\frac{\partial p}{\partial p_k}+D''(K)\frac{\partial K}{\partial p_k}\right)\\
(\theta-1)\varepsilon_{K,p_k} &= \underbrace{\frac{p}{p+D'(K)}}_{s^p}\varepsilon_{p,p_k}+\frac{D'(K)}{p+D'(K)}\varepsilon_{K,p_k}\underbrace{\left(\frac{D''(K)K}{D'(K)}\right)}_{\alpha(K)}\\
(\theta-1)\varepsilon_{K,p_k} &= s^p\varepsilon_{p,p_k}+(1-s^p)\varepsilon_{K,p_k}\alpha(K)\\
\varepsilon_{K,p_k} &= \frac{-s^p}{1-\theta+(1-s^p)\alpha(K)},
\end{aligned} \tag{A.6}$$

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 $\alpha(K)=\frac{D''(K)K}{D'(K)}$, and the last line solves for ε_{K,p_k} and uses the fact that $\varepsilon_{p,p_k}=1$.

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

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

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

To interpret Equations A.6 and A.7, note that s^p is the share of the price of capital in the total marginal cost of investment $(p+D'(K))$.[60] 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 $D'(K)$.[61] 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.

Comparing Equations A.6 and A.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 $D(K)=\frac{\gamma}{2}\left(\frac{K}{K_0}-1\right)^2K_0$ 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:

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

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

[61] 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.

A.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:

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

Thus, the optimal revenue and profit are:

$$\begin{aligned}
R^* &= \left\{\underbrace{\left[\frac{(1-\alpha)(1-\sigma)}{w}\right]^{\frac{1-\sigma\eta}{1-\eta}}\left[\frac{\sigma}{p^M}\right]^{\frac{\sigma\eta}{1-\eta}}A}_{A^R}\right\}^{1-\underbrace{\frac{\alpha(1-\sigma)\eta}{1-\eta[(1-\alpha)(1-\sigma)+\sigma]}}_{\theta}} K^{\frac{\alpha(1-\sigma)\eta}{1-\eta[(1-\alpha)(1-\sigma)+\sigma]}} = (A^R)^{1-\theta}K^{\theta},\\
\Pi^* &= \{1-\eta[(1-\alpha)(1-\sigma)+\sigma]\}\,R^*\\
&= \left\{\underbrace{(1-\tau)^{\frac{1}{1-\theta}}\,\{1-\eta[(1-\alpha)(1-\sigma)+\sigma]\}^{\frac{1}{1-\theta}}\,A^R}_{A^{\Pi}}\right\}^{1-\theta} K^{\theta} = (A^{\Pi})^{1-\theta}K^{\theta}, \qquad \text{(A.8)}
\end{aligned}$$

where the parameter θ, and profit shocks A^{Π} are defined by:

$$\theta = \frac{\alpha(1-\sigma)\eta}{1-\eta[(1-\alpha)(1-\sigma)+\sigma]},$$
$$A^{\Pi} = (1-\tau)^{\frac{1}{1-\theta}} \{1-\eta[(1-\alpha)(1-\sigma)+\sigma]\}^{\frac{1}{1-\theta}} \left[\frac{(1-\alpha)(1-\sigma)}{w}\right]^{\frac{1-\sigma\eta}{1-\eta}} \left[\frac{\sigma}{p^M}\right]^{\frac{\sigma\eta}{1-\eta}} A.$$

A.3 Value Function and Normalization

This section details the derivation of the value function.

A.3.1 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 CIT 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 ($\xi K^*$), 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:

$$V^0(K, D, A^{\Pi}) = \int_0^{\bar{\xi}} V(K, D, A^{\Pi}, \xi) dG(\xi). \tag{A.9}$$

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

$$
\begin{aligned}
V^b(K, D, A^\Pi, \xi) &= (1-\tau)\Pi(K, A^\Pi) + \tau\hat{\delta}D \\
&+ \max_{I>0}\left\{-[1+\nu-\tau\hat{\delta}(1+\nu)]I - \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* + \beta\mathbb{E}[V^0(K', D', A^{\Pi'})|A^\Pi]\right\} \\
V^s(K, D, A^\Pi, \xi) &= (1-\tau)\Pi(K, A^\Pi) + \tau\hat{\delta}D \\
&+ \max_{I>0}\left\{-[1+ \quad -\tau\hat{\delta}(1+\nu)]I - \frac{\gamma}{2}\left(\frac{I}{K}K\right)^2 - \xi K^* + \beta\mathbb{E}[V^0(K', D', A^{\Pi'})|A^\Pi]\right\} \\
V^i(K, D, A^\Pi, \xi) &= (1-\tau)\Pi(K, A^\Pi) + \tau\hat{\delta}D + \beta\mathbb{E}[V^0(K(1-\delta), D(1-\hat{\delta}), A^{\Pi'})|A^\Pi]
\end{aligned}
$$

The capital stock K and depreciation allowance D evolve according to the following laws of motion:

$$
\begin{aligned}
K' &= (1-\delta)K + I \\
D' &= (1-\hat{\delta})[D + (1+\nu)I].
\end{aligned}
$$

A.3.2 Simplification

Winberry (2018) 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 p_v, which is defined recursively as

$$p_v = \hat{\delta} + (1-\hat{\delta})\beta\mathbb{E}[p_v']. \tag{A.10}$$

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

$$\begin{aligned}
\tilde{V}^0(K, A^\Pi) &= \int_0^{\bar{\xi}} \tilde{V}(K, A^\Pi, \xi) dG(\xi) \\
\tilde{V}^b(K, A^\Pi, \xi) &= \max_{I>0} \; (1-\tau)\Pi(K, A^\Pi) - \left[[1+\nu-\tau p_v(1+\nu)]I + \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K + \xi K^* \right] \\
&\quad + \beta \mathbb{E}[\tilde{V}^0(K', A^{\Pi'})|A^\Pi] \\
\tilde{V}^s(K, A^\Pi, \xi) &= \max_{I<0} \; (1-\tau)\Pi(K, A^\Pi) - \left[[1 \qquad -\tau p_v(1+\nu)]I + \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K + \xi K^* \right] \\
&\quad + \beta \mathbb{E}[\tilde{V}^0(K', A^{\Pi'})|A^\Pi] \\
\tilde{V}^i(K, A^\Pi, \xi) &= (1-\tau)\Pi(K, A^\Pi) + \beta \mathbb{E}[\tilde{V}^0(K(1-\delta), A^{\Pi'})|A^\Pi]
\end{aligned}$$

We sketch the brief proof here. Rewrite the value function as

$$\begin{aligned}
V(K, D, A, \xi) = (1-\tau)\Pi(K, A) + \tau\hat{\delta}D + \max_I - \left\{ [1+\nu-\tau\hat{\delta}(1+\nu)]\mathbb{1}_{I>0} + [1-\tau\hat{\delta}(1+\nu)]\mathbb{1}_{I\leq 0} \right\} I \\
-\frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \mathbb{1}_{I\neq 0} + \beta \mathbb{E}[V(K', D', A', \xi')|A]
\end{aligned} \tag{A.11}$$

Consider the set of functions of the form $f(K, A, D, \xi) = g(K, A, \xi) + \tau p_v D$, where $p_v = \hat{\delta} + (1-\hat{\delta})\mathbb{E}[p_v']$, and the operator T defined by the right hand side of Bellman Equation (A.11).

Claim: The operator T maps a function of the form $f(K, A, D, \xi) = g(K, A, \xi) + \tau p_v D$ to itself.
Proof: Applying the operator T to $f(K, A, D, \xi)$, we get that

$$\begin{aligned}
Tf(K, A, D, \xi) = (1-\tau)\Pi(K, A) + \tau\hat{\delta}D + \max_I - \left\{ [1+\nu-\tau\hat{\delta}(1+\nu)]\mathbb{1}_{I>0} + [1-\tau\hat{\delta}(1+\nu)]\mathbb{1}_{I\leq 0} \right\} I \\
-\frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \mathbb{1}_{I\neq 0} + \beta \mathbb{E}[g(K', A', \xi') + \tau p_v' D'|A]
\end{aligned}$$

By the law of motion for the depreciation allowance $D' = (1-\hat{\delta})[D + (1+\nu)I]$, we have that

$$\begin{aligned}
Tf(K,A,D,\xi) &= (1-\tau)\Pi(K,A) + \tau\hat{\delta}D + \max_I -\left\{[1+\nu-\tau\hat{\delta}(1+\nu)]\mathbb{1}_{I>0} + [1-\tau\hat{\delta}(1+\nu)]\mathbb{1}_{I\leq 0}\right\} I \\
&\quad - \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \mathbb{1}_{I\neq 0} + \beta\mathbb{E}[g(K',A',\xi')|A] + \tau(1-\hat{\delta})\beta\mathbb{E}[p_v']D + \tau(1-\hat{\delta})\beta\mathbb{E}[p_v'](1+\nu)I \\
&= (1-\tau)\Pi(K,A) + \tau[\hat{\delta} + (1-\hat{\delta})\beta\mathbb{E}[p_v']]D + \\
&\quad \max_I -\left\{[1+\nu-\tau(1+\nu)(\hat{\delta}+(1-\hat{\delta})\beta\mathbb{E}[p_v'])]\mathbb{1}_{I>0} + [1-\tau(1+\nu)(\hat{\delta}+(1-\hat{\delta})\beta\mathbb{E}[p_v'])]\mathbb{1}_{I\leq 0}\right\} I \\
&\quad - \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \mathbb{1}_{I\neq 0} + \beta\mathbb{E}[g(K',A',\xi')|A] \\
&= \Pi(K,A) + \tau p_v D + \max_I -\{[1+\nu-\tau(1+\nu)p_v]\mathbb{1}_{I>0} + [1-\tau(1+\nu)p_v]\mathbb{1}_{I\leq 0}\} I \\
&\quad - \frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \mathbb{1}_{I\neq 0} + \beta\mathbb{E}[g(K',A',\xi')|A],
\end{aligned} \tag{A.12}$$

where the last equation follows the definition of $p_v = \hat{\delta} + (1-\hat{\delta})\mathbb{E}[p_v']$. Note that the right-hand side of Equation (A.12) is also a function of the form $h(K,A,\xi) + \tau p_v D$. That is, the operator T maps function $f(K,A,D,\xi) = g(K,A,\xi) + \tau p_v D$ to itself. Since the set of 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:

$$V(K,A,D,\xi) = \tilde{V}(K,A,\xi) + \tau p_v D. \tag{A.13}$$

Substituting Equation (A.13) back into the original value function (Equation (A.11)) and canceling-out common terms on both sides, we have

$$\begin{aligned}
\tilde{V}(K,A,\xi) = (1-\tau)\Pi(K,A) + \max_I -\{[1+\nu-\tau p_v(1+\nu)]\mathbb{1}_{I>0} + [1-\tau p_v(1+\nu)]\mathbb{1}_{I\leq 0}\} I \\
-\frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K - \xi K^* \mathbb{1}_{I\neq 0} + \beta\mathbb{E}[\tilde{V}(K',A',\xi')|A].
\end{aligned}$$

A.3.3 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

$$\begin{aligned}
v^0(k,b,\varepsilon) &= \int_0^{\bar{\xi}} v(k,b,\varepsilon,\xi)dG(\xi) \\
v^b(k,b,\varepsilon,\xi) &= \max_{i>0}\ (1-\tau)\pi(k,b,\varepsilon) - \left[[1+\nu-\tau p_v(1+\nu)]i + \frac{\gamma}{2}\left(\frac{i}{k}\right)^2 k + \xi k^*\right] + \beta\mathbb{E}\left[v^0\left(k',b',\varepsilon'\right)|b,\varepsilon\right], \\
v^s(k,b,\varepsilon,\xi) &= \max_{i<0}\ (1-\tau)\pi(k,b,\varepsilon) - \left[[1-\tau p_v(1+\nu)]i + \frac{\gamma}{2}\left(\frac{i}{k}\right)^2 k + \xi k^*\right] + \beta\mathbb{E}\left[v^0\left(k',b',\varepsilon'\right)|b,\varepsilon\right], \\
v^i(k,b,\varepsilon,\xi) &= (1-\tau)\pi(k,b,\varepsilon) + \beta\mathbb{E}\left[v^0\left(k'(1-\delta),b',\varepsilon'\right)|b,\varepsilon\right].
\end{aligned}$$

The law of motion for capital k is

$$k' = (1-\delta)k + i,$$

where investment is normalized by $i = k' - (1-\delta)k = I/exp(\omega)$.

B Policy Background

This appendix section documents details of the VAT reform (Section B.1) and the CIT reform (Section B.2). Table F.1 summarizes the impact of VAT and CIT reforms on the user cost of capital (UCC).

B.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.[62]

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.

B.2 CIT Reform

In 2008, the Chinese government implemented a Corporate Income Tax (CIT) reform that harmonized the CIT rate for domestic and foreign firms. This reform reduced the CIT rate for domestic firms from 33% to 25% and it raised CIT rate for foreign firms from lower rates to 25% (e.g., see Chen et al. (2019)).

In spite of the changes to the CIT, the effect on the user cost of capital (UCC) was limited since the CIT only distorts the capital price through depreciation deductions. Table F.1 summarizes the VAT rate, CIT rate, and UCCs for domestic and foreign firms from 2007 to 2011. We report two UCC's—a theoretical one and the sample average. The theoretical UCC is calculated using the statutory VAT rate as well as the CIT rate ($= (1+\nu_{\text{statutory}})(1-\tau_{\text{statutory}}p_v)/(1-\tau_{\text{statutory}})$); the sample average UCC is calculated using statutory VAT rate and the empirical CIT rate ($= (1+\nu_{\text{statutory}})(1-\tau_{\text{empirical}}p_v)/(1-\tau_{\text{empirical}})$).[63] While the theoretical UCC drops by 3.8 percentage points in 2008, we do not see a decrease in the sample average. Notably, the UCC then drops by 18.1 percentage points following the VAT reform in 2009. The theoretical and sample average UCC 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.

[62] The regulated industries include coke processing, electrolytic aluminum production, small-scale steel production, and small thermal power generation.

[63] The empirical CIT rate is calculated as τ = actual CIT payable/net profit. We do not observe the separate VAT paid for equipment so we use statutory VAT rate for both measures.

C Data

In this section, we provide more details of the data we use and how we construct the key variables in our empirical analysis.

Comparison to ASM

To examine the data quality, we compare our main data set, the administrative tax records from the Chinese State Administration of Tax—Tax data henceforth—to the Annual Survey of Manufacturing (ASM), which is widely used in research on Chinese firms. Since we only have ASM data from 1998 to 2007 and the Tax data from 2007 to 2011, our comparison is based on a merged sample in year 2007. In particular, we compare the following three groups of firms: 1) unmatched Tax firms, i.e., firms existing only in the Tax data; 2) unmatched ASM firms, i.e., firms existing only in ASM; 3) matched firms, i.e., firms existing in both the Tax data and ASM. For matched firms, we further investigate whether major measures—sales and fixed assets—from the two data sets match well or not. Figure F.1 shows the inverse hyperbolic sine (IHS) measures for sales (Panel A) and fixed assets (Panel B) for the three groups.

There are two patterns worth noting. First, the Tax data cover a wider range of firms compared to the ASM. The ASM only covers those firms with annual sales over 5 million RMB, which yields a sharp cutoff in the sales distribution. The sales distribution of firms existing only in the Tax data, however, is left to that of other firms, indicating the Tax data covers many smaller firms. Second, the sales measures from the two data sets overlap well for matched firms. The measure of fixed assets show the same data patterns as the one of sales.

Investment Measure

We construct our measure of equipment investment by subtracting the increase in buildings from total increase in fixed assets for production. We do so because the direct measure of equipment investment only exists in 2007 and is missing from 2008 to 2011 in the Tax data. To test the validity of this measure, we compare the 2007 indirect measure the 2007 direct measure and find that the indirect measure is equal to the direct measure for 84.68% of observations, which is reassuring. For coherence, we thus use the indirect measure for all the five years.

D Additional Reduced-Form Results

In this section, we present additional reduced-form results.

D.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:

$$G_i = \mathbb{1}\{\alpha + X_i\beta + \Delta Y_i\gamma + u_i > 0\}, \tag{D.1}$$

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.[64] The error term u_i is independently and identically drawn from 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 F.2 reports the estimates of the probit model.

We use the specification in column (6) to generate propensity scores for reweighting. Figure F.2 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 F.3 shows that after reweighting, domestic and foreign firms are balanced in observable characteristics including investment, sales, fixed assets, and the number of workers.

D.2 Event Study Estimates

Table F.3 reports coefficients used in Figure 6 from 2007 to 2011. Particularly, we run the following regression:

$$Y_{ijt} = G_i\gamma_t + \mu_i + \varepsilon_{ijt}, \tag{D.2}$$

where G_i is an indicator that equals one for domestic firms, and μ_i is firm fixed effects. 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-

[64]Growth in log investment is not included because of collinearity with the indicator of firm's investing.

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 F.4 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.

D.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 user-cost-of-capital (UCC) driven by the reform affected investment outcomes. In particular, we estimate the following regression

$$Y_{ijt} = \beta \log(\text{UCC}_{ijt}) + \mu_i + \delta_{jt} + X_{it}'\gamma + \varepsilon_{ijt}, \tag{D.3}$$

where UCC is the user cost of capital from Equation 5. As in Equation 7, 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 D.3. First, both investment and the CIT rate, and thus the UCC, 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 β toward zero. Second, measurement error in investment and the UCC would also bias the estimate toward zero.

To solve these problems, we use a synthetic UCC as an instrument for the actual UCC. In the synthetic UCC, we allow for ν to change with the reform but we hold all other aspects of the UCC constant. Table F.5 shows that this instrument is a powerful predictor of the actual UCC since, as we discuss in Section 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 UCC 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 F.7 reports estimates of semi-elasticities of investment with respect to the UCC. The coefficients on UCC are all negative, indicating investment increases as the UCC 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 UCC by 10% leads to an increase in the fraction of firms investing by 2.4-3.1 percentage points. Similarly, cutting the UCC 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 UCC elasticities between -2.4 and -2.1 for the sample of firms with positive investment. Finally, the last row of Table F.7 shows larger estimates for the IHS, which arise from the larger weight the IHS places on extensive-margin responses.

Table F.7 shows that regardless of how we measure outcomes, the estimates of β are 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.

E Additional Structural Estimation Results

This appendix provides additional details on the structural estimation.

E.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 A.2, we start by taking logarithms of Equation A.8:

$$r_{it} = (1-\theta)a_{it}^R + \theta k_{it}. \tag{E.1}$$

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 (E.1), 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 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:

$$r_{it} = \rho_\varepsilon r_{i,t-1} + \theta k_{it} - \rho_\varepsilon \theta k_{i,t-1} + b_t^* + \omega_i^* + m_{i,t} - \rho_\varepsilon m_{i,t-1} + (1-\theta)e_{it}, \tag{E.2}$$

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 (E.2) with its first-differenced (FD) equation:

$$\Delta r_{it} = \rho_\varepsilon \Delta r_{i,t-1} + \theta \Delta k_{it} - \rho_\varepsilon \theta \Delta k_{i,t-1} + \Delta b_t^* + \Delta m_{i,t} - \rho_\varepsilon \Delta m_{i,t-1} + (1-\theta)\Delta e_{it}. \tag{E.3}$$

We construct a GMM estimator using two sets of moments based on both the level Equation (E.2) and FD Equation (E.3). 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.[65] In our data, we have the moment condition

$$\mathbb{E}[Z_i' U_i] = 0, \quad \forall i,$$

where

$$Z_i = \begin{bmatrix} Z_i^D & \mathbf{0} \\ \mathbf{0} & Z_i^L \end{bmatrix} = \begin{bmatrix} r_{i,07} \; k_{i,07} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & r_{i,07} \; k_{i,07} \; r_{i,08} \; k_{i,08} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \Delta r_{i,08} \; \Delta k_{i,08} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \Delta r_{i,08} \; \Delta k_{i,08} \; \Delta r_{i,09} \; \Delta k_{i,09} \end{bmatrix}$$

$$U_i = \begin{bmatrix} U_i^D \\ U_i^L \end{bmatrix} = \begin{bmatrix} \Delta m_{i,10} - \rho_\varepsilon \Delta m_{i,09} + (1-\theta)\Delta e_{i,10} \\ \Delta m_{i,11} - \rho_\varepsilon \Delta m_{i,10} + (1-\theta)\Delta e_{i,11} \\ (1-\theta)(1-\rho_\varepsilon)\omega_i + m_{i,10} - \rho_\varepsilon m_{i,09} + (1-\theta)e_{i,10} \\ (1-\theta)(1-\rho_\varepsilon)\omega_i + m_{i,11} - \rho_\varepsilon m_{i,10} + (1-\theta)e_{i,11} \end{bmatrix}$$

[65]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.

We then estimate θ and ρ_ε using the GMM estimator.

E.2 Markup

An alternative way to obtain the revenue equation in Appendix A.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

$$\theta = \frac{\alpha(1-\sigma)(1-\zeta)}{1-(1-\zeta)[(1-\alpha)(1-\sigma)+\sigma]}, \tag{E.4}$$

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 (E.4) 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.

E.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 $\hat{\theta}$

$$\hat{a}^R_{it} = r_{it} - \hat{\theta} k_{it}.$$

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:

$$\hat{a}_{it} - \hat{\rho}_\varepsilon a_{it-1} = b_t - \hat{\rho}_\varepsilon b_{t-1} + (1 - \hat{\rho}_\varepsilon)\omega_i + e_{it}, \tag{E.5}$$

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 coefficients by β_t. Then ρ_b and σ_b jointly solve the following equations:

$$\begin{aligned} var(\beta_t) &= (-2\hat{\rho}_\varepsilon \rho_b + 1 + \hat{\rho}_\varepsilon{}^2)\sigma_b^2 \\ cov(\beta_t) &= [-\hat{\rho}_\varepsilon \rho_b^2 + (1 + \hat{\rho}_\varepsilon{}^2)\rho_b - \hat{\rho}_\varepsilon]\sigma_b^2. \end{aligned}$$

We bootstrap this procedure 100 times to obtain standard errors for these parameters.

E.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 F.4, 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 $\hat{\bar{\xi}} = 0.119$ 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.

E.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 F.8 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 5.2.

F 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 the net-of-tax resale price to be less than one; 3) aggregate productivity shocks; and 4) allowing changes in the CIT to impact the weighted average cost of capital (WACC) which is affected by CIT cut. Lastly, we show VAT and CIT cuts with the same UCC reduction may have different effectiveness in stimulating investment.

F.1 Robustness of Policy Simulations

We first show 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. Following estimates from House and Shapiro (2008), we set ε^s to be 10.[66] Using our difference-in-difference estimate for investment rate—36% increase—it follows that the capital price increases by 3.6%.

As a robustness check to our main simulation, we feed in a 3.6% increase in capital price 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 $(1 - \tau p_v)(1 + 17\%)$ to $(1 + 3.6\%) \times (1 - \tau p_v)$, and increases the resale price of capital from $1 - \tau p_v(1 + 17\%)$ to $(1 + 3.6\%) \times (1 - \tau p_v)$. Column (2) of Table F.10 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.

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 0.95 (Cooper and Haltiwanger, 2006). As we show in column (3) of table F.10, 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 F.10 reports the results of this simulation. Our results are robust to allowing for a concomitant productivity drop.

[66] House and Shapiro (2008) estimate the elasticity of supply to be between 6 and 14 using Bonus Depreciation in the US.

Weighted Average Cost of Capital

Our model assumes that changes in CIT do not affect the cost of capital. Note that this assumption has no effect on our estimation. However, the effects of changes in CIT may be different if the CIT affects the costs of capital.

Here, we extend the constant interest rate r by allowing the CIT 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 CIT 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%.

Table F.11 reports the simulation results allowing for interactions between the CIT and the WACC. In particular, the discount rate $\beta = \frac{1}{1+\text{WACC}}$. The CIT 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 $\frac{(1+\nu)(1-\tau p_v)}{1-\tau}$. Additionally, it increases the expected return on capital, $\frac{1}{\beta}-(1-\delta)$, by reducing the discount rate β. Column (3) reports the results when the CIT cut changes the WACC and thus the discount rate. 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.

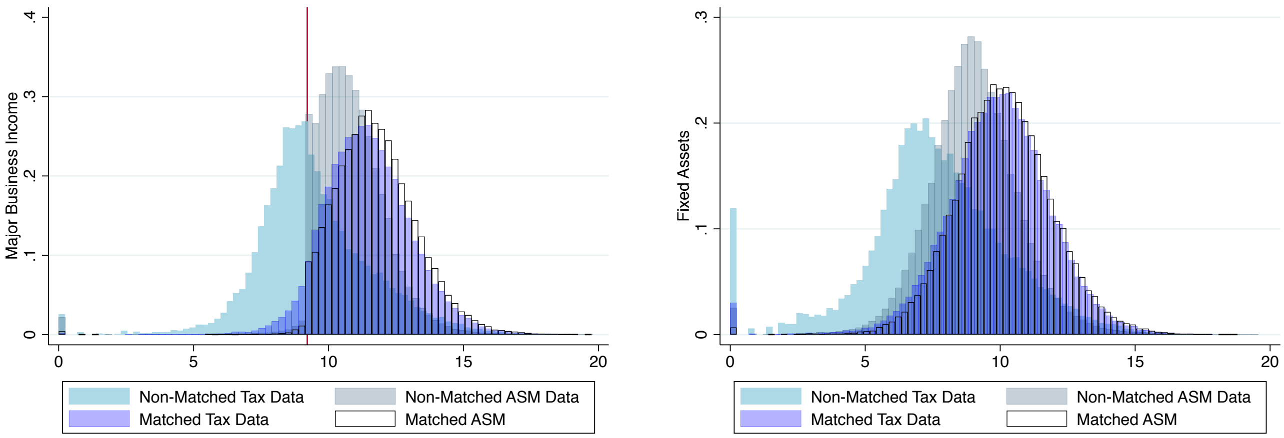
F.2 UCC Elasticities are Not Sufficient Statistics

To show that the UCC is not a sufficient statistic, Table F.12 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 UCC reduction. We use the estimated frictions, i.e., $\gamma = 1.43$, $\bar{\xi} = 0.12$, to simulate tax cuts. Table F.12 shows the results with initial VAT rate at 17% and CIT rate at 15.4%. We compare two reforms with the same reduction in UCC: 1) VAT reform cuts VAT from 17% to 14.2% (i.e., 2.8% rate reduction), and 2) CIT reform cuts CIT rate from 15.4% to 5.4% (i.e., 10% rate reduction). Both reforms reduce UCC by 2.4%. Column (3) also allows the CIT cut to affect the WACC, as in the last section. Because these different reforms have the same effect on the UCC, the fact that the effects on investment differ implies that UCC elasticities are not sufficient statistics for the effects of different policies on investment.

Note that, while a 10% CIT cut has a stronger effect on investment than a 2.8% VAT cut, the CIT cut is far less effective than the VAT cut since the former also leads to large decreases in tax revenue. Furthermore, once we consider the effect on the WACC, the CIT cut is even less effective at stimulating investment.

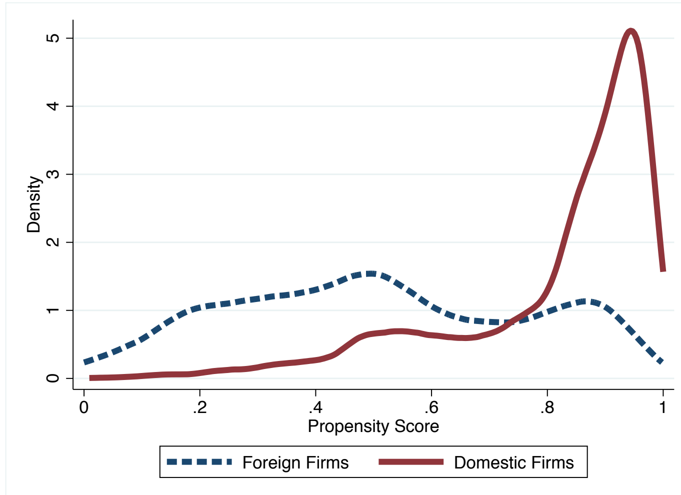
Figure F.1: Comparison of Matched and Unmatched Firms in Tax Data and ASM

A. Major Business Income (Sales) **B. Fixed Assets**



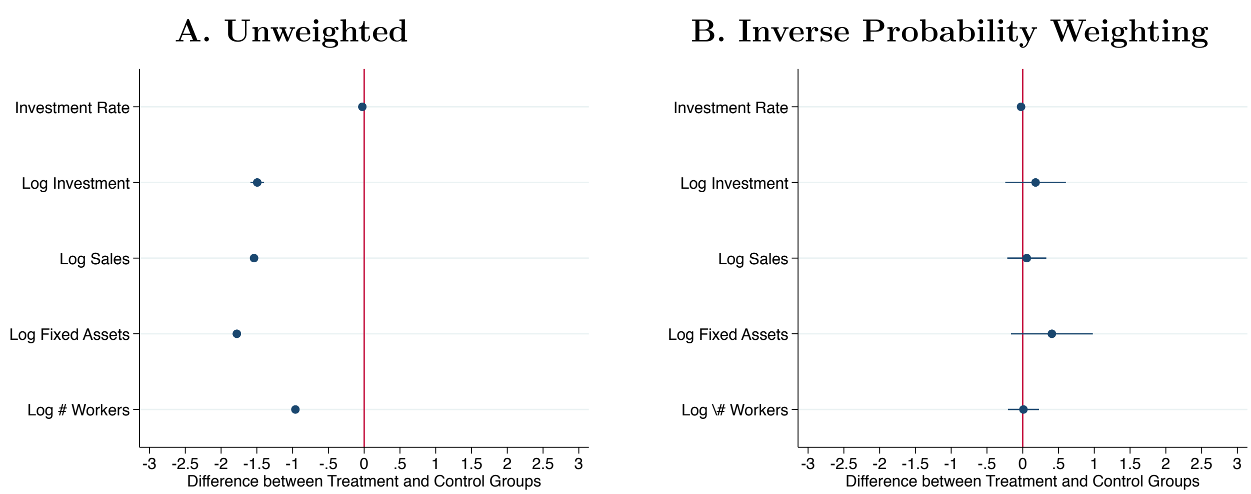
Notes: This figure compares variables from the Tax Data and the Annual Survey of Manufactures (ASM) for 2007. We compare three groups of firms: 1) unmatched Tax firms, i.e., firms existing only in the Tax data, 2) unmatched ASM firms, i.e., firms existing only in ASM, and 3) matched firms. Panel A shows the distribution of sales (in the inverse hyperbolic sine (IHS) transformation). The light blue area indicates the sales distribution of unmatched Tax firms. The grey area indicates the sales distribution of unmatched ASM firms. The dark blue color indicates the sales distribution of matched firms using the measure from Tax data; the transparent area with black borders indicates the distribution of matched firms using the measure from ASM. Similarly, Panel B shows the distribution of IHS measures of fixed assets.

Figure F.2: 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 (D.1)). The estimation results are reported in column (6) in Table F.2. 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.

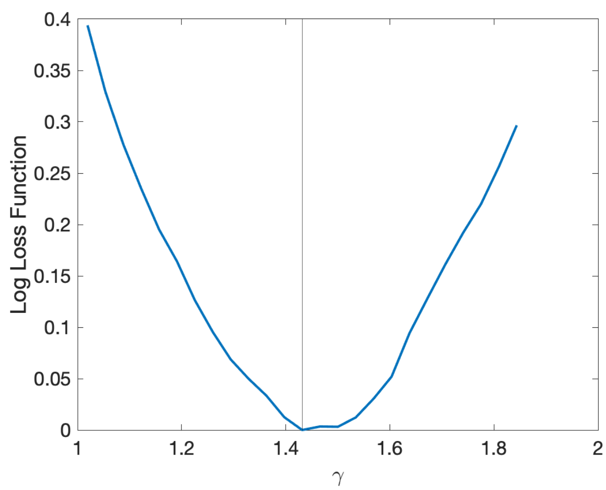
Figure F.3: Mean Difference between Treatment and Control Groups



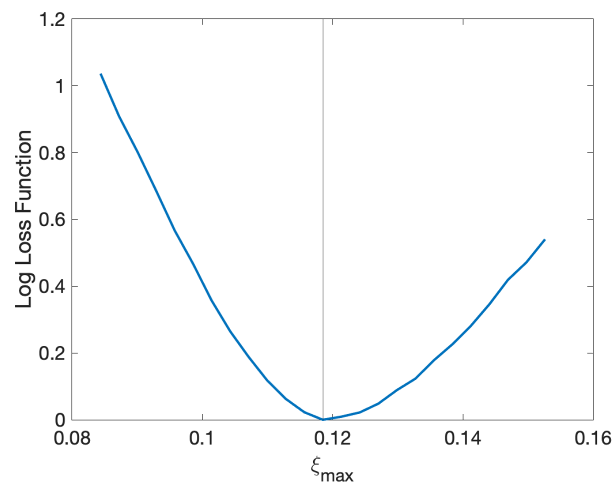
Notes: This graph shows the difference in major variables between the treatment group (i.e., domestic firms) and control group (i.e., foreign firms). The left panel shows the differences before weighting; The right panel shows the differences using inverse probability weighting (IPW). The propensity score is estimated using probit model (see Equation (D.1)). The estimation results are reported in column (6) in Table F.2.

Figure F.4: Loss Function from Structural Estimation

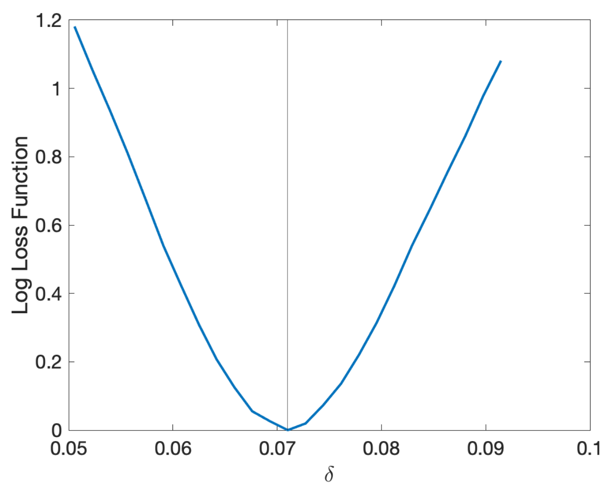
A. γ



B. $\bar{\xi}$



C. δ

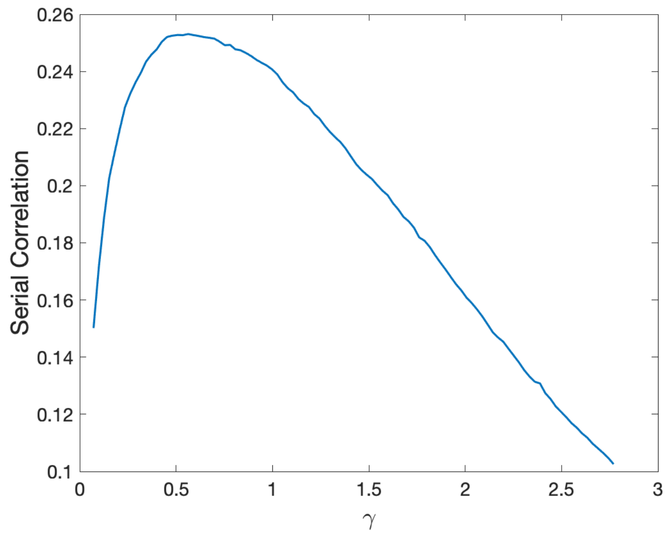


Notes: This graph displays the loss function against each parameter, holding the other two parameters at optimal values. The loss function is calculated by:

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

where the moments $m(\phi)$ include six pre-reform static moments, as well as two investment responses from reduced-form analysis (see Section 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 $\gamma = 1.432$. Panel B and C plot the log loss function against $\bar{\xi}$ and δ, respectively.

Figure F.5: Correlation between Serial Correlation and Convex Adjustment Cost γ



Notes: This graph plots simulated serial correlation against convex cost γ, holding the other two parameters at their estimated values, i.e., fixed cost $\bar{\xi} = 0.119$ and depreciation rate $\delta = 0.710$.

Table F.1: Changes in Tax Rate, Theoretical and Effective User Cost of Capital

Year	CIT(%)	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 (UCC) of domestic and foreign firms, respectively. UCC is calculated by UCC $= (1+\nu)(1-\tau p_v)/(1-\tau)$, where ν is VAT rate, τ is CIT rate, $p_v = 0.803$ is discounted present value of capital depreciation schedule. Column (1) and (2) report the statutory rates of CIT and VAT for domestic and foreign firms, respectively. Theoretical UCC is calculated using statutory VAT and CIT rates. Sample average refers to the average UCC in data, which is calculated using statutory VAT rate but empirical CIT rate. The sample average statistics are calculated using full balanced panel, i.e., firms existing for five years in the sample. Empirical CIT rate is calculated by $\tau =$ actual CIT payable/net profit, which is closer to the "effective" CIT rate.

Table F.2: 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***	-0.866***
	(0.042)	(0.094)	(0.085)	(0.130)	(0.083)	(0.097)
Exporter	-1.004***	-0.287**	-0.309***	-0.373**	-0.280***	-0.328***
	(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***	-0.651***
	(0.024)	(0.045)	(0.050)	(0.101)	(0.045)	(0.050)
% Firms Investing Growth		-0.267				2.953
		(0.346)				(1.872)
Investment Rate Growth			-0.272			-1.049**
			(0.358)			(0.496)
Log Investment Growth				-0.020		
				(0.099)		
IHS Investment Growth					0.022	0.102*
					(0.019)	(0.058)
#Obs	77,939	21,433	20,172	5,836	21,422	20,170
Industry FE	Y	Y	Y	Y	Y	Y
Region FE	Y	Y	Y	Y	Y	Y

Notes: This table displays probit regression results for the propensity score estimation in Equation (D.1). 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.

Table F.3: Estimates of Event Study

	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
R^2	0.009	0.015	0.019	0.008	0.007	0.011
Industry × Year FE	Y		Y	Y		Y
Province × Year FE		Y	Y		Y	Y

Notes: This table estimates event study regressions of the form:

$$Y_{it} = G_i \times \gamma_t + \mu_i + \varepsilon_{ijt},$$

where G_i is an indicator that equals one for domestic firms, and μ_i is firm fixed effects. Dependent variable Y_{ijt} is the investment measure for firm i in industry j 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. Standard errors are clustered at the firm level.

Table F.4: 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
R^2	0.009	0.053	0.006	0.008	0.034	0.005
Industry × Year FE	Y	Y	Y	Y	Y	Y

Notes: This table conducts robustness checks for the event study regressions of the form:

$$Y_{it} = G_i \times \gamma_t + \mu_i + \varepsilon_{ijt},$$

where G_i is an indicator that equals one for domestic firms, and μ_i is firm fixed effects. Dependent variable Y_{ijt} is the investment measure for firm i in industry j 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 D.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 F.5: Estimates of Difference-in-Difference Regressions: UCC

	UCC			Log UCC		
	(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
R^2	0.735	0.736	0.737	0.762	0.762	0.763
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:

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

where Y_{it} is the user cost of capital (UCC), G_i is the treatment indicator, and $Post_t$ is the post-reform indicator. Particularly, the dependent variable for column (1) to (3) is $UCC = (1+\nu)(1-\tau p_v)/(1-\tau)$ where ν is the statutory VAT rate, τ is the empirical CIT rate, and p_v is the discounted present value of capital depreciation schedule. The dependent variable for column (4) to (6) is the logarithm of UCC. 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 F.6: Robustness Check: Investment Including Leasing

	Extensive Margin			Investment Rate		
	(1)	(2)	(3)	(4)	(5)	(6)
Domestic × Post	0.059***	0.044***	0.046***	0.035***	0.037***	0.038***
	(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
R^2	0.010	0.016	0.020	0.008	0.007	0.011
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:

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

where Y_{it} is a measure of investment including leasing, G_i is the treatment indicator, and $Post_t$ is the post-reform indicator. 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 F.7: UCC Semi-Elasticity Regressions Results

	OLS	IV						
	Year FE	Year FE	Industry-Year FE	Province-Year FE	Both FE	Cash Flow	Firm Controls	CIT Rate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Dependent Variable: Dummy Variable if Firms Investing								
log UCC	-0.055*	-0.317***	-0.318***	-0.263***	-0.266***	-0.238***	-0.260***	-0.277***
	(0.031)	(0.058)	(0.060)	(0.062)	(0.064)	(0.064)	(0.064)	(0.074)
N	77677	77661	77661	77661	77661	74959	77265	77661
Panel B. Dependent Variable: Investment Rate								
log UCC	-0.056***	-0.198***	-0.208***	-0.215***	-0.220***	-0.217***	-0.201***	-0.217***
	(0.013)	(0.023)	(0.023)	(0.024)	(0.025)	(0.025)	(0.025)	(0.030)
N	73115	73102	73102	73102	73102	71731	72743	73102
Panel C. Dependent Variable: Log Investment								
log UCC	-0.945***	-2.406***	-2.401***	-2.209***	-2.235***	-2.244***	-2.136***	-2.122***
	(0.193)	(0.291)	(0.301)	(0.314)	(0.322)	(0.328)	(0.319)	(0.403)
N	19607	19607	19606	19604	19603	19164	19594	19603
Panel D. Dependent Variable: IHS Investment								
log UCC	-0.896***	-4.211***	-4.236***	-3.967***	-3.986***	-3.785***	-3.816***	-3.540***
	(0.231)	(0.501)	(0.515)	(0.526)	(0.535)	(0.542)	(0.533)	(0.616)
N	77677	77661	77661	77661	77661	74959	77265	77661

Notes: This table estimates (semi-)elasticity regression of the form:

$$Y_{it} = \beta \log(\text{UCC}_{it}) + \mu_i + \delta_{jt} + X_{it}'\gamma + \varepsilon_{it},$$

where UCC_{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 UCC as instrument, where theoretical UCC 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 CIT rate. All regressions include firm fixed effects. Standard errors are clustered at the firm level.

Table F.8: Sensitivity Analysis of Structural Moments

Moments	10% Change		
	γ	$\bar{\xi}$	δ
Pre-Reform Static Moments			
Avg. Investment Rate	-0.0058	0.0007	0.0006
Share<0.1	-0.5705	0.0218	-0.0065
Share<0.2	-0.1568	-0.0011	-0.0098
Share<0.3	0.5000	-0.0322	-0.0108
Serial Correlation	-0.0562	-0.0052	0.0002
SD. Investment Rate	-0.0739	0.0047	0.0013
Reduced-Form Investment Responses			
Extensive DID	-0.0163	-0.0002	-0.0001
Intensive DID	-0.0118	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 F.9: Structural Estimation and Reduced-Form Moments of Investment Spikes

	Extensive Margin % Firms Investing with $IK > 0.2$	Intensive Margin Spike Investment Rate
Data	0.073	0.035
Model	0.064	0.036

Notes: This table displays additional reduced-form moments regarding investment spike, complementing Table 7. The first row reports difference-in-difference estimates of investment spike responses (column (3) and (6) in Table 4). 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., $\gamma = 1.43$, $\bar{\xi} = 0.12$, for the simulation.

Table F.10: Robustness of Simulating 17% VAT Cut

Change in	Baseline (1)	Upward-Sloping Capital Supply (2)	Resale Price $p_s = 0.95$ (3)	Aggregate Productivity Drop (4)
Average Investment Rate	0.290	0.231	0.290	0.294
Aggregate Investment Rate	0.290	0.232	0.290	0.294
Fraction of Firms Investing	0.098	0.090	0.098	0.102
Tax Revenue	-0.279	-0.277	-0.279	-0.277
Firm Value	0.114	0.090	0.114	0.114
Ratio of Investment to Tax Revenue	1.039	0.836	1.035	1.062
Ratio of Firm Value to Tax Revenue	0.410	0.325	0.409	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 capital supply is upward sloping with the functional form of $p^K = I^{1/\varepsilon^s}$. The elasticity of capital supply with respect to pre-tax capital price ε^s is set to 10. Column (3) assumes the net-of-tax resale price to be 0.95. In column (4), we feed in a one standard deviation permanent drop of aggregate productivity.

Table F.11: Simulating Tax Reforms Incorporating Weighted Average Cost of Capital (WACC)

Change in	Baseline	CIT Cut 15.4% to 10%	
	17%	Constant WACC	Varying WACC
	(1)	(2)	(3)
Average Investment Rate	0.29	0.09	0.03
Aggregate Investment Rate	0.29	0.10	0.04
Fraction of Firms Investing	0.10	0.06	0.02
Tax Revenue	-0.28	-0.19	-0.23
Firm Value	0.11	0.10	0.05
Ratio of Investment to Tax Revenue	1.04	0.54	0.18
Ratio of Firm Value to Tax Revenue	0.41	0.54	0.21

Notes: This table displays simulation results for CIT cut from 15.4% to 10% which 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 F.12: Tax Cuts with Same UCC Reduction

Change in	VAT Cut	CIT Cut	
		Constant WACC	Varying WACC
	(1)	(2)	(3)
Tax Rate (%)	-2.8	-10	-10
UCC (%)	-2.4	-2.4	-2.4
Average Investment Rate (Non-negative, %)	4.7	16.5	5.5
Fraction of Firms Investing (%)	2.3	11.1	4.1
Tax Revenue (%)	-2.9	-35.7	-41.9
Ratio of Investment Rate to Tax Revenue	1.62	0.46	0.18

Notes: The table shows the results with initial VAT rate at 17% and CIT rate at 15.4%. We compare two reforms with the same reduction in UCC: 1) VAT reform cuts VAT from 17% to 14.2% (i.e., 2.8% rate reduction), and 2) CIT reform cuts CIT rate from 15.4% to 5.4% (i.e., 10% rate reduction). Those two reforms have the same impacts on UCC, reducing UCC 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 CIT 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.