Estimating Capital-Labor Substitution in China: Evidence from Firm-Level Data

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Abstract

In this study, we use comprehensive firm-level panel data to estimate firm-level and aggregate-level elasticities of capital-labor substitution in China. For identification, we rely on plausibly exogenous variation in the user cost of capital induced by a tax reform in 2009. Our difference-in-differences estimation shows that the reform increased both a firm's capital stock and its employment level, with a larger impact on capital than on labor. Combined with a factor demand model, these reduced-form estimates suggest a firm-level elasticity of 3.43, implying high substitutability between capital and labor within firms. Furthermore, when factor reallocations across firms and industries are considered, an aggregation exercise yields an aggregate-level elasticity of 4.36 for the entire manufacturing sector. In sum, our results suggest that capital and labor in China are highly substitutable at both the firm level and aggregate level.

Keywords: *elasticity of substitution; capital-labor substitution; tax reform; China*
JEL Classification: *E10; D22; H25*

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1 Introduction

This article uses micro data to estimate the elasticity of substitution between capital and labor for the Chinese economy. The elasticity of capital-labor substitution, first introduced by Hicks (1932) and Robinson (1933), measures the ease with which a firm or an economy can switch between capital and labor during its production process.[1] As a fundamental concept in economics, the elasticity of substitution has been a key parameter in theoretical models. The economic outcomes may vary over time or across space due to different values of the elasticity of substitution, reflecting underlying differences in production technologies.

Early research explored the relationship between the elasticity of substitution and economic growth. de La Grandville (1989) argues that high capital-labor substitutability can drive long-term economic growth.[2] Yuhn (1991) empirically supports this hypothesis by comparing South Korea and the U.S. The study shows that South Korea, which experienced rapid growth, exhibited a high elasticity of substitution, whereas the U.S., with a lower elasticity, had slower growth. Similarly, Easterly and Fischer (1995) attribute the Soviet Union's sluggish growth and collapse to its low capital-labor substitutability. In the post-reform era, China experienced some of the highest economic growth rates globally. Thus, it would be valuable to examine whether the Chinese economy has a high elasticity of substitution, as this could offer new insights into China's economic miracle.

Equally important, economists have long been interested in how the elasticity of substitution relates to the distribution of income across factors. This interest dates back to Hicks (1932) and is more recently revived by Piketty and Zucman (2014). They posit that

[1] The elasticity of substitution between factors is measured as the percentage change in the ratio of the quantities of factors used divided by the percentage change in the ratio of their prices. Robinson (1933) (p.256) defines the elasticity of substitution along a production isoquant with output fixed at $\bar{Y}$. Under perfect competition, it can be expressed as

$$\sigma_{KL} = \left. \frac{\frac{d(K/L)}{K/L}}{\frac{d(F_L/F_K)}{F_L/F_K}} \right|_{Y=\bar{Y}} = \left. \frac{\frac{d(K/L)}{K/L}}{\frac{d(w/r)}{w/r}} \right|_{Y=\bar{Y}}$$

With two inputs, an elasticity greater than one indicates that capital and labor are substitutes, while a value less than one indicates that they are complements.

[2] de La Grandville (1989) contends that high elasticity allows an economy to accumulate capital rapidly without significantly reducing its marginal product. It also suggests that this mechanism probably contributed to the growth miracle in Japan until the late 1980s. de La Grandville's theoretical work is further extended by various studies. For instance, Xue and Yip (2012) argue that higher elasticity of substitution, which increases savings in the steady state, can lead to higher per capita income.

the evolution of factor shares depends crucially on whether this elasticity exceeds one.[3] In addition to the works on growth and distribution, theories of technological progress have also highlighted the role of this elasticity in guiding the direction of innovation (Acemoglu (2002)). Since China is experiencing both rapid technological progress and a declining labor share, it is even more valuable to measure the substitutability of capital and labor in its economy.[4]

Despite its theoretical importance, empirical estimates of the elasticity of capital-labor substitution for China are scarce.[5] This reflects the dual challenges of (1) obtaining factor price movements that are independent of technical change bias to credibly estimate the firm-level elasticity (Diamond et al. (1978)) and (2) estimating the aggregate-level elasticity from firm-level elasticities (Houthakker (1955)).

In this study, we tackle the first challenge by leveraging the plausibly exogenous variation in the user cost of capital caused by a tax reform to estimate firm-level elasticity of substitution. To address the second challenge, we use the methodology of Oberfield and Raval (2021), which accounts for reallocations outside the firm, to derive the aggregate elasticity of substitution from firm-level estimates.

Our estimation process involves the following three steps. First, we estimate the effects of the 2009 value-added tax (VAT) reform on labor and capital, using a panel of manufacturing firms and a difference-in-differences (DD) design. The VAT reform reduced the cost of capital for domestic firms but left capital costs largely unchanged for foreign firms in China. Following Chen et al. (2023), we use foreign firms as the control group for the domestic firms affected by the reform. Thus, our DD estimates capture changes in capital and labor use driven by shifts in factor prices, free from bias due to technical changes. The regression results show that the reform led to a substantial increase in capital stock at the firm level: treated firms saw capital rise by over 25% within five years. However,

[3]Prominent studies include: (1) Piketty and Zucman (2014) and Piketty (2014) both argue that when the elasticity of substitution is higher than one, an increasing capital-labor ratio causes a decline in labor share due to the capital deepening; (2) Karabarbounis and Neiman (2014) suggest that a decline in labor share can be attributed to the decrease in investment prices, provided that the elasticity of substitution is greater than one.

[4]There are a number of studies that emphasize the importance of the elasticity of substitution in a variety of additional areas, including structural change (Alvarez-Cuadrado et al. (2018)), fiscal policy (Chirinko (2002)), and monetary policy (Chirinko and Mallick (2017)).

[5]There is, however, a large empirical literature on estimating the elasticity of substitution at various levels in various countries (Knoblach and Stöckl (2020)).

this capital accumulation was accompanied by much smaller gains in labor input, with employment rising by less than 3% over the same period.

Second, we derive the firm-level elasticity of substitution by combining our reduced-form estimates with a theoretical framework. After the VAT reform, two effects influence firms' adjustments in capital and labor. The lower cost of capital encourages firms to expand production, increasing both capital stock and hiring (the "scale effect"). At the same time, the "substitution effect" leads firms to use more capital and less labor. For capital, both effects are positive. However, the impact on employment depends on which effect dominates: the scale effect increases employment, while the substitution effect reduces it. Building on the insights of Harasztosi and Lindner (2019) and Curtis et al. (2021), we use a simple model of factor demand to separate out the scale effect and the substitution effect underlying firm behavior. We can therefore express the firm-level elasticity as a function of the estimated responses of capital and labor. Based on calibrated parameters for demand elasticity and input cost shares, the model produces a key result: the firm-level elasticity of substitution is calculated at 3.43, implying that capital and labor are substitutes in production for a typical manufacturing firm in China. Repeating the same procedure using industry subsamples separately provides estimates of firm-level elasticities for each industry.

Finally, we adopt the method proposed by Oberfield and Raval (2021) to transform the firm-level elasticities into industry-level elasticities and then into the aggregate-level elasticity for the entire manufacturing sector. The industry-level elasticity of substitution is calculated as a weighted average of the firm-level elasticity of substitution and the industry demand elasticity.[6] This calculation takes into account inter-firm reallocation within industries. The results show that although there is considerable heterogeneity in the industry-level elasticities, most of them exceed one, indicating that capital and labor are substitutable within most industries. These industry-level elasticities are then used to construct an aggregate-level elasticity of substitution that accounts for factor reallocation across industries. The aggregate-level elasticity of substitution is calculated as a weighted average of the mean industry-level elasticity of substitution and the cross-industry demand

[6]The weights for this calculation reflect the relative importance of intra-firm substitution and reallocation.

elasticity.[7] The resulting aggregate-level elasticity of substitution is estimated to be 4.36, suggesting a high degree of substitutability between capital and labor at the aggregate level in China.

As a robustness check, we use an alternative quasi-experimental variation in factor prices—a policy-induced labor cost shock—to estimate the elasticities of substitution. Specifically, we exploit the exogenous variation in minimum wage exposure between 1998 and 2007, using a different panel of firms. By applying a similar factor demand model and aggregation process, we calculate firm-level and aggregate-level elasticities of 3.11 and 4.24, respectively, which are consistent with the estimates from our main analysis. The close alignment of these values strengthens the robustness of our main findings.

Our finding that capital and labor are substitutes at both the firm and aggregate levels in China contrasts with the empirical results of Oberfield and Raval (2021) and others, who find that capital and labor are complements in the U.S.[8] This difference likely stems from fundamental differences in production technologies and institutional factors, such as the role of labor unions, between China and the U.S. The variation in labor-capital substitutability has important implications, as the two countries could experience significantly different economic outcomes when exposed to similar shocks, according to the theories mentioned earlier.

This study contributes to an enormous literature on the estimation of the elasticity of substitution between capital and labor. Despite the importance of this elasticity in the analysis of economic growth and related issues, there is considerable disagreement about its precise value. In particular, the empirical literature, primarily focused on developed economies such as the U.S., has provided a wide range of estimates for the elasticity of substitution (see Knoblach and Stöckl (2020) for a comprehensive review).

Research on the elasticity of substitution for China, the world's second-largest economy and a manufacturing powerhouse, is both scarce and in need of improvement. For instance, previous studies have either focused on firm-level elasticities (e.g., Berkowitz et al. (2017)), which may not reflect aggregate elasticity, or relied on aggregate time-series data that

[7] The weights assigned to each term reflect the respective contributions of within-industry substitution and cross-industry reallocation.

[8] Using a similar approach, Curtis et al. (2021) also find capital and labor to be complements in U.S. production.

are susceptible to confounding effects from biased technological change (e.g., Chang et al. (2016)). Our study addresses these gaps by using plausibly exogenous variation for identification and accounting for reallocations outside the firm, yielding more reliable estimates of both micro and macro elasticities for China.

Our research also contributes to the literature on the impacts of taxation on labor market outcomes. Some studies (e.g., Suárez Serrato and Zidar (2016); Cornelissen et al. (2024)) examine the effects of profit tax change on firms and workers. While recent papers focus on accelerated depreciation policies in the U.S. (e.g., Ohrn (2019); Garrett et al. (2020); Curtis et al. (2021)), we examine a VAT reform in China. Although employment effects in the U.S. vary across policies, we estimate a small but positive impact of capital investment incentives on employment in China. Unlike studies on the U.S., which find minimal effects on labor earnings, we find that these incentives significantly increase workers' earnings in affected firms. The differing labor responses between China and the U.S. are likely due to China's stronger investment incentives[9] and/or varying levels of capital-labor substitution between them.

The remainder of the paper is organized as follows. Section 2 provides details on the policy background and data used in our analysis. Section 3 presents the reduced-form analysis that estimates the impact of the VAT reform on the use of capital and labor by manufacturing firms. In section 4, we use the reduced-form estimates to calculate the firm-level elasticity of substitution. Then, in Section 5, we aggregate the firm-level elasticity to obtain the industry and aggregate elasticities. Section 6 further examines the robustness of our elasticity estimate by using changes in the minimum wage as an alternative source of variation in factor prices. Section 7 concludes the paper.

[9]The bonus depreciation policy in the U.S. from 2001-2011 lowered investment cost by an average of 2.5% (Curtis et al. (2021)). In contrast, China's VAT reform reduced investment cost by 14.5% (see subsection 2.1 for details of this calculation).

2 Background and Data

2.1 Background of the VAT Reform

This subsection describes the institutional background of China's 2009 VAT reform and explains how it created quasi-experimental variation in the user cost of capital for our estimation.

Since its nationwide implementation in 1994, VAT has been China's primary source of tax revenue. As its name implies, VAT is levied on the value added, calculated as the difference between total sales value and the cost of purchased materials. Unlike many other countries with VAT systems, China initially adopted a production-based VAT, where capital goods purchases were not deductible. This design led to double taxation on capital goods, both as final products for producers and as intermediate inputs for users.

In the 2000s, the Chinese government addressed this distortion by reforming the VAT system, shifting it from production-based to consumption-based. The new system allowed firms to deduct input VAT on capital equipment purchases, encouraging investment and technological upgrades. The reform was piloted in July 2004 for select industries in three northeastern provinces and was expected to gradually expand, following the pattern of previous reforms in China. However, in a surprising move, the government announced in late 2008 that the reform would be extended to all industries nationwide by January 2009. Our empirical analysis focuses on this final stage of the 2009 reform.

To illustrate the reform's impact on after-tax investment costs for newly eligible firms, consider a firm purchasing capital equipment for 1,000 yuan. Before the reform, the firm would have paid a 17% VAT on the purchase, raising the total cost to 1,170 yuan. After the reform, the firm could deduct the VAT paid on the equipment from its VAT on sales, reducing the direct investment cost by 170 yuan. As a result, the reform lowered the after-tax user cost of capital by 14.5% for any given equipment price P_E, calculated as $17\% P_E/(1 + 17\%)P_E$.

The 2009 VAT reform serves as a plausibly exogenous source of variation in factor prices, impacting the after-tax cost of capital investment for domestic firms but not for certain foreign firms. Prior to 2009, foreign firms in industries classified as *encouraged* by the government were already eligible for VAT deductions on capital equipment purchases, positioning them as a suitable control group in our difference-in-differences (DD) design. The Chinese government periodically publishes the *Catalogue for the Guidance of Foreign Investment Industries*, categorizing investment projects into encouraged, restricted, prohibited, and allowed (with the latter encompassing projects not explicitly classified in the other three categories). Additionally, firms participating in the *Midwest Advantageous Project* qualify for preferential VAT treatment. However, due to data limitations, we lack precise information on the tax preference status of individual foreign firms.[10] Consequently, our primary analysis includes all foreign firms as a control group. According to Chen et al. (2023), this approximation likely introduces minimal bias, as they find that (1) most foreign firms benefit from preferential treatment, and (2) results are nearly identical whether all foreign firms or only those with preferential status are used as controls. To further validate our findings, we also perform a separate analysis focusing exclusively on foreign firms in the government-designated encouraged industries.

2.2 Data

The primary source of micro data is the National Tax Survey Database (NTSD), created by the State Taxation Administration (STA) of China. Conducted annually, the survey covers both industrial and service firms. The sample includes focused firms that the tax authorities closely monitor, and sample firms chosen with a stratified sampling scheme (based on location, industry, and firm size). Each firm in the survey has a unique tax identifier that enables the construction of a panel. All participating firms must complete a comprehensive questionnaire about their operations, balance sheets, and tax-related information. Since local tax bureaus are vertically controlled by the upper-level governments, the tax survey is less affected by local political influences. Furthermore, thanks to an electronic data-collection system that automatically checks for consistency and the prudence of firms who understand the consequences of knowingly misreporting information to tax authorities,

[10] Chen et al. (2023) use the foreign direct investment records from the Ministry of Commerce (MOC), which provide detailed information about the preferential treatment status of all foreign firms, to define the treatment group in their analysis.

this dataset is less vulnerable to misreporting than other contemporary surveys.[11]

Our analysis examines two key outcome variables: capital and labor inputs used in the firm's production. Labor input is measured by the total number of employees, while capital input is measured by the value of the capital stock, comprising two categories: production equipment and production structures. In instances where the capital stock's value for a given year is not reported, we back it out by adding the value of the investment in that year to the capital stock in the preceding year or subtracting the value of the investment in that year from the capital stock in the subsequent year.[12]

Our working sample is a balanced panel of manufacturing firms that remain in the data from 2007 to 2013. We apply several restrictions to the sample. First, we exclude pilot regions where VAT reforms were implemented prior to 2009 to avoid potential confounding impacts. Second, we drop firms that changed their ownership type, a key variable we use to define the treatment and control groups, during the sample period. Last, we exclude firms with missing or outlier values of a few important variables related to capital and labor. More specifically, we restrict our sample to firms that report non-negative values of fixed assets for production, positive values of wage payable, non-negative and non-missing values of revenue, and maintain a workforce of at least one employee. Imposing these restrictions results in a sample size of approximately 37,000 firms every year.[13]

Table 1 presents the summary statistics of the firms in our analysis sample, consisting of 262,108 firm-year observations. The average capital stock for productive use is approximately 51 million RMB ($\approx$ 6.7 million USD in 2007 prices), and the average number of employees is about 374. We observe that, on average, domestic firms (our treatment group), which account for 72% of all firms, are smaller than foreign firms (our control group) in terms of both capital stock and employment.[14] Specifically, the mean capital stock of

[11] The detailed information about the tax survey data can be found in Brandt et al. (2023). According to Chen et al. (2023), it is unlikely that firms can substantially over-report the equipment investment. The structure of China's VAT system, which incorporates third-party reporting, significantly enhances the likelihood of detecting misreporting by firms, particularly in the case of substantial purchases such as production equipment.

[12] For further details on data and variable construction, see Appendix A.

[13] The details on the variable definitions can be found in Appendix B.

[14] The fraction of domestic firms varies significantly across industries, as shown in Appendix Figure 1 . All firms in the tobacco product industry are domestically owned, in accordance with a legal requirement in China. Therefore, firms in the tobacco product industry are not used in estimating the elasticities of substitution at both the industry and aggregate levels.

Table 1: Summary Statistics for Firm Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All Firms			**Domestic Firms**			**Foreign Firms**		
Variables	Mean	SD	Observations	Mean	SD	Observations	Mean	SD	Observations
Capital Outcomes									
Investment (1,000 yuan)	4,441	17,222	262,108	3,570	15,386	188,272	6,660	21,035	73,836
Capital (1,000 yuan)	51,318	142,854	262,108	41,284	129,219	188,272	76,905	170,163	73,836
Labor Outcomes									
Employment	373.52	628.23	262,108	312.55	552.24	188,272	528.99	767.97	73,836
Earnings Per Worker (1,000 yuan)	25.07	18.06	262,108	21.80	14.87	188,272	33.40	22.29	73,836

Notes: This table reports the summary statistics of firm characteristics. The sample is a balanced panel of manufacturing firms that remain in the National Tax Survey Database from 2007 to 2013. Wage and earnings per worker are deflated to the 2007 level with the consumer price index, while investment and capital stock are deflated to the 2007 level with the national price indices for investment.

domestic firms is 52% of that of foreign firms, and the mean employment of domestic firms is 59% of that of foreign firms.

3 Effects of the VAT Reform on Capital and Labor

In this section, we estimate the reduced-form impacts of the reform on capital and labor outcomes at the firm level. Our primary findings are based on a DD research design, which we will go over in detail below.

3.1 A Difference-in-Differences (DD) Design

As detailed in Section 2, domestic firms in non-pilot regions could not deduct input VAT on equipment before 2009, whereas most foreign firms could do so throughout our sample period. Therefore, the 2009 reform significantly reduced the after-tax investment cost, or the user cost of productive capital, for domestic firms, but had no impact on the same cost for these foreign firms. In a DD framework, we consider domestic firms as the treated group and foreign firms as the control group, assuming that both groups' outcomes would have followed a similar trend in the absence of the reform. Although this identifying assumption is not directly verifiable, we will conduct several tests to support its validity. As for the timing of treatment, we define the post period as the sample periods in or after 2009, which spans five years in our sample.

We begin our analysis by estimating an event-study regression of the following form:

$$Y_{it} = \alpha_i + \sum_{y=2007, y\neq 2008}^{2013} \beta_y \text{Domestic}_i \times \mathbf{1}[y = t] + \delta_t + \varepsilon_{it}, \tag{1}$$

where Y_{it} is an outcome of interest for firm i in year t. α_i is the firm fixed effects that capture unobserved time-invariant firm-specific factors. Domestic_i is an indicator that equals one for domestic firms and zero for foreign firms. $\mathbf{1}[\cdot]$ is an indicator function that equals one when the embraced statement is true and zero otherwise. δ_t is the year fixed effects that capture year-specific macro shocks that are common to all firms. This dynamic specification enables us to investigate the presence of pre-trends by examining the leading term(s) of $\hat{\beta}_y$ for $t < 2008$. A lack of differential trends in the year(s) before the reform is consistent with the identification assumption. Meanwhile, the $\hat{\beta}_y$ for all $t \geq 2009$ trace the dynamics of the causal effect of the reform on the capital or labor outcome.

To quantify the average effects of the reform, we subsequently estimate a "static" DD specification:

$$Y_{it} = \alpha_i + \beta \text{Domestic}_i \times \text{Post}_t + \delta_t + \varepsilon_{it}, \tag{2}$$

where Post_t is a time indicator that equals one for observation in 2009 or later, and zero otherwise. Other variables in this equation are defined similarly as in equation (1). Our primary parameter of interest, β, measures the effects of the reform on the outcome. For inference, we cluster standard errors at the firm level when estimating equations (1) and (2).

3.2 Reduced-Form Results

Before estimating the effect of the reform on the *stock* of capital, we first assess its impact on the *flow* of capital, or capital investment. Consistent with these findings, our analysis shows that the 2009 VAT reform, which marked the final stage of the reform, also significantly boosted firm investment in equipment. Specifically, our event-study analysis reveals that the availability of VAT incentives led to a substantial rise in firm investment (Panel A, Appendix Figure 2).[15] Importantly, we find no evidence of any pre-existing trend in investment prior to the reform. Our "static" DD results indicate that the reform led to an approximately 54% increase in investment for newly eligible firms, as shown in Column (1), Panel A, Appendix Table 1. While our baseline estimation only includes firm and year fixed effects, we obtain quite similar results when we control for the time trends based on industry, province and firm size (Column (2)-Column (5)). Besides, we present the long-difference estimates in Column (6), which report a sizable impact of the reform on investment five years later.

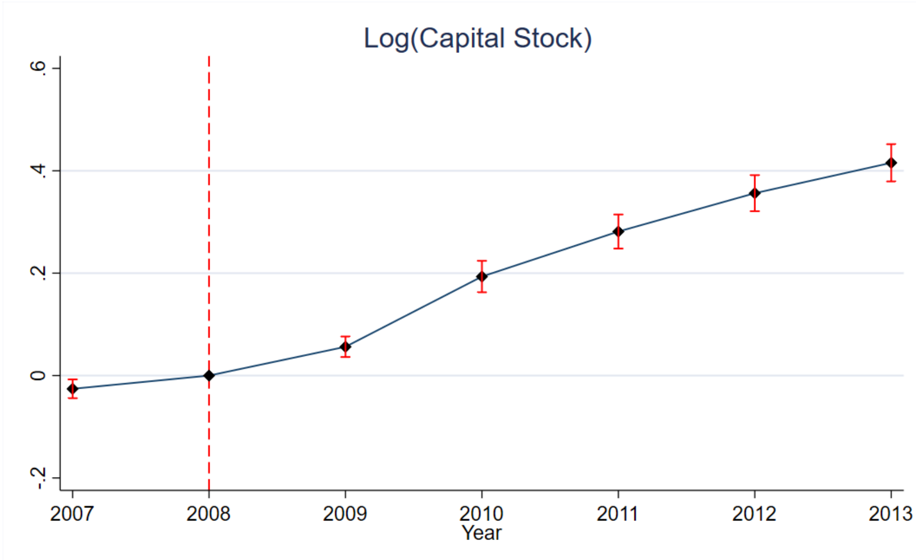
In line with our investment results, our subsequent analysis indicates that the reform led to a significant increase in the capital stock of the treated firms. Here, we define capital stock as including both equipment and structures used in production. Panel A of Figure 1

[15]The corresponding event-study estimates for log investment, as well as those for log capital stock, log employment, and log earnings per worker, can be found in Appendix Table 2.

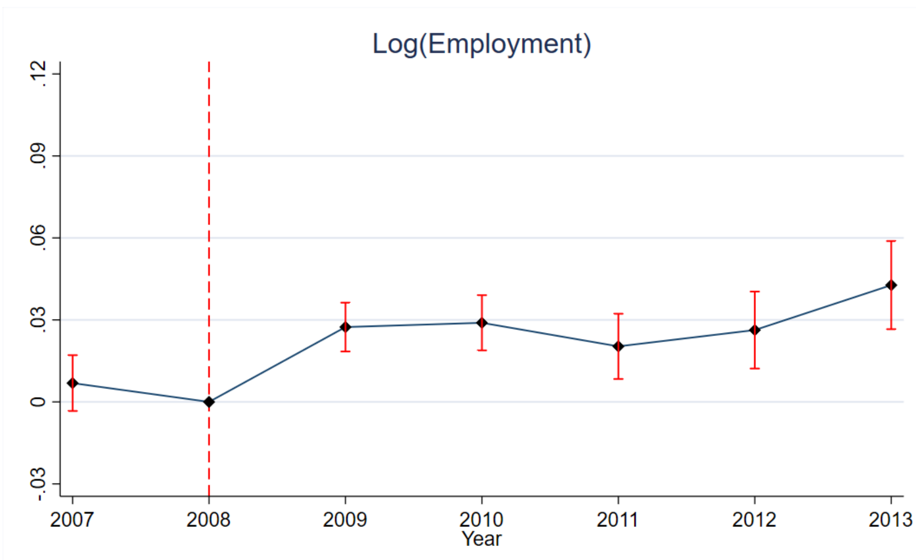
presents the event study graph, showing that treated firms experienced a persistent increase in their capital stock relative to untreated firms.[16] Prior to the reform, the differences in capital stock between treated and control firms were minimal. Though the pre-reform coefficient estimate for 2007 is smaller than post-reform estimates (accounting for only about 6% of the 2013 estimate) it remains statistically significant, which might be due to the large sample size. To examine the robustness of our findings against potential deviations from parallel pre-trends, we apply the method developed by Rambachan and Roth (2023). This method provides bounds on the maximum allowable deviations from parallel trends that would still support our results. As shown in Appendix C, our analysis reveals that our results are robust to pre-trend deviations up to the largest observed deviation in the pre-reform period ($\overline{M} = 1$), with an estimated "breakdown value" of at least $\overline{M} = 1.75$, indicating high degree of robustness. The regression analysis, which captures the average effects of the policy over five years, estimates that the reform increased firms' capital stock by approximately 27% (Column (1), Panel A, Table 2). Using the approach outlined in Chen and Roth (2024), we estimate the treatment effect on the transformed capital stock outcome by applying a logarithmic transformation to positive values of capital stock, while setting zero values to zero, effectively using log(1 + capital stock). This transformation estimates the treatment effect in logarithmic terms, treating zero values as equivalent to a base unit of capital stock (e.g., 1,000 yuan). This estimate is robust to different sets of controls (Columns (2)-(5), Panel A, Table 2). Column (2) incorporates industry-year fixed effects, while Column (3) uses province-year fixed effects, demonstrating the robustness of our findings and alleviating concerns about confounding effects from industry or provincial growth variations, given that foreign firms are concentrated differently across these categories. Additionally, Column (4) includes firm size bins for 2008 interacted with year fixed effects, addressing potential shocks related to firm size. This inclusion leaves the results largely unchanged, addressing concerns about the influence of differential growth rates across firm sizes. Lastly, recognizing the gradual increase in capital stock, we report a long-difference (LD) estimate for the final year of our sample period, showing that by the fifth year, the reform had increased the firms' capital stock by approximately 42%.

[16] Panel A of Appendix Figure 3 links these results to the visual evidence, with the dashed gray line normalizing the capital stock measures of foreign firms to those of domestic firms in 2008.

Figure 1: Event-Study Estimates of the Effects of VAT Reform on Capital and Labor



(a) Panel A: Stock of Productive Capital



(b) Panel B: Employment

Notes: This figure displays the effects of the VAT reform on Log capital stock in panel A and Log employment for production in panel B. Plotted coefficients are estimated from equation (1). The specification in each panel includes year and firm fixed effects. 95% confidence intervals are included for each annual point with standard error clustered at the firm level.

Our findings confirm that the VAT reform significantly boosted equipment investment and capital stocks in manufacturing. We now turn to the key question of whether firms used this capital increase to substitute labor or to hire additional workers for the new equipment. We find that the treated firms increased their employment slightly due to the reform. Panel B of Figure 1 displays the event-study coefficients depicting the reform's effects on log employment.[17]

Table 2: DD Estimates of the Effects of VAT Reform on Capital Stock and Employment

	(1)	(2)	(3)	(4)	(5)	(6)
	Difference-in-differences					Long difference
Panel A: Log Capital Stock						
Domestic × Post	0.273***	0.262***	0.240***	0.285***	0.245***	0.416***
	(0.013)	(0.013)	(0.014)	(0.013)	(0.014)	(0.019)
R-squared	0.862	0.862	0.863	0.862	0.863	0.862
Observations	262,108	262,108	262,108	262,108	262,108	262,108
Panel B: Log Employment						
Domestic × Post	0.026***	0.015***	0.021***	0.039***	0.029***	0.043***
	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.008)
R-squared	0.928	0.929	0.929	0.928	0.929	0.928
Observations	262,108	262,108	262,108	262,108	262,108	262,108
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	No	No	No	Yes
Industry × Year FE	No	Yes	No	No	No	No
Province × Year FE	No	No	Yes	No	Yes	No
Firm Size_{2008} × Year FE	No	No	No	Yes	Yes	No

Notes: This table uses tax survey data to estimate the effects of the VAT reform on firm outcomes. The estimation sample is a balanced panel of manufacturing firms that remain in the National Tax Survey Database from 2007 to 2013. Columns (1)-(5) report the results from estimating the difference-in-differences model outlined in equation (2). Column (1) includes firm fixed effects and year fixed effects. Column (2) includes firm fixed effects and 2-digit industry-by-year fixed effects. Column (3) includes firm fixed effects and province-by-year fixed effects. Column (4) includes firm fixed effects and firm size bins interacted with the year fixed effects. Column (5) includes firm fixed effects, province-by-year fixed effects, and firm size bins interacted with the year fixed effects. Column (6) reports the long difference estimates, or the effects of the reform in 2013 estimated with an event-study specification outlined in equation (1). Standard errors, shown in parentheses, are clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Before the reform, the treated and control firms had similar trends in employment. However, after the reform, the treated firms experienced a small but statistically significant increase in the number of workers. This effect remains relatively stable at around 3% throughout the sample period, with a slight upward trend towards the end. Panel B of Table 2 reports the estimated average post-treatment effects of the reform on employment. Our baseline estimate, presented in Column (1), shows that, on average, employment at

[17] Panel B of Appendix Figure 3 connects these results to the visual evidence, with the dashed gray line normalizing the employment measures of foreign firms to those of domestic firms in 2008.

treated firms increased by less than 3% over five years. When we incorporate time fixed effects specific to industry, province, and firm size as control variables, we obtain remarkably similar outcomes (see Column (2)-Column (5), Panel B of Table 2). The last column of Table 2 presents the long-difference (LD) estimate, indicating that the reform led to an increase in the treated firm's employment by approximately 4% five years after the reform was implemented.

As a side note, we also find that the treated firms increased their earnings per worker in response to the reform (Panel B of Appendix Figure 2). Relative to the firms in the control group, employees in the treated firms saw an increase in average earnings per worker. Specifically, the regression results (Columns (1)-(5), Panel B, Appendix Table 1) show that, on average, the reform led to an increase in earnings per worker for treated firms by 5%-6% in the first five years. As the long-difference results show, the magnitude of the estimated effects of the reform is even larger in the fifth year of the reform (Column (6), Panel B, Appendix Table 1). These results support the idea that tax incentives for investment could benefit workers by increasing wages.

3.3 Robustness Checks

In Table 3, we test the robustness of our reform effect estimates on capital and labor by applying various sample restrictions, weights, and controls, each addressing specific concerns.

The first concern is the potential confounding effect of the broad economic stimulus plan in response to the financial crisis, known as the Four Trillion Yuan Package, which included the 2009 VAT reform. This package involved the provision of low-cost credit by the central government through regional government financing vehicles. It is also important to note that these subsidized credits were not specifically targeted towards the manufacturing sector. Instead, as Bai et al. (2016) demonstrate, they were primarily allocated to infrastructure projects such as railways and roads (38%), post-Wenchuan earthquake reconstruction (25%), affordable housing (10%), and social welfare initiatives (27%). However, state-owned enterprises (SOEs) are more likely to benefit from credit expansion compared to private firms. To address concerns that SOEs may contaminate the treatment group by

Table 3: Sensitivity of Baseline DD Estimates

	(1)	(2)	(3)	(4)	(5)	(6)
	Excluding SOEs	Excluding Listed Firms	Excluding Small Taxpayers	Inverse Prob. Weighting	Additional Firm Controls	Unbalanced
Panel A: Log Capital Stock						
Domestic × Post	0.277***	0.275***	0.270***	0.263***	0.271***	0.273***
	(0.013)	(0.013)	(0.014)	(0.015)	(0.013)	(0.013)
R-squared	0.861	0.860	0.862	0.855	0.862	0.862
Observations	253,232	259,308	228,039	261,975	262,103	262,423
Panel B: Log Employment						
Domestic × Post	0.031***	0.026***	0.029***	0.028***	0.024***	0.027***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)
R-squared	0.929	0.927	0.926	0.926	0.929	0.928
Observations	253,232	259,308	228,039	261,975	262,103	265,238
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: In this table, we show the difference-in-difference estimates within different samples. Column (1) restricts the sample to non-SOE firms. Column (2) excludes publicly listed firms. Column (3) excludes the small-scale taxpayers who enjoyed low tax rates before the VAT reform. Column (4) weights observations by the inverse probability weighting (IPW). Column (5) adds an exporter dummy, quadratic age bin dummies, and 4-digit industry dummies as additional controls. Column (6) uses an unbalanced panel. We allow the missing value of employment and capital stock. Regressions include both year fixed effects and firm fixed effects. Standard errors are presented in parentheses and are clustered at the firm level. Standard errors, shown in parentheses, are clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

receiving additional incentives to invest, we exclude SOEs from the sample and re-estimate the models, finding similar effects of the VAT reform (Column (1)). We also find comparable estimates for firms with limited ties to industries that gained the most from the stimulus package (Appendix Table 3).

Another concern is that listed firms are more sensitive to changes in capital costs due to greater scrutiny from investors, shareholders, and the financial market. As a result, shifts in capital costs can have a larger impact on their profitability, investment decisions, and competitiveness. To address this, we exclude listed firms from our sample, but the results, shown in Column (2), remain similar to the baseline estimates.

In addition, small-scale taxpayers in China benefited from preferential tax rates even before the VAT reform, which may have reduced their incentive to invest in capital equipment compared to other treated firms. Including them in the treatment group could lead to an underestimation of the reform's effects. However, excluding these small-scale taxpayers from the analysis has little impact on the results, as shown in Column (3).

As noted in Section 2.2, foreign firms are generally larger than domestic firms across many dimensions. A key concern for our analysis is the potential bias arising from differences in observable characteristics between these firms. To mitigate this, we reweight our sample to align the distribution of firm characteristics between domestic and foreign firms, thereby reducing potential bias from these disparities.

Specifically, we employ a two-step approach. First, we generate propensity scores for determining the likelihood of firms being treated. This is achieved by estimating a probit model, where the firm's investment, capital stock, employment, and main business revenue serve as independent variables. In the second step, we utilize the model-predicted propensity scores to reweight our data. This reweighting process allows us to assign appropriate weights to each observation, ensuring that the distribution of firm characteristics aligns more closely between treated and untreated firms.[18] Panel B of Appendix Figure 4 shows that after reweighting, domestic and foreign firms are balanced in the observable characteristics. Column (4) in Table 3 shows that our estimates are robust when we use the inverse probability weighting (IPW) method to ensure the domestic and foreign firms are observably comparable.

[18]The details about the reweighting process can be found in Appendix D.

We further show that our results are also robust to controlling for additional firm-level characteristics. In Column (5) of Table 3, we add an exporter dummy, quadratic firm age bin dummies, and 4-digit industry dummies as additional controls. It turns out that the estimated effects of the VAT reform after this adjustment are quite similar to our baseline estimates. Finally, we include observations with missing information on employment or capital stock in the regression. The last column of Table 3 shows that our results are largely insensitive to the inclusion of these observations.

Table 4: Additional Robustness Checks: Government-Designated Encouraged Industries

	(1)	(2)	(3)	(4)	(5)	(6)
	Difference-in-differences					**Long difference**
Panel A: Log Capital Stock						
Domestic × Post	0.284***	0.284***	0.264***	0.303***	0.273***	0.411***
	(0.025)	(0.026)	(0.028)	(0.027)	(0.029)	(0.034)
R-squared	0.868	0.869	0.870	0.868	0.870	0.869
Observations	66,878	66,873	66,878	66,878	66,878	66,878
Panel B: Log Employment						
Domestic × Post	0.035***	0.030***	0.045***	0.054***	0.054***	0.042***
	(0.010)	(0.011)	(0.012)	(0.011)	(0.012)	(0.008)
R-squared	0.933	0.933	0.934	0.933	0.934	0.922
Observations	66,878	66,873	66,878	66,878	66,878	66,878
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	No	No	No	Yes
Industry × Year FE	No	Yes	No	No	No	No
Province × Year FE	No	No	Yes	No	Yes	No
Firm Size$_{2008}$ × Year FE	No	No	No	Yes	Yes	No

Notes: This table uses tax survey data to estimate the effects of the VAT reform on firm outcomes. The estimation sample is a balanced panel of manufacturing firms within encouraged industries that remain in the National Tax Survey Database from 2007 to 2013. Columns (1)-(5) report the results from estimating the difference-in-differences model outlined in equation (2). Column (1) includes firm fixed effects and year fixed effects. Column (2) includes firm fixed effects and 2-digit industry-by-year fixed effects. Column (3) includes firm fixed effects and province-by-year fixed effects. Column (4) includes firm fixed effects and firm size bins interacted with the year fixed effects. Column (5) includes firm fixed effects, province-by-year fixed effects, and firm size bins interacted with the year fixed effects. Column (6) reports the long difference estimates, or the effects of the reform in 2013 estimated with an event-study specification outlined in equation (1). Standard errors, shown in parentheses, are clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

A limitation of our main analysis is that we use all foreign firms as the control group, which includes some foreign firms that did not receive preferential tax treatment. To address this, we conduct a robustness check by restricting the control group to foreign firms within "encouraged" industries, aiming to reduce any bias from including foreign firms that may not have benefited from the preferential VAT policy before the reform. Since the *Catalogue for the Guidance of Foreign Investment Industries* primarily categorizes projects rather than industries, we compile a dataset identifying an industry as "encouraged" if it contains any projects classified as such. It's important to note that firms outside these industries might still engage in "encouraged" projects, as they can operate across various sectors. With this caveat in mind, we limit our analysis to firms explicitly categorized within "encouraged" industries based on the 2007 version of the Catalogue. As shown in Table 4, the results remain robust under this sample restriction, consistent with Chen et al. (2023), who found similar effects of the VAT reform when using all foreign firms versus only those with preferential treatment.

4 From Reduced-Form Estimates to Firm-Level Elasticity

We can now translate the firms' reduced-form responses to the firm-level elasticity of substitution with a simple model of factor demand. According to this model, the marginal effects of the reform on either labor or capital can be decomposed into the scale effect and the substitution effect. Our reduced-form estimates, which correspond to the marginal effects, can then be used to infer the firm-level elasticity of factor substitution.

Our model setup, which is based on Harasztosi and Lindner (2019) and Curtis et al. (2021), is quite standard and straightforward. Consider a monopolistically competitive firm with constant returns to scale production function $F(K, L)$, where K is capital and L is labor. The firm minimizes its cost of production by making optimal choices of capital and labor inputs. Let $C(w, R)$ denote the firm's unit cost function, where w is wage, and R is rental rate. The demand for the firm's product has a constant price elasticity. To maximize profits, a firm chooses inputs to minimize costs and then chooses the level of output. As an exogenous policy shock, the VAT reform reduces the firm's user cost of capital, which we denote by $\phi = \frac{\partial \log(\text{Cost of Capital})}{\partial \text{Reform}} < 0$.

We derive the effects of the VAT reform on a firm's production using profit maximization for a firm producing variety ω, i.e.,

$$\text{Max}_{q(\omega)}\, p(q(\omega))q(\omega) - C(w,R)q(\omega).$$

By taking the F.O.C with respect to $q(\omega)$ and rearranging terms, we obtain the following condition:

$$\Bigg[\underbrace{\frac{\partial p(\omega)}{\partial q(\omega)}\frac{q(\omega)}{p(\omega)}}_{-\frac{1}{\kappa}} + 1\Bigg] p(\omega) = C(w,R),$$

or,

$$p(\omega) = \underbrace{\frac{\kappa}{\kappa - 1}}_{\mu} C(w,R), \tag{3}$$

where μ is the markup. Taking the logarithm and differentiating with respect to R, we get the following equation:

$$\frac{\partial \log[p(\omega)]}{\partial R} = \frac{C_R}{C} + \frac{\partial \log \mu}{\partial R}.$$

As the markup μ is a constant, the second term on the right-hand side is 0. By Shephard's Lemma ($K = q \cdot C_R$), the elasticity of production prices with respect to capital cost is equal to S_K, the share of capital cost in the total cost:

$$\frac{\partial \log[p(\omega)]}{\partial \log R} = \frac{C_R R}{C} = \frac{KR}{cq} = S_K.$$

It is, therefore, straightforward to derive the effects of any change in the cost of capital on total revenue:

$$\frac{\partial \log[p(\omega)\cdot q(\omega)]}{\partial \log R} = \frac{\partial \log[p(\omega)]}{\partial \log R} + \underbrace{\frac{\partial \log[q(\omega)]}{\partial \log[p(\omega)]}}_{-\eta} \frac{\partial \log[p(\omega)]}{\partial \log R} = S_K - \eta S_K. \tag{4}$$

The scale effect, ηS_K, depends on the extent to which the VAT reform impacts the quantity sold ($q(\omega)$) by a particular firm.

Recall that we denoted the capital cost reduced by the VAT reform as $\phi = \frac{\partial \log(\text{Cost of Capital})}{\partial \text{Reform}} <$

0. Equation (4) can therefore be rewritten as:

$$\frac{\partial \log[p(\omega) \cdot q(\omega)]}{\partial \text{Reform}} = (1-\eta) S_K \times \phi.$$

Let us now examine the impact of the VAT reform on the input decisions of the affected firms. Using Shephard's Lemma, we can determine the optimal choice of each input based on the optimal output quantity and the first derivative of the cost function. Specifically, taking the logarithm of Shephard's Lemma and differentiating with respect to R, we get the following equation:

$$\frac{\partial \log[K(\omega)]}{\partial R} = \frac{C_{RR}}{C_R} + \frac{\partial \log q(\omega)}{\partial R}.$$

Note that $R = \frac{\partial R}{\partial \log R}$. Multiplying both sides of the equation and substituting the derived expression for the capital cost share, we obtain:

$$\frac{\partial \log[K(\omega)]}{\partial \log R} = R\frac{C_{RR}}{C_R} - \eta S_K. \tag{5}$$

Again, based on Shephard's Lemma and a production function with constant returns to scale, we can derive the following equations:

$$qc(w, R) = wL + RK = wC_w q + RC_R q,$$
$$C(w, R) = C_R R + C_w w.$$

Taking the derivative of the equation above with respect to the cost of capital gives:

$$C_R = C_{RR} R + C_R + C_{wR} w,$$
$$R\frac{C_{RR}}{C_R} = -w\frac{C_{wR}}{C_R} = -\frac{wL}{qC} \cdot \frac{CC_{wR}}{C_R C_w} = -S_L \sigma_{KL}.$$

Combining the last equation with equation (5) gives:

$$\frac{\partial \log[k(\omega)]}{\partial \log R} = -\eta S_K - S_L \sigma_{KL}.$$

Again, letting $\phi = \frac{\partial \log(\text{Cost of Capital})}{\partial \text{Reform}} < 0$, we get:

$$\frac{\partial \log[k(\omega)]}{\partial \text{Reform}} = (-\eta S_K - S_L \sigma_{KL})\, \phi.$$

Following the same procedure, we can derive the effects of the VAT reform on the optimal labor input for the affected firms. By taking the logarithm of Shephard's Lemma, $L = C_w \cdot q$, and differentiating with respect to R, we obtain the following equation:

$$\frac{\partial \log[L(\omega)]}{\partial R} = \frac{C_{wR}}{C_w} + \frac{\partial \log q(\omega)}{\partial R}.$$

The above equation can be rewritten as:

$$\frac{\partial \log[L(\omega)]}{\partial \log R} = \frac{RC_R}{C} \cdot \frac{CC_{wR}}{C_R C_w} - \eta S_K = (\sigma_{KL} - \eta)\, S_K.$$

Together with $\phi = \frac{\partial \log(\text{Cost of Capital})}{\partial \text{Reform}} < 0$, we obtain:

$$\frac{\partial \log[L(\omega)]}{\partial \text{Reform}} = (\sigma_{KL} - \eta)\, S_K \phi.$$

With these simple assumptions and the derivation outlined above, we can characterize β^K, the effects of the reform on the firm's demand for capital as:

$$\beta^K = (\underbrace{-S_K \eta}_{\text{scale effect}} \quad \underbrace{-S_L \sigma_{KL}}_{\text{substitution effect}}) \times \underbrace{\phi}_{\Delta \text{ cost of } K}, \tag{6}$$

where S_L and S_K are labor cost share and capital cost share, respectively, η the elasticity of demand, and σ_{KL} the elasticity of substitution between capital and labor. Notice that ϕ, the reduction in the cost of capital induced by the VAT reform, affects capital demand not only through the choice of minimizing inputs (the substitution effect), but also through the choice of profit-maximizing output level (the scale effect). The sign of β^K is unambiguously positive, as both the scale and substitution effects are negative, reinforcing one another.

Similarly, we can characterize β^L, the effects of the reform on the firm's demand for labor as:

$$\beta^L = (\underbrace{-S_K \eta}_{\text{scale effect}} \quad \underbrace{+S_K \sigma_{KL}}_{\text{substitution effect}}) \times \underbrace{\phi}_{\Delta \text{ cost of } K}, \tag{7}$$

which can also be decomposed into scale and substitution effects induced by the reform. Here, the scale effect and the substitution effect work in opposite directions; therefore, the sign of β^L ultimately depends on which effect dominates. A positive β^L, which we have estimated with a quasi-experimental design, suggests that the scale effect dominates the substitution effect in the labor response to the VAT reform.

We can define the cost-weighted average of the effects of the VAT reform on a firm's production inputs as:

$$\bar{\beta} = S_K \beta^K + S_L \beta^L = -S_K \eta \times \phi > 0. \tag{8}$$

Intuitively, this weighted average captures the overall increase in the use of all inputs due to the reform, without accounting for any substitution effect. Taking the ratio between equations (7) and (8) gives us $\frac{\beta^L}{\bar{\beta}} = 1 - \frac{\sigma_{KL}}{\eta}$. As a result, the elasticity of capital-labor substitution, σ_{KL}, can be written as:

$$\sigma_{KL} = \eta \left(1 - \frac{\beta^L}{\bar{\beta}}\right) = \eta \left(1 - \frac{1}{S_L + S_K \frac{\beta^K}{\beta^L}}\right). \tag{9}$$

Using equation (9), we now compute σ_{KL} based on our reduced-form estimates of β^K and β^L, along with other parameters that come from existing estimates in the literature, government statistics, or our own calculations based on the NTSD sample. In particular, we approximate η, the demand elasticity, with a trade elasticity of about 4.0 estimated by Li (2018) to. We do this for two reasons. First, given that a considerable fraction of China's manufacturing output is intended for export, international markets play an important role in driving the demand. Second, the trade elasticity is reliably estimated using plausibly exogenous variations in tariffs. For the cost shares, S_L and S_K, we use the estimates in the 2010 input-output table provided by the National Bureau of Statistics (NBS) of China as a benchmark.[19]

Table 5 reports estimates of the firm-level capital-labor elasticity of substitution. The baseline estimate, shown in the first column, is based on our DD estimates of β^K and β^L (Column (1) of Table 2), along with NBS's estimates of S_L and S_K (0.37 and 0.63, respectively) and an η of 4.0 as estimated by Li (2018), with additional support from our

[19]See Appendix A.6 for a detailed description of the NBS statistics.

Table 5: Estimation of the Firm-Level Elasticity of Capital-Labor Substitution

	(1) NBS S_K	(2) $S_K = 0.5$	(3) Low η	(4) High η
Estimates of Average σ_{KL} ($\beta^K = 0.273$; $\beta^L = 0.026$, from DD)				
Average σ_{KL}	3.43	3.30	2.57	4.28
Estimates of Long-run σ_{KL} ($\beta^K = 0.416$; $\beta^L = 0.043$, from LD)				
Long-run σ_{KL}	3.38	3.25	2.54	4.23
Cost Shares:				
Labor (S_L)	0.37	0.5	0.37	0.37
Capital (S_K)	0.63	0.5	0.63	0.63
Demand Elasticity (η)	4.00	4.00	3.00	5.00

Notes: This table presents several results relating our reduced-form estimates to the model outcomes across several alternative settings of cost share and demand elasticity η. In column (1), we approximate labor cost share by labor share provided by NBS. In column (2), we set the labor cost share to 0.5. In column (3) and column (4), we change the value of η.For the calculation of the average σ_{KL}, we utilize the coefficients of β^K and β^L obtained from the difference-in-differences (DD) estimation, specifically referenced in column (1) of Table 2. Similarly, to derive the long-run σ_{KL}, we apply the coefficients of β^K and β^L from the 2013 event study, as indicated in the last column of Table 2.

calculation of an industry-wide average η value of approximately 4.0, based on data from Brandt et al. (2017). The resulting estimate of σ_{KL} is 3.43, suggesting that capital and labor are substitutes in production at the firm level in China. By using the LD estimate reported in Column (6) of Table 2 instead of the DD estimate, we obtain a very similar estimate of the elasticity reported in the same column of Table 5. The rest of Table 5 reports the estimates of the elasticity under different assumed values for the cost shares and demand elasticity. In particular, the σ_{KL} estimated with the LD estimate (reported in Column (6) of Table 2) turns out to be very similar to the baseline estimate. The remaining columns in the table report elasticities with cost shares estimated with equal-sized cost shares (Column (2)) and varying magnitudes of the demand elasticity (Columns (3) and (4)). For all the combinations of parameters, we consistently estimate a σ_{KL} well above one, reinforcing the conclusion that labor and capital inputs are substitutes in production within firms in China.

To examine industry heterogeneity and prepare for the estimation of the aggregate-level elasticity, we estimate the firm-level elasticity of substitution for each two-digit industry in two steps. First, we estimate the reduced-form impacts of the VAT reform on the firm's use of capital and labor with the industry subsample for each industry. Then, we use the same factor demand model to derive the industry-specific firm-level elasticity of substitution. The estimates of the firm-level elasticity of substitution for each industry are shown by the red cross markers in Figure 2. The graph reveals considerable heterogeneity in these elasticity estimates, ranging between 0.72 and 12.04.[20] 27 out of the 28 estimates exceed one, suggesting that capital and labor are substitutes in production within firms for most industries in China. As Figure 2 shows, sectors such as Processing of Timber, Articles of Wood; Furniture; Leather, Fur, Feather and Related Products exhibit the lowest levels of capital-labor elasticity. Notably, these three industries are relatively more labor-intensive. Conversely, sectors including Transport Equipment; Special-Purpose Machinery; Pharmaceutical Products have the highest levels of capital-labor elasticity. These are relatively more capital intensive sectors. Overall, we find a strong positive correlation between capital intensity and capital-labor elasticity across industries (Appendix E). In the next section, we will use these industry-specific firm-level elasticities to estimate the elasticity at more aggregate levels.

5 Industry- and Aggregate-Level Elasticities

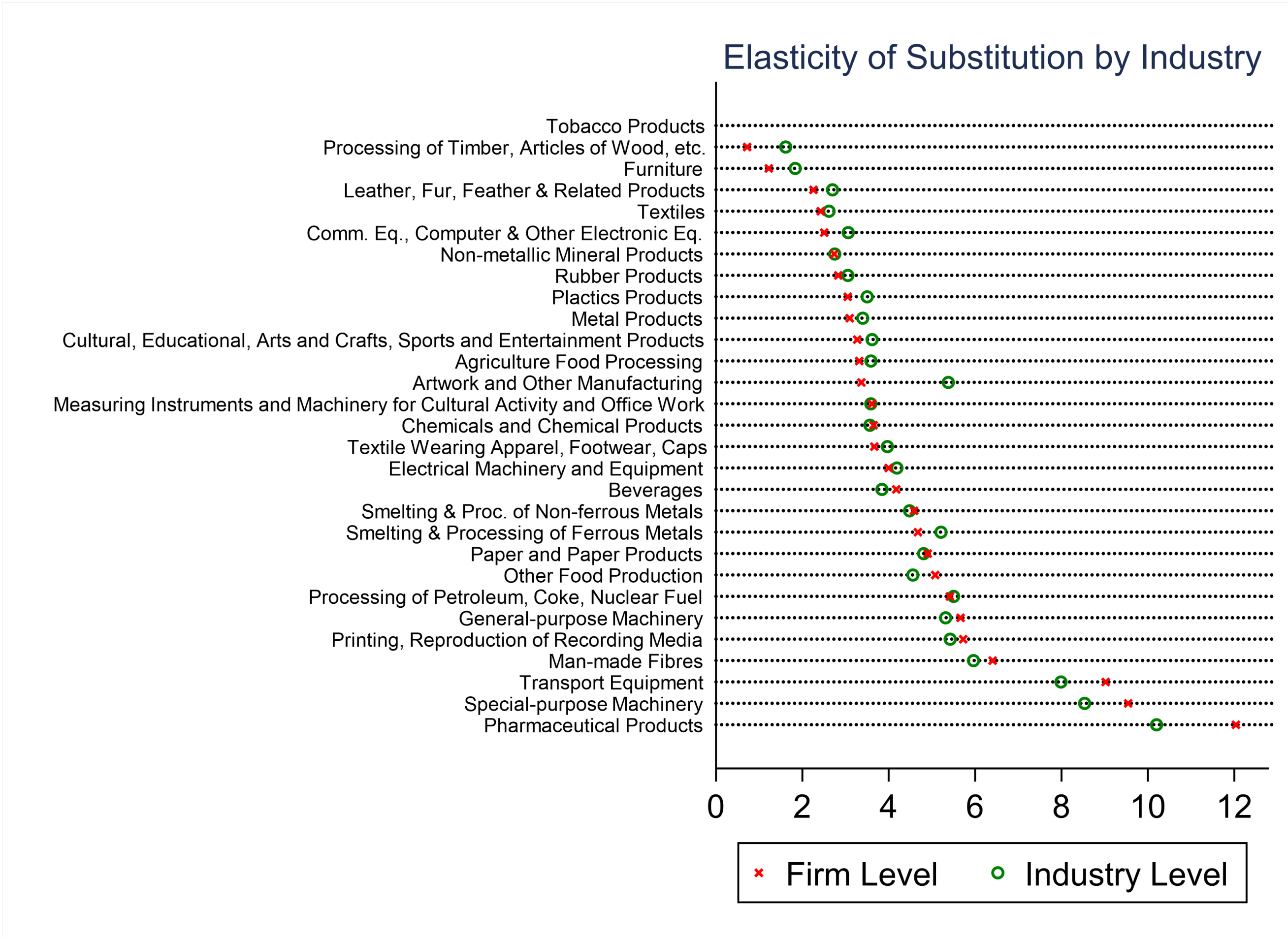
Our firm-level elasticity estimates capture capital and labor adjustments within firms but not at more aggregate levels. This section aims to account for reallocations across firms and industries, deriving industry- and aggregate-level elasticities using the methodology in Oberfield and Raval (2021). First, we aggregate firm-level elasticities we obtained in Section 4 to industry-level, allowing for factor reallocation within industries. We then use these industry-level elasticities to construct a manufacturing sector-level elasticity that accounts for cross-industry factor reallocation.

5.1 From Firm-level Elasticities to Industry-Level Elasticities

First, let us aggregate the firm-level elasticity to the industry level for each industry n. Oberfield and Raval (2021) show that the industry-level elasticity of substitution (σ_n^N) can

[20] The elasticity for the tobacco product industry cannot be estimated because there are no foreign-owned firms that serve as the control group in our estimation strategy.

Figure 2: Elasticity of Substitution by Industry



Note: This figure displays the firm-level elasticity and industry-level elasticity of substitution for each industry.

be written as a convex combination of the industry's firm-level elasticity of (σ_n) and the industry's elasticity of demand (ξ_n):

$$\sigma_n^N = (1 - \chi_n)\sigma_n + \chi_n \xi_n, \tag{10}$$

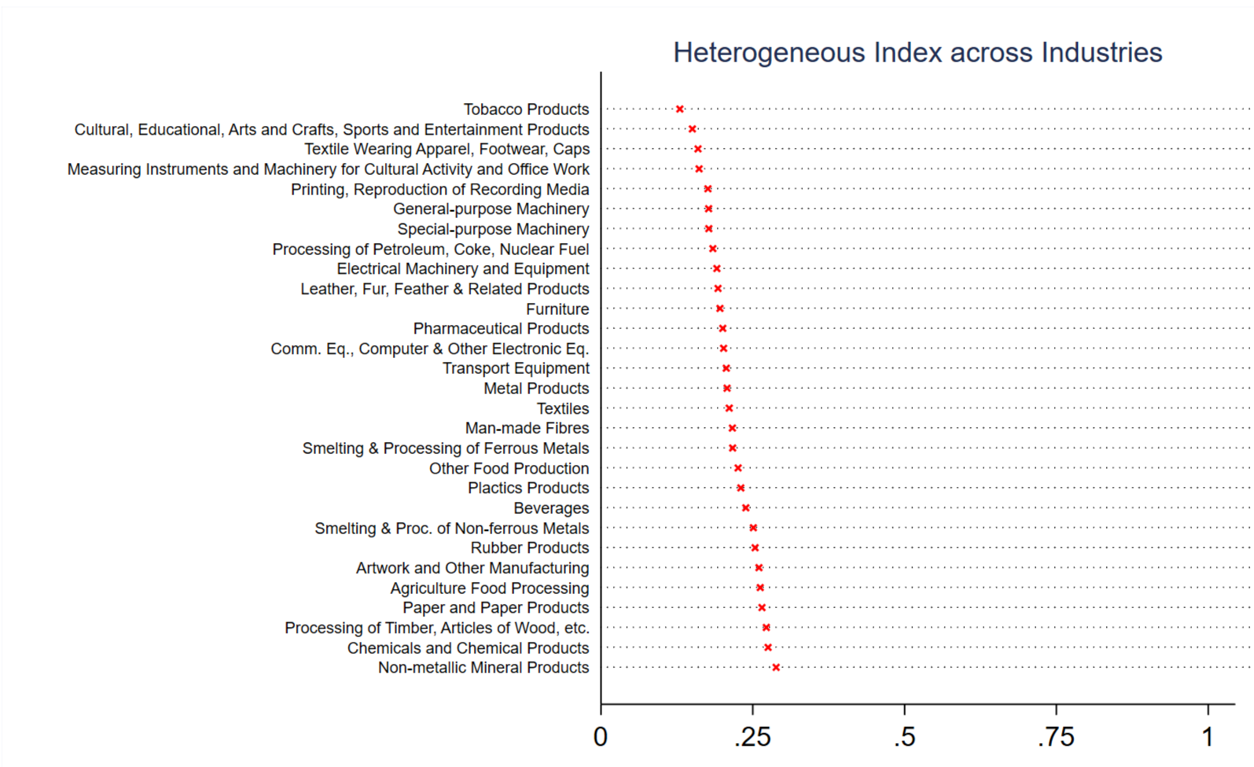
where χ_n is the heterogeneity index for industry n, and χ_n is proportional to the cost-weighted variance of the capital cost shares and takes values between zero and one.[21] Intuitively, the larger the value of χ_n, the greater the variation in capital intensities within

[21] $\chi_n \equiv \Sigma_{i \in I_n} \frac{(\alpha_{ni} - \alpha_n)^2}{\alpha_n(1-\alpha_n)} \theta_{ni}$, where α_{ni} is firm i's capital share of costs, θ_{ni} is firm i's share of industry n's capital and labor expenditures, and α_n is a weighted average of the capital cost shares of the firms in industry n.

an industry, and the more important reallocation of inputs becomes relative to within-firm substitution. The industry's demand elasticity (ξ_n) also plays an important role: the larger it is, the more consumers respond to relative price changes, and thus the larger the reallocation effect. A detailed derivation of equation (10) can be found in Appendix F.

The parameters on the right-hand side of equation (10) are drawn from multiple sources. We have already estimated σ_n for each industry, with results displayed in Figure 2 (red markers). The value of ξ_n is derived from markup estimates in Brandt et al. (2017), utilizing the quasi-experimental tariff variation from China's WTO accession. Following Benzarti and Harju (2021), we calculate markups, assuming ξ_n is the inverse of the industry n average markup.[22] To obtain χ_n, we use our NTSD sample, with the detailed methodology in Appendix F. Figure 3 presents χ_n values, ranging from 0.13 to 0.33, with an average of about 0.2.

Figure 3: Heterogeneous Indices of Industries in China's Manufacturing Sector



Note: This figure displays the industry-level heterogeneous index for each industry.

Plugging these parameters into equation (10) yields the aggregate-level elasticity of

[22] Appendix Figure 5 provides ξ_n values for each industry.

substitution for each industry, which are shown as green circles in Figure 2. Note that the industry-level elasticities (green circles) are not substantially different from the industry-specific firm-level elasticities (red markers) because the heterogeneity indices are quite small for all industries (Figure 3).[23] The average industry-level elasticity is about 4.

5.2 From Industry-Level Elasticities to Aggregate-Level Elasticity

Next, we further aggregate the industry-level elasticities to the aggregate level, which allows for the reallocation of production inputs across industries. Specifically, we calculate the aggregate-level elasticity of substitution (σ^{agg}) as

$$\sigma^{\text{agg}} = (1 - \chi^{\text{agg}})\bar{\sigma}^N + \chi^{\text{agg}}\xi, \tag{11}$$

where $\bar{\sigma}^N$ is a weighted average of σ_n^N, ξ is the cross-industry demand elasticity, and χ^{agg} is the cross-industry heterogeneity index.[24] Intuitively, the larger the value of χ^{agg}, the greater the variation in capital intensities across industries, and the more important cross-industry factor reallocation becomes relative to within-industry substitution. A detailed derivation of equation (11) can be found in Appendix G.

We now estimate the elasticity of substitution at the aggregate level using equation (11). Based on our previous estimates of σ_n^N, we calculate $\bar{\sigma}^N$ to be 4.64. In addition, using our own NTSD sample, we estimate χ_n to be 0.079. We follow Oberfield and Raval (2021) and set ξ to 1. Finally, by substituting these values into equation (11), we obtain an aggregate-level elasticity of substitution of 4.36. Note that the elasticity at the manufacturing sector level, or the aggregate-level elasticity, is larger than the elasticity at the firm level because the former additionally reflects the reallocation of factors across firms and industries. In summary, our estimation suggests that capital and labor are substitutes in production at the macro level in China.

[23] As we mentioned in the main text, the industry-level elasticity is a weighted average of the firm-level elasticity within that industry and the industry's demand elasticity. Thus, if the demand elasticity is greater than the elasticity of substitution, the industry-level elasticity will be greater than the firm-level elasticity for the same industry, and vice versa.

[24] $\bar{\sigma}^N = \sum_{n\in N} \frac{\alpha_n(1-\alpha_n)\theta_n}{\sum_{n'\in N}\alpha_{n'}(1-\alpha_{n'})\theta_{n'}}\sigma_n^N$ and $\chi^{\text{agg}} \equiv \sum_{n\in N}\frac{(\alpha_n-\alpha)^2}{\alpha(1-\alpha)}\theta_n$. See Appendix G for details.

The elasticity we estimate likely represents a lower bound on the parameter, as our methodology does not take into account firm entry and exit as a further margin of adjustment. A reduction in the cost of capital may lead to the entry of capital-intensive firms and the exit of labor-intensive firms. Our reduced-form estimates, based on a balanced panel of firms, capture only within-firm substitution but do not reflect the adjustment attributable to firm dynamics such as entry and exit. We provide a detailed characterization of this potential bias in Appendix H, concluding that it is unlikely to affect our overall finding that capital and labor are highly substitutable at the macro level in China.

5.3 Discussion

Our estimates of substitution elasticities in China are higher than most U.S. estimates, such as those in Oberfield and Raval (2021). This difference may reflect fundamental variations in production technologies and institutional factors, such as labor unionization. In the U.S., unions continue to play an important role in protecting workers' labor rights. In theory, by limiting discretion in hiring and firing, unions can prevent the employer from fully adjusting its capital-labor ratio in response to a wage increase. Consistent with this view, Freeman and Medoff (1982) uses U.S. data to show that the presence of unions makes it more difficult to substitute hours worked by production workers for other inputs, including capital. Similarly, Maki and Meredith (1987), using industry-level data from Canada, show that strong unionization impedes the substitution of capital for labor, thereby lowering the elasticity of substitution. In China, however, the unionization landscape is very different. Independent unions are not legal. The only sanctioned union is the All-China Federation of Trade Unions, which is known to work with companies to facilitate smoother labor relations rather than to advocate for workers' rights. Such institutional differences between the U.S. and China may explain the difference in the magnitude of the elasticity of substitution between the two countries.

Moreover, our findings that capital and labor are highly substitutable in China may also reflect that its labor force, especially in manufacturing, is dominated by low- and middle-skilled workers. This notion is consistent with recent work by Caunedo et al. (2023), which finds that even within the U.S., labor is substitutable for capital in the middle- and low-skilled occupations (although capital and labor are complements in the aggregate).

Our estimate of the firm-level elasticity is consistent with the estimated elasticity of substitution between capital and low-wage workers in Hungary (Harasztosi and Lindner (2019)), whose income level is comparable to that of China. Specifically, their study uses variation in the minimum wage to estimate a firm-level elasticity of 2.60 for manufacturing firms and 3.35 for all firms. The similarity between our results and theirs can be attributed to several factors. First, Harasztosi and Lindner (2019) focus on low-wage, low-skilled workers, who are more comparable to manufacturing workers in China than the average worker in other rich countries. Second, both our study and theirs use plausibly exogenous policy variation for identification, which helps reduce the bias in the elasticity estimates. Third, both studies allow for factor adjustment within similar time frames of approximately five years.

Our work is not alone in finding that capital and labor are substitutes in China. At the firm level, Berkowitz et al. (2017) use a model-based approach and estimated an average industry-level elasticity of 1.55.[25] At the aggregate level, Chang et al. (2016) utilize a relatively small sample of aggregate data and estimated aggregate-level elasticities of substitution ranging from 1.38 to 4.53. Although both studies yield parameters that differ somewhat from ours, their findings still align with our conclusion that capital and labor function as substitutes in China.

5.4 Implications

Our estimate of the aggregate-level elasticity of substitution between capital and labor is helpful in gaining insight into several policy issues in economics. First, an aggregate-level elasticity greater than one suggests that China's high level of output and growth to date may have benefited from a high elasticity of substitution (de La Grandville (1989)). Looking ahead, we expect China's high economic growth to be sustained if this elasticity remains roughly the same in the future.[26] Second, with an aggregate-level elasticity of substitution greater than one, a rising capital-income ratio may lead to a declining labor income share

[25] Specifically, their methodology depends on critical identification assumptions about the timing of the firm's input use and the importance of exports in the decision.

[26] For more details on the relationship between capital-labor elasticity and economic growth, see Appendix I.

in China, as pointed out by Piketty (2014). The declining labor share could potentially widen the income gap if the returns to capital are concentrated in the wealthier segments of the Chinese society.[27] Third, with an aggregate-level elasticity of substitution greater than one, technological change will be directed toward the more abundant factor (Acemoglu (2002)). Specifically, as capital becomes more abundant relative to labor in China, the direction of technological progress will gradually change from being biased toward labor to being biased toward capital.

6 Re-estimating the Elasticities Using Labor Cost Shock

Up to this point, we have focused on estimating the firm-level elasticity of substitution based on the capital cost shock caused by a VAT reform. To test the robustness of our results, this section re-estimates the elasticity of factor substitution by utilizing quasi-experimental variation in factor prices from the labor side, specifically through changes in China's minimum wage.

We start by estimating the impact of exposure to minimum wage changes across Chinese cities between 1998 and 2007 on both employment and capital stock. For this purpose, we use firm-level data from the Annual Survey of Industrial Firms conducted by the NBS. This survey serves as a comprehensive and reliable source of information on industrial firms.[28] Following the literature (Mayneris et al. (2018); Hau et al. (2020)), we define a firm as exposed to a minimum wage shock if its average wage at time $t-1$ was below the local minimum wage at time t. Our DD estimation suggests that firms exposed to minimum wage increases reduced employment by 11% relative to nonexposed firms. However, there does not appear to be a statistically significant difference in the adjustment of capital stock between these two groups of firms. The minimal response of capital stock to changes in employment suggests that capital and labor likely function as substitutes (details of the analyses are available in Appendix K).

Next, we use a very similar partial equilibrium model that accounts for adjustment mechanisms with respect to both capital and labor inputs (Harasztosi and Lindner (2019)).[29]

[27] For more details on the link between capital-labor elasticity and labor share, see Appendix J.
[28] A detailed discussion of these data can be found in Brandt et al. (2012).
[29] Details of the derivation can be found in the Appendix L.

Specifically, the firm-level capital-labor elasticity of substitution is

$$\sigma_{KL} = \eta \left(1 - \frac{1}{S_K + S_L \frac{\gamma^L}{\gamma^K}} \right), \tag{12}$$

where η is the elasticity of demand, S_K and S_L are the capital and labor cost shares, respectively, and γ_L and γ_K are the effects of the minimum wage change on employment and the capital stock, respectively.[30]

This approach allows us to convert the reduced-form estimates into our estimates of the firm-level elasticity of substitution. The resulting elasticity is 3.11, indicating a substantial degree of substitution between capital and labor at the firm level. Furthermore, in an aggregation exercise, we calculate the aggregate-level (manufacturing sector level) elasticity of substitution to be 4.26. These results are remarkably similar to the estimation results obtained from our analysis of the VAT reform.

7 Conclusion

The elasticity of substitution between capital and labor plays a critical role in several areas of economics. However, estimating this parameter is challenging due to potential confounding factors such as technological bias, which can independently affect changes in input use independent of factor prices. Identifying and obtaining credible estimates of the capital-labor substitution elasticity has been limited, with most estimates focusing primarily on developed economies.

In this study, we address the identification challenge by using policy-induced variations in factor prices to estimate the elasticity of capital-labor substitution in China. First, we estimate the impact of a VAT reform that lowered the user cost of capital on a firm's demand for both capital and labor. Our estimation results, based on a panel of manufacturing firms, indicate that the reform has a positive impact on both capital stock and employment, although the effect on capital stock is significantly larger than that on employment. Based on these reduced-form estimates, we obtain a firm-level elasticity of 3.43, suggesting a high degree of substitutability between capital and labor within firms. We then take into

[30] The details of the estimation can be found in Column (1) of Table K2 in Appendix K.

account the reallocation of factors across firms and industries, estimating an aggregate-level elasticity of 4.36, which indicates a high degree of substitutability between capital and labor at the aggregate level. as well. Furthermore, using labor cost shock from minimum wage changes, we produce similar values of the elasticity of substitution at both the micro and macro levels. Our estimate of the aggregate-level elasticity for China stands in contrast to the United States, where most studies find an elasticity of less than one.

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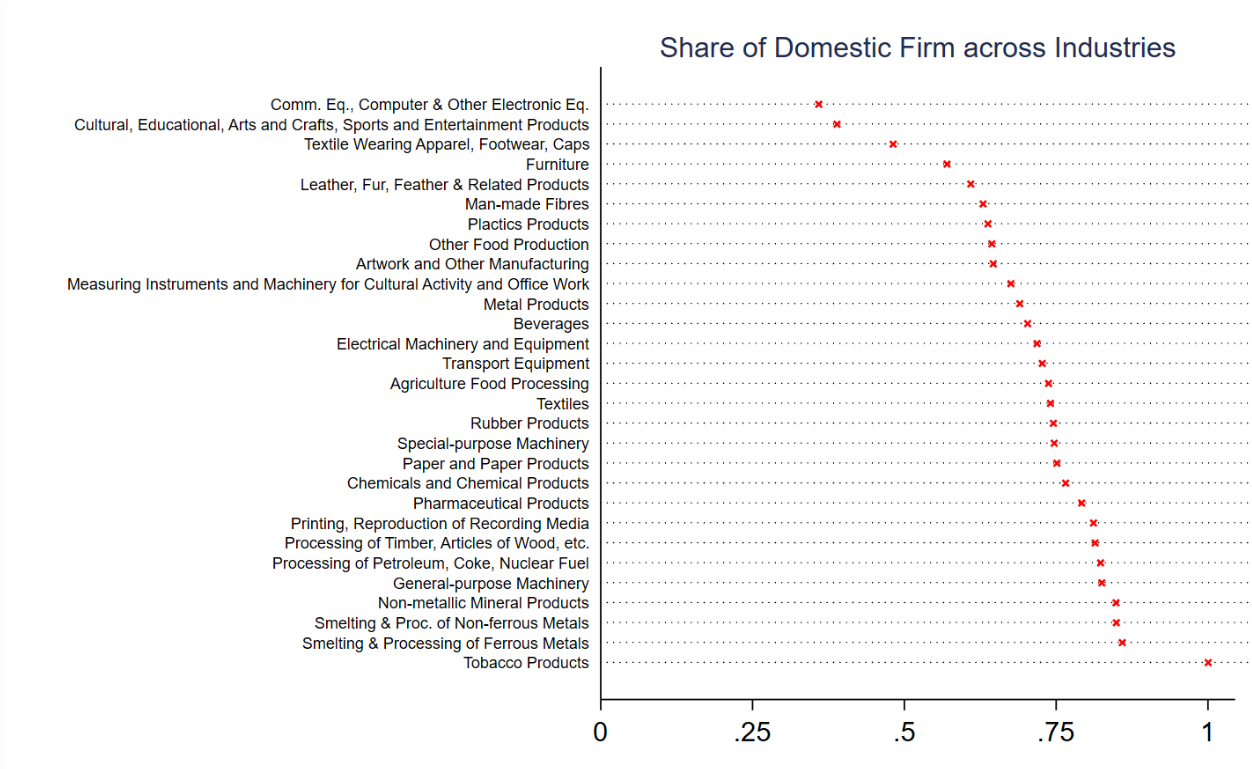
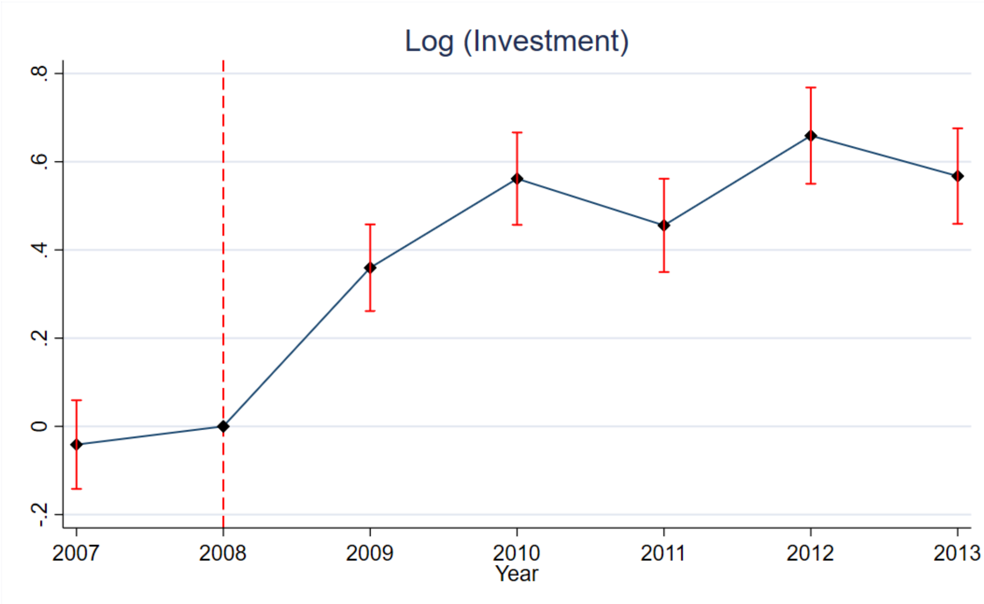
Appendix Figures and Tables

Appendix Figure 1: Share of Domestic Firms by Industry

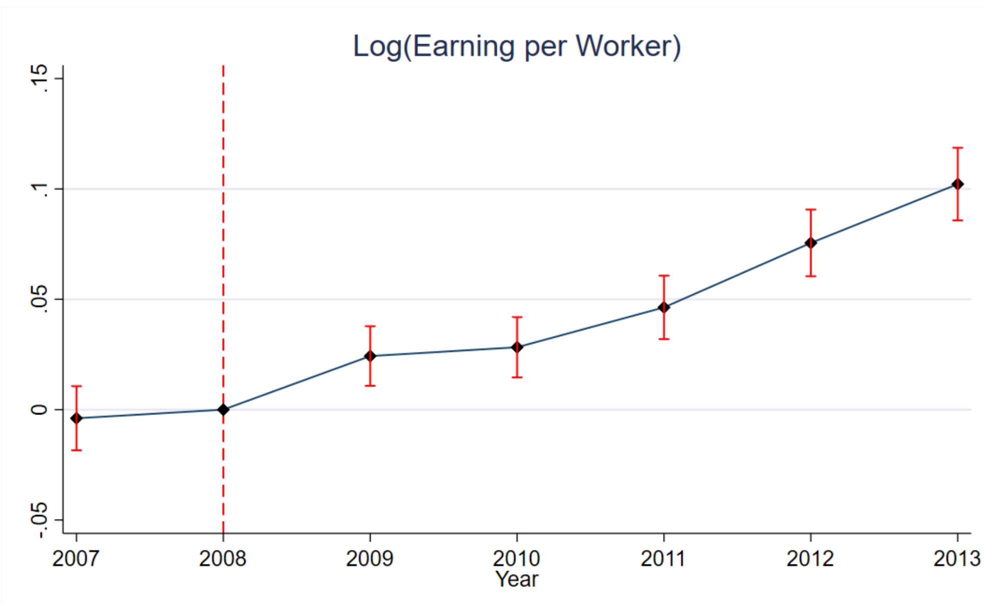


Source: A balanced sample of manufacturing firms in the National Tax Survey Database from 2007 to 2013.

Appendix Figure 2: Effects of VAT Reform on Investment and Earnings per Worker



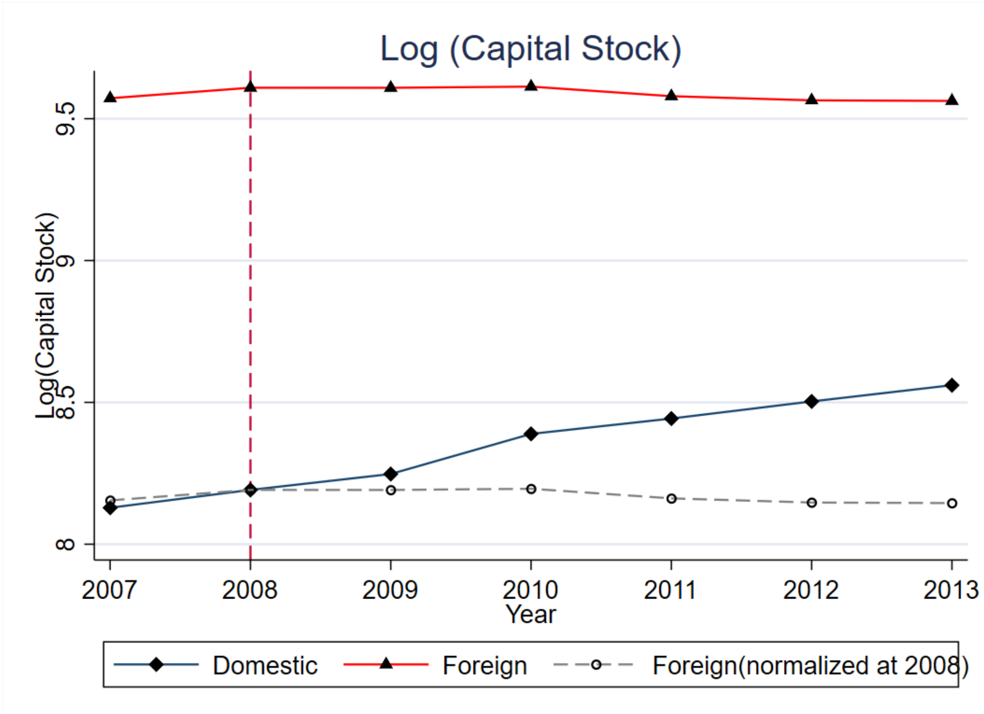
(a) Panel A: Equipment Investment



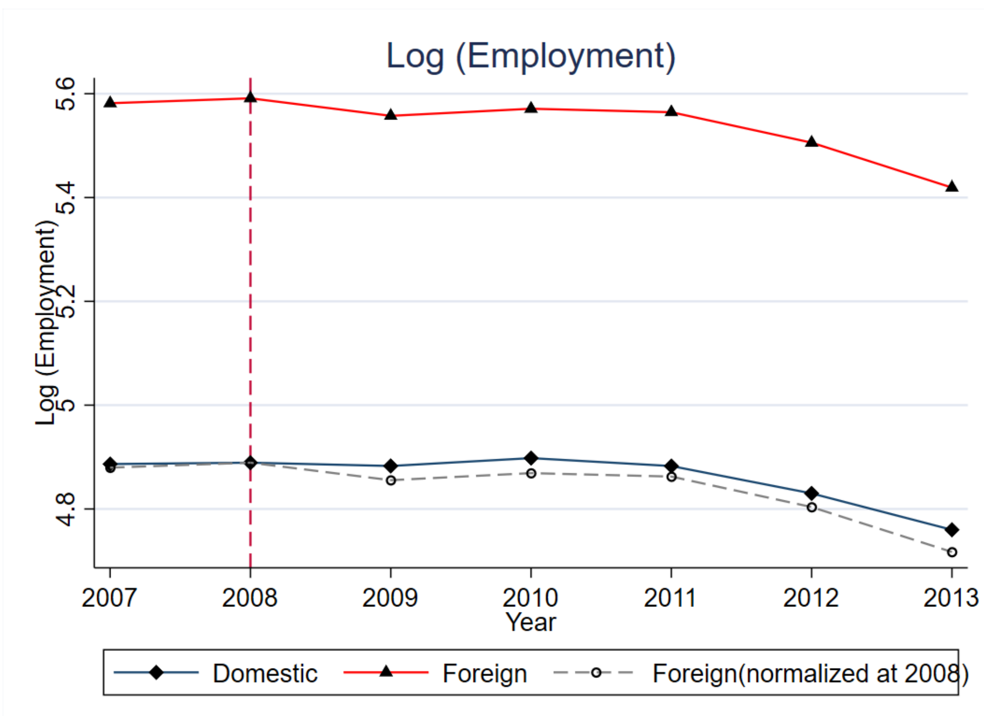
(b) Panel B: Earnings per Worker

Notes: This figure displays the effects of the VAT reform on log employment in panel A and log earnings per worker in panel B. Plotted coefficients are estimated from equation (1). The specification in each panel includes year and firm fixed effects. 95% confidence intervals are included for each annual point with standard error clustered at the firm level.

Appendix Figure 3: Visualized Effects of VAT Reform on Capital and Employment



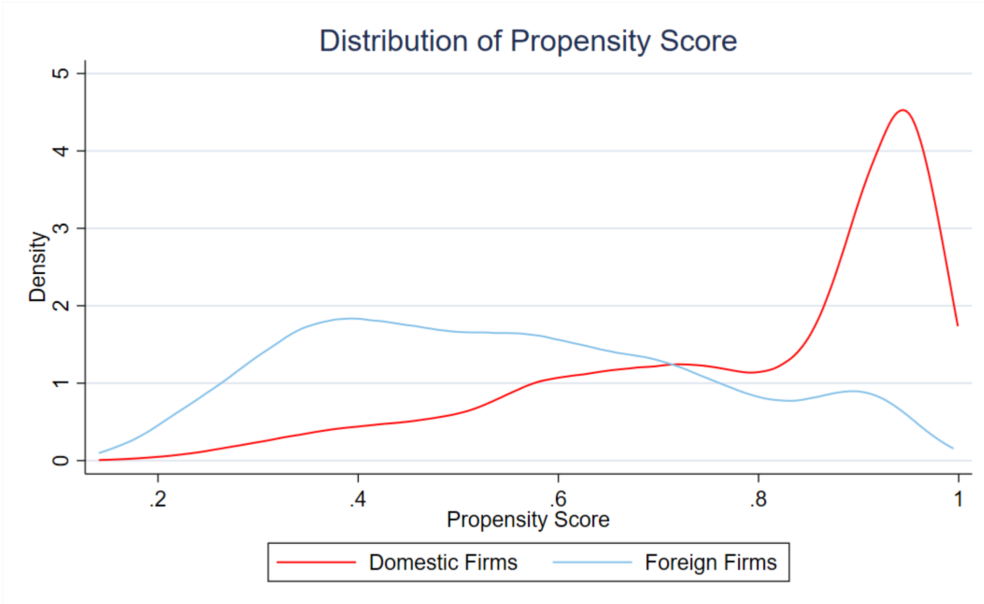
(a) Panel A: Capital Stock



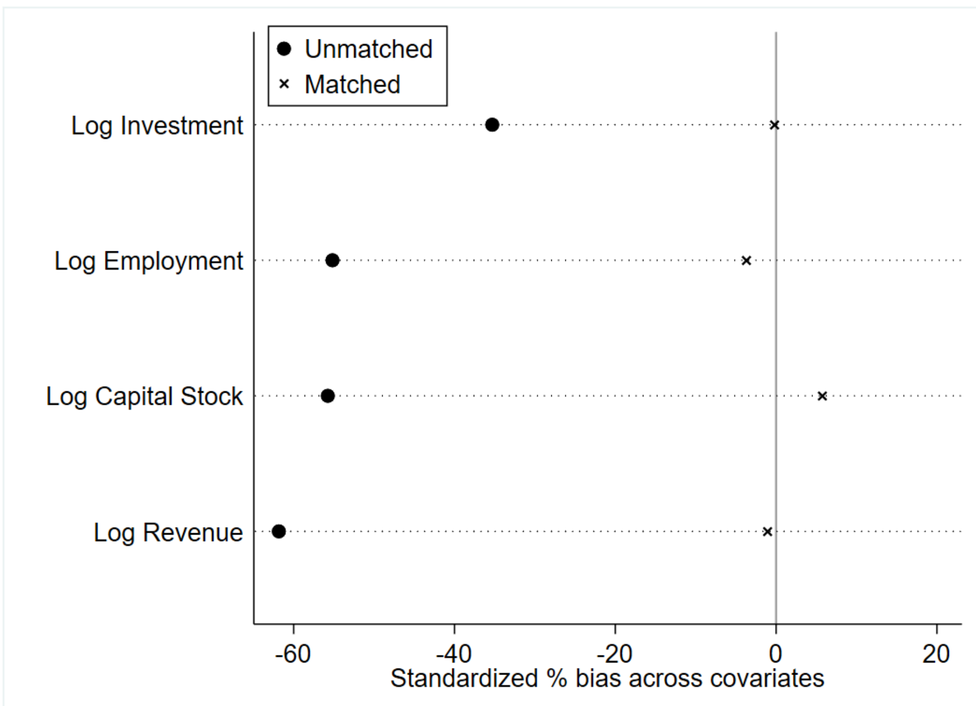
(b) Panel B: Employment

Notes: This figure displays the effects of the VAT reform on capital stock in panel A and employment in panel B each year for domestic firms (the treatment group) and foreign firms (the control group). The red line represents capital stock or employment of foreign firms, the navy blue line represents capital stock or employment of domestic firms, and the dash gray line represents the investment of foreign firms that are normalized to that of domestic firms in 2008.

Appendix Figure 4: Inverse Probability Weighting



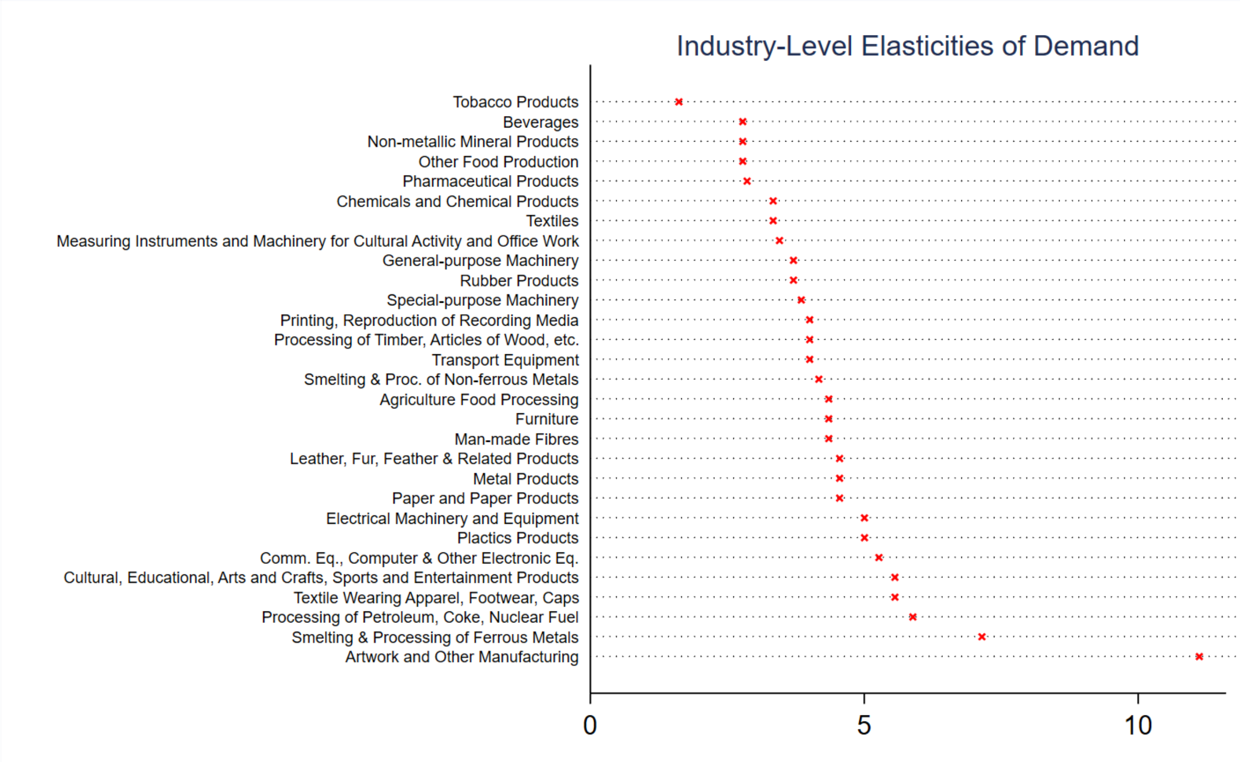
(a) Panel A: Distribution of Propensity Score



(b) Panel B: Mean Difference between Treatment and Control Groups

Notes: Panel A plots the distributions of the estimated propensity scores for domestic firms and foreign firms, respectively. Panel B shows the differences in major variables between the treatment group and control group before weighting and after weighting.

Appendix Figure 5: Industry-Level Elasticities of Demand



Notes: After adopting the markups from Brandt et al. (2017), we proceed to incorporate the approach outlined in Benzarti and Harju (2021) and make the assumption that the elasticity of demand for each industry is equal to the reciprocal of its corresponding markup.

Appendix Table 1: Effects of VAT Reform on Investment and Earnings per Worker

	(1)	(2)	(3)	(4)	(5)	(6)
	Difference-in-differences					Long difference
Panel A: Log Investment in Equipment						
Domestic × Post	0.541***	0.509***	0.439***	0.518***	0.441***	0.567***
	(0.035)	(0.037)	(0.040)	(0.037)	(0.040)	(0.055)
R-squared	0.440	0.441	0.447	0.441	0.449	0.440
Observations	262,108	262,108	262,108	262,108	262,108	262,108
Panel B: Log Earnings per Worker						
Domestic × Post	0.057***	0.064***	0.049***	0.052***	0.047***	0.102***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.008)
R-squared	0.625	0.626	0.629	0.625	0.629	0.625
Observations	262,108	262,108	262,108	262,108	262,108	262,108
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	No	No	No	Yes
Industry × Year FE	No	Yes	No	No	No	No
Province × Year FE	No	No	Yes	No	Yes	No
Firm Size_{2008} × Year FE	No	No	No	Yes	Yes	No

Notes: This table uses tax data to estimate the effects of the VAT reform on firm outcomes. The estimation sample is a balanced panel of manufacturing firms that remain in the National Tax Survey Database from 2007 to 2013. Columns (1)-(5) report the results from estimating the difference-in-differences model outlined in equation (2). Column (1) includes firm fixed effects and year fixed effects. Column (2) includes firm fixed effects and 2-digit industry-by-year fixed effects. Column (3) includes firm fixed effects and province-by-year fixed effects. Column (4) includes firm fixed effects and firm size bins interacted with the year fixed effects. Column (5) includes firm fixed effects, province-by-year fixed effects, and firm size bins interacted with the year fixed effects. Column (6) reports the long difference estimates, or the effects of the reform in 2013 estimated with an event-study specification outlined in equation (1). Standard errors, shown in parentheses, are clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Appendix Table 2: Event-Study Estimates of the Effects of VAT Reform

	(1) Log (Capital stock)	(2) Log (Investment)	(3) Log (Employment)	(4) Log(Earnings per Worker)
2007	-0.026***	-0.041	0.007	-0.003
	(0.009)	(0.051)	(0.005)	(0.008)
2008	0	0	0	0
	(.)	(.)	(.)	(.)
2009	0.056***	0.360***	0.027***	0.019**
	(0.010)	(0.050)	(0.005)	(0.008)
2010	0.193***	0.562***	0.029***	0.025***
	(0.016)	(0.053)	(0.005)	(0.008)
2011	0.281***	0.456***	0.020***	0.053***
	(0.017)	(0.054)	(0.006)	(0.008)
2012	0.356***	0.659***	0.026***	0.067***
	(0.018)	(0.056)	(0.007)	(0.008)
2013	0.416***	0.567***	0.043***	0.074***
	(0.019)	(0.055)	(0.008)	(0.009)
Observations	262,108	262,108	262,108	262,108
R-squared	0.862	0.440	0.928	0.629
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes: This table uses tax data to estimate the dynamic effects of the VAT reform on firm outcomes in terms of capital stock, investment employment and earning per worker respectively. The estimation sample is a balanced panel of manufacturing firms that remain in the National Tax Survey Database from 2007 to 2013. Columns (1) - (4) report the effects on capital stock, investment, employment and salary respectively. Standard errors, shown in parentheses, are clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Appendix Table 3: Robustness Check: The Four-Trillion Yuan Package

	(1)	(2)	(3)	(4)
	Log Employment		**Log Capital Stock**	
	Food and Textile-related Industry	Excluding Sichuan	Food and Textile-related Industry	Excluding Sichuan
Domestic × Post	0.032***	0.026***	0.258***	0.274***
	(0.013)	(0.006)	(0.028)	(0.013)
R-squared	0.893	0.916	0.848	0.862
Observations	49,350	256,417	49,350	256,417
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes: Columns (1) and (3) estimate the regressions for firms in industries whose demand was less affected by the Four-Trillion Yuan Package, including Food processing (13), Food manufacturing (14), Drink manufacturing (15), Textile (17), Textile clothes, shoes and hats manufacturing (18), Leather, fur, feather and their product manufacturing (19). Columns (2) and (4) estimate the regressions excluding firms in Sichuan province where Wenchuan earthquake took place. Standard errors, shown in parentheses, are clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Appendices

Appendix A Data and Variable Construction

In this appendix, we present additional information on the data and how we derived the main variables for our empirical analysis. Our primary data source is the National Tax Survey Database (NTSD), a dataset created by the State Tax Administration of China (STA). The NTSD is similar to other databases, such as the Chinese Annual Survey of Industrial Firms (ASIF) or the Longitudinal Research Database (LRD) maintained by the U.S. Bureau of the Census. The NTSD consists of taxpayer firms that can be identified by their taxpayer identification code (*nashuiren shibiema*). Large Chinese firms, such as the China National Petroleum Corporation (CNPC), may have multiple subsidiaries, each of which will be included in the NTSD as individual firms.

Every year, the NTSD survey samples firms from two different lists. The first list comprises key firms, including those that generated over 70% of local VAT revenue in the previous year, firms with preferential tax treatment, exporters, and publicly listed firms. Each of these firms is surveyed annually. The second list contains all other firms, which are typically smaller than those on the first list. Only a random subset of the firms on the second list is surveyed yearly. We focus primarily on a balanced panel of firms, mainly consisting of relatively large firms on the first list.

The NTSD survey is conducted between March and April each year and covers the firms' performance for the previous year. For instance, the 2010 survey was conducted in 2011 and inquired about firms' information in 2010. Below, we provide additional details on how we constructed some key variables in our primary analysis.

A.1 Ownership

One of the key variables we employ in our study is a firm's registration type. The survey captures 39 ownership types, including joint ventures between different ownership structures. Based on this information, we categorize each firm into one of two groups: domestic firms and foreign firms. Foreign firms in our sample consist of those from Hong Kong, Macau, and Taiwan, as well as those from foreign countries. Additionally, foreign firms can be either joint ventures or wholly owned. In some of our analyses, such as the robustness analysis in section 3, we further divide domestic firms into state-owned firms, private firms, and hybrid or collective firms. During the sample period, some firms changed their ownership structure (from domestic firms to foreign firms, or vice versa). We exclude these firms from our primary sample to ensure a clean identification.

A.2 Employment and Wages

In the survey, each firm reports its total employment. We consider negative values of employment as missing. However, zero values of employment may not necessarily be due to misreporting. For instance, instead of putting employees on their payroll, some firms procure labor services from "labor dispatching" companies (*laowu paiqian gongsi*). The workers who provide the labor service are legally considered employees of the "labor dispatching" companies. Hence, they are not counted as workers of the firms that purchased the labor services.

Firms provide various types of employee compensation, such as wages, employee supplementary benefits, unemployment insurance, retirement and health insurance, and housing benefits. We aggregate wages and supplementary employee benefits to generate a consistent measure of compensation for the entire period. To ensure the robustness of our findings, we also include other fringe benefits in the compensation calculation and obtain similar results.

A.3 Investment and Capital Stock

One of the advantages of using NTSD is its direct reporting of investment values, including information on the breakdown of different types of investment, such as investment in productive fixed assets and investment in productive structures. Given that the VAT reform encourages firms to invest in equipment, we define equipment investment as the difference between investment in productive fixed assets and investment in productive structures. In 2007, firms were asked to report their investment in equipment, and we found that our calculated equipment investment closely matched the directly reported investment in equipment. However, in some cases, the value of investment in equipment may be missing or negative. To address this, we estimate the value of an investment in equipment as the difference in equipment stock between consecutive years. If the value is still missing, we assume that the firm did not make any new investment in equipment that year. To validate this approach, we use the information on the reported deduction of the VAT of equipment used for production. If a firm has made new investments in equipment, the owner of the firm will apply for its VAT deduction, which is automatically checked for consistency by the electronic data-collection system. If there is no deduction of the VAT of equipment used for production, it is very likely that the firm had no investment in equipment used for production that year. Around 90% of firms with zero investment in productive equipment had a directly reported deduction of zero for the VAT of equipment used for production, supporting the validity of our approach.

We also use a similar method to estimate investment in structures with missing or negative values. To ensure consistency across years, we define capital stock as the sum of two types of capital - equipment for production and structure for production. If the value of the capital stock is unavailable in a particular year, we estimate it by adding the value of an investment in that year to the capital stock in the previous year or subtracting the value of an investment in that year from the capital stock in the next year. We only include firm-year observations with non-negative capital stock in our analysis sample. To account for inflation, we deflate both investment and capital stock measures using price indices from the *China Statistical Yearbooks*.

A.4 Industry Classification

The NTSD adopts a four-digit Chinese Industry Classification (CIC) system comparable to the U.S. SIC system. The CIC system was first published in 1984 and underwent several revisions in 1994, 2002, 2011, and 2017. The 2011 revision incorporated more detailed classifications for some industries and merged others. Since our study covers the period between 2007 and 2013, we created a harmonized classification by grouping some industries before or after the revision to ensure comparability of industry codes throughout the entire study period.

A significant proportion of firms in our data changed industries over time. According to the U.S. industry classification system, a firm in China is assigned to a particular sector based on its main product by sales revenue. Given China's rapidly growing economy and expanding exports, it is not surprising to observe more sectoral changes in China compared to other countries.

A.5 Rental Rate

We adopt the same definition of the rental rate (R) in the same way as Oberfield and Raval (2021). Specifically, we define the rental rate for year t as:

$$R_t = T_t(p_{t-1}r_t + \delta_t p_t),$$

where r_t is the constant external real rate of return (with the risk-free interest rate around 4%), p_t is the price index for capital, σ_t is the depreciation rate,[31] and T_t is the effective rate of capital taxation. We compute T_t using the same approach as Oberfield and Raval (2021), given by:

$$T_t = \frac{1 - \mu_t z_t - k_t}{1 - \mu_t},$$

[31] According to China's accounting standards, the book value of the asset will be depreciated over ten years using the straight-line depreciation method. Thus, we set the depreciation rate to be 10%.

where z_t is the present value of depreciation deductions for tax purposes on one yuan's investment in capital over the lifetime of the investment, k_t is the effective rate of the investment tax credit, and μ_t is the effective corporate income tax rate. Based on Li and Meng (2022), we set the effective rate of the investment tax credit at 14.5%. The effective corporate income tax rate in China is 25%. Following Chen et al. (2023), we assume a discount rate of 5% and a depreciation rate of 10%, which gives z_t a value of 0.81.

To estimate the rental rate during our entire study period from 2007 to 2013, we use the rental rate in 2010 as a benchmark, which is 12.5%.

A.6 Labor Share

Labor share is defined as the ratio of labor income to GDP at market prices. In other words, labor share indicates how labor income represents the aggregate compensation of earnings obtained by employees from GDP decomposition by the income approach. The Input-Output table conducted by the National Bureau of Statistics (NBS) provides a reliable estimation of labor share at the national level. Because the NBS does not update the input-output table yearly, the time series is only available for year 1995, 1997, 2000, 2002, 2005, 2010, 2012 and 2015, with our analysis concluding in 2015. To estimate the labor share during our entire study period from 2007 to 2013, we use the labor share calculated from the Input-Output table in 2010 as a benchmark.

Appendix B Variable Definitions

Table B1: Variable Definitions

Variable Name	Description
Domestic	An indicator that takes the value of one if the firm is domestically owned, i.e., has no registered capital from Hong Kong, Macau, Taiwan, or any foreign countries, and zero otherwise.
Post	An indicator that equals one if the observation is in or after 2009, and zero otherwise.
Log Employment	The natural logarithm of the total number of employees.
Log Earnings per Worker	The natural logarithm of the average earnings. Average earnings are defined as the total wage (including bonus and subsidy) divided by total employment.
Log Investment in Equipment	Investment in Equipment is defined as the difference between investment in productive fixed assets and investment in productive structures. For positive investment values, we apply a logarithmic transformation. For cases where investment is zero, we set the transformed value to zero, effectively using log(1 + investment in equipment).
Log Capital Stock	Capital stock is defined as the sum of two types of capital - equipment for production and structure for production. For positive values of capital stock, we apply a logarithmic transformation. In cases where the capital stock is zero, we set the transformed value to zero, effectively utilizing log(1 + capital stock).

Continue Appendix Table B1

Variable Name	**Description**
Firm Size Fixed Effect	Firm size is defined as the total revenue of that firm in 2008. Firm size fixed effects are defined based on quartiles of firm size across all the firms in the estimation sample.
SOE	An indicator that equals one if the firm is a state-owned enterprise and zero otherwise.
Listed Firm	An indicator that equals one if the firm is a publicly listed firm and zero otherwise.
Small Scale Taxpayer	An indicator that takes the value of one if the firm enjoys a favorable VAT tax rate and zero otherwise. In China, firms in particular industries can enjoy preferential VAT tax rates. For example, according to the tax law in 2022, firms selling agricultural goods, books, newspapers, and magazines enjoy a favorable VAT tax rate of 13%. Moreover, small-scale VAT taxpayers can enjoy an even lower VAT tax rate of 3%.

Appendix C A More Credible Approach to Parallel Trends

In this section we follow the methodology proposed by Rambachan and Roth (2023) and demonstrate that while the parallel trends assumption is mildly violated when using capital stock as the outcome variable, the causal parameter of interest remains largely identifiable once we account for the pre-trend. This suggests that, despite the deviation from strict parallel trends, incorporating information from the pre-treatment period mitigates potential biases and allows for reliable estimation of the treatment effect in our case.

C.1 Framework of Rambachan and Roth (2023)'s Approach

Our analysis is situated within a canonical (non-staggered) Difference-in-Differences (DD) framework. Following the notation of Rambachan and Roth (2023), we focus on estimating a vector of event study coefficients, denoted as $\hat{\beta} = \left(\hat{\beta}'_{\text{pre}}, \hat{\beta}'_{\text{post}}\right)' \in \mathbb{R}^{\underline{T}+\overline{T}}$, where $\hat{\beta}_{\text{pre}}$ and $\hat{\beta}_{\text{post}}$ correspond to the estimated coefficients for $\underline{T}$ pre-treatment periods and $\overline{T}$ post-treatment periods, respectively. We assume that $\hat{\beta}$ is a consistent estimator for the reduced-form parameter, which can be further decomposed as follows:

$$\beta = \underbrace{\begin{pmatrix} 0 \\ \tau_{\text{post}} \end{pmatrix}}_{=:\tau} + \underbrace{\begin{pmatrix} \delta_{\text{pre}} \\ \delta_{\text{post}} \end{pmatrix}}_{=:\delta}$$

In this context, τ represents the causal parameter of interest, which is assumed to be zero during the pre-treatment period, while δ captures the bias arising from differences in underlying trends. For example, in a standard (non-staggered) Difference-in-Differences (DD) framework, $\hat{\beta}$ may represent the coefficients obtained from an event-study regression specification, with τ corresponding to the vector of period-specific average treatment effects on the treated (ATT) for a particular policy, and δ reflecting discrepancies in the trends of untreated potential outcomes between the treated and comparison groups. The usual parallel trend assumption requires that $\delta_{\text{post}} = 0$, and then $\beta_{\text{post}} = \tau_{\text{post}}$ under parallel trends. Scholars often use $\delta_{\text{pre}} = 0$ to support the hypothesis here. Unfortunately, in our case, δ_{pre} deviates slightly from zero, indicating a mild violation of the parallel trend assumption in the pre-treatment period. In this section, we will demonstrate that, despite this deviation, our results remain robust and reliable when accounting for the pre-trend in the analysis.

Rather than assuming that the parallel trends assumption holds precisely, we adopt the approach proposed by Rambachan and Roth (2023), imposing constraints on the potential post-treatment differences in trends, δ_{post}, based on the observed pre-treatment trends, δ_{pre}.

The underlying rationale is that the pre-treatment trends provide valuable information about the counterfactual differences in trends after the treatment. Formally, we assume that $\delta \in \Delta$, where Δ is a researcher-specified set, and demonstrate that the post-treatment causal parameter, τ_{post}, is partially identified under these imposed restrictions. We assume that the confounding factors that create post-treatment violations of parallel trends are similar in magnitude to those in the pre-treatment period. This intuition can be rigorously represented by specifying a Δ that bounds the maximal post-treatment violation of parallel trends by a parameter $\overline{M}$ times the maximal pre-treatment violation of parallel trends.

C.2 Sensitivity Analysis

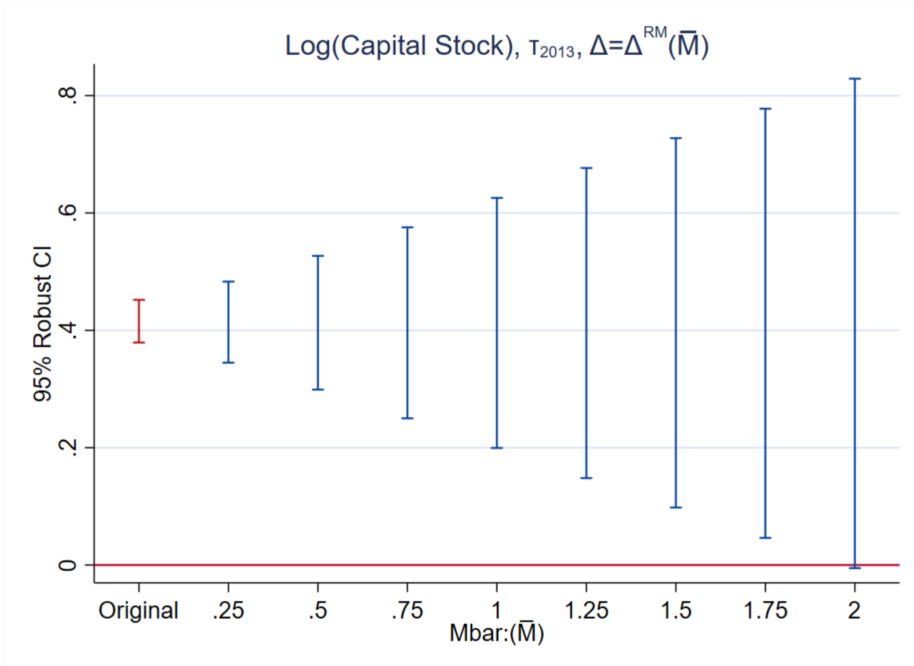
In our empirical context, we are mindful of the potential for differential economic shocks affecting domestic and foreign firms, which could lead to violations of the parallel trend assumption. To be more specific, there may be some unobserved macroeconomic shocks that would have affected domestic firms and foreign firms differently even in absence of the VAT reform. We contend that it is reasonable to assume that the magnitude of these differential shocks in the post-treatment period is not substantially different from those in the pre-treatment period. Consequently, we follow the approach of Rambachan and Roth (2023) by imposing restrictions on δ, explicitly bounding the relative magnitude of the post-treatment violations of parallel trends based on the observed deviations during the pre-treatment period. In other words, we base our analysis on bounds on relative magnitudes $\Delta^{RM}(\overline{M})$.

Panel A of Figure C1 presents the robust confidence intervals for the 2013 treatment effect, using varying values of $\overline{M}$ in $\Delta^{RM}(\overline{M})$. The findings suggest that when $\overline{M} = 1$ is imposed - indicating that post-treatment deviations from parallel trends are no larger than those observed pre-treatment - the robust confidence interval for the causal effect on capital stock in 2013 ranges from 0.199 to 0.626. While this interval is broader than the original OLS confidence interval, which assumes strict adherence to parallel trends, it still rules out a null effect on capital stock in 2013. Moving further to the right in the figure, we observe that the threshold value for the null effect, or the "breakdown" point, is approximately $\overline{M} = 2$.

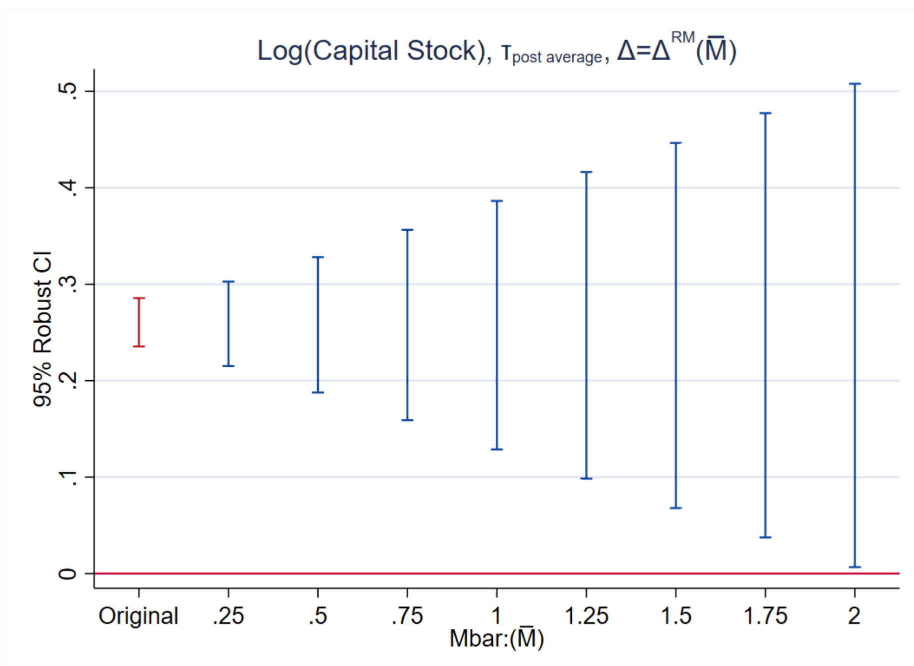
In Panel B of Figure C1, we present analogous results for the average causal effect on capital stock across all five post-treatment periods. Even when $\overline{M} = 2$, the robust confidence set does not include zero. Therefore, our conclusion of a significant effect on capital stock hinges on the assumption that post-treatment violations of parallel trends are no more than twice as large as those in the pre-treatment period.

In summary, our finding of a significant effect on capital stock remains robust even when the post-treatment deviations from parallel trends are constrained to be up to twice the magnitude of the pre-treatment deviation. This demonstrates a high degree of robustness in our estimation.

Figure C1: Sensitivity Analysis on Log (Capital Stock)



(a) Panel A: Treatment effect in 2013



(b) Panel B: Average treatment effect across all post-treatment years

Notes: This figure shows robust confidence sets for the treatment effect in terms of capital stock in 2013 (Panel A) and on average (Panel B) for $\Delta^{RM}(\overline{M})$ using different values of $\overline{M}$.

Appendix D Inverse Probability Weighting (IPW)

This section shows the details of the inverse probability weighting (IPW) method we used in section 3. As we mentioned, domestic firms and foreign firms might have different observable characteristics, such as investment, capital stock, employment, and wage payable. To release this concern, we follow Chen et al. (2023) to reweight our sample to match the distribution of some observable characteristics between domestic and foreign firms. The details are as follows:

We first generate propensity scores for being treated by estimating the following probit model:

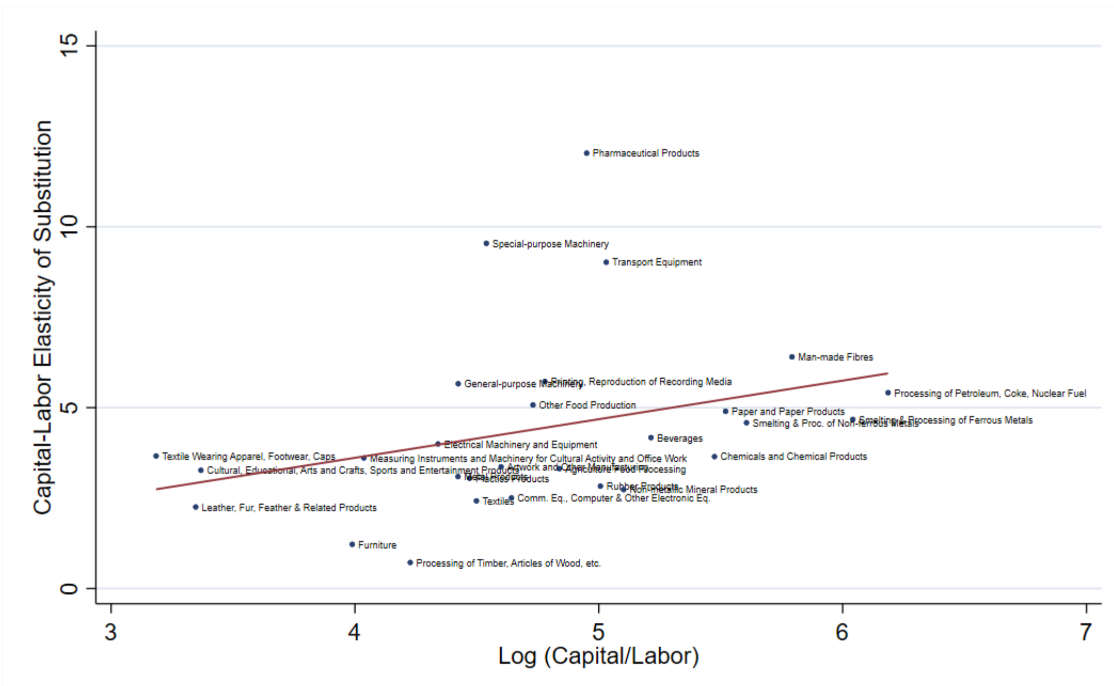
$$D_i = \mathbf{1}\left\{\alpha + X_i\beta + u_i > 0\right\},$$

where D_i is the treatment variable, X_i is a set of firm-specific variables, including investment, capital stock, employment, and main business revenue, and u_i is the error term. Our analysis is based on the firms' characteristics of the pre-reform year. That is, we use the data in 2008 for all firm-specific terms. We then use the generated propensity scores from the probit model for reweighting. Panel A of Appendix Figure 4 shows the distribution of propensity scores of domestic firms and foreign firms, respectively. Panel B of Appendix Figure 4 shows that after reweighting, domestic and foreign firms are balanced in observable characteristics, including investment, capital stock, employment, and main business revenue. After reweighting, our treatment and control groups are comparable in key dimensions.

Appendix E Capital Intensity and Capital-Labor Elasticity of Substitution across Industries

In this section, we examine the relationship between the capital-labor elasticity of substitution and the capital intensity of various industries as of 2008, one year before the implementation of the reform. Capital intensity is defined as the logarithm of capital stock per worker. Figure E1 illustrates a positive correlation between capital-labor elasticity of substitution and capital intensity.

Figure E1: Correlation between Capital Intensity and Capital-labor Elasticity of Substitution



Note: This figure displays the correlation between the capital-labor elasticity of substitution and the Log capital-labor ratio for each corresponding industry.

In addition to our primary analysis, we calculate the capital-labor ratio for each two-digit industry in 2008, the year preceding the VAT reform. This calculation allows us to evaluate the reform's impact on firm performance across different levels of capital intensity. Specifically, we focus on two distinct groups: capital-intensive industries, defined as those in the highest 50% of capital intensity, and other industries. The findings from this analysis are detailed in Tables E1 and E2.

Utilizing the same methodological framework, we estimate the firm-level capital-labor elasticity of substitution for both high and low capital intensity industries. Our estimates indicate that the elasticity of substitution is 4.86 for industries with high capital intensity and 3.02 for those with low capital intensity. These results provide valuable insights into the differential impacts of the VAT reform on industries with varying degrees of capital intensity, highlighting the nuanced relationship between capital allocation and labor dynamics within the context of tax policy changes.

Table E1: Effects of VAT Reform on Capital Stock and Employment (High Capital Intensity Industry)

	(1)	(2)	(3)	(4)	(5)
Panel A: Log Capital Stock					
Domestic × Post	0.263***	0.268***	0.245***	0.281***	0.253***
	(0.019)	(0.020)	(0.022)	(0.021)	(0.022)
R-squared	110,222	110,217	110,222	110,222	110,222
Observations	0.862	0.862	0.863	0.862	0.863
Panel B:Log Employment					
Domestic × Post	-0.033***	-0.031***	-0.024**	-0.019**	-0.016*
	(0.008)	(0.008)	(0.009)	(0.009)	(0.010)
R-squared	110,222	110,217	110,222	110,222	110,222
Observations	0.933	0.933	0.934	0.933	0.934
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	No	No	No
Industry × Year FE	No	Yes	No	No	No
Province × Year FE	No	No	Yes	No	Yes
Firm Size_{2008} × Year FE	No	No	No	Yes	Yes

Notes: This table uses tax data to estimate the effects of the VAT reform on firm outcomes within high capital intensity industries. The estimation sample is a balanced panel of manufacturing firms that remain in the National Tax Survey Database from 2007 to 2013. Columns (1)-(5) report the results from estimating the difference-in-differences model outlined in equation (1) Column (1) includes firm fixed effects and year fixed effects. Column (2) includes firm fixed effects and 2-digit industry-by-year fixed effects. Column (3) includes firm fixed effects and province-by-year fixed effects. Column (4) includes firm fixed effects and firm size bins interacted with the year fixed effects. Column (5) includes firm fixed effects and province-by-year fixed effects and firm size bins interacted with the year fixed effects. Standard errors, shown in parentheses, are clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table E2: Effects of VAT Reform on Capital Stock and Employment (Low Capital Intensity Industry)

	(1)	(2)	(3)	(4)	(5)
Panel A: Log Capital Stock					
Domestic × Post	0.276***	0.259***	0.236***	0.283***	0.239***
	(0.017)	(0.017)	(0.019)	(0.017)	(0.019)
R-squared	151,886	151,884	151,886	151,886	151,886
Observations	0.859	0.859	0.860	0.859	0.860
Panel B: Log Employment					
Domestic × Post	0.047***	0.040***	0.042***	0.059***	0.048***
	(0.007)	(0.007)	(0.008)	(0.007)	(0.008)
R-squared	151,886	151,884	151,886	151,886	151,886
Observations	0.925	0.926	0.926	0.925	0.926
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	No	No	No
Industry × Year FE	No	Yes	No	No	No
Province × Year FE	No	No	Yes	No	Yes
Firm Size_{2008} × Year FE	No	No	No	Yes	Yes

Notes: This table uses tax data to estimate the effects of the VAT reform on firm outcomes within low capital intensity industries. The estimation sample is a balanced panel of manufacturing firms that remain in the National Tax Survey Database from 2007 to 2013. Columns (1)-(5) report the results from estimating the difference-in-differences model outlined in equation (1) Column (1) includes firm fixed effects and year fixed effects. Column (2) includes firm fixed effects and 2-digit industry-by-year fixed effects. Column (3) includes firm fixed effects and province-by-year fixed effects. Column (4) includes firm fixed effects and firm size bins interacted with the year fixed effects. Column (5) includes firm fixed effects and province-by-year fixed effects and firm size bins interacted with the year fixed effects. Standard errors, shown in parentheses, are clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Appendix F Industry-level Elasticity of Substitution

In Section 4, we estimated the capital-labor elasticity of substitution as a firm-level elasticity, which did not take into account the possible reallocation of factors across firms or industries. In this section, we aim to estimate the elasticity of substitution at the industry level using the framework proposed by Oberfield and Raval (2021). Their method uses a nested CES production function to account for reallocation towards more capital-intensive firms within an industry. Here, we provide the details of the derivation.

Assuming there are N industries in the economy and I_n firms in each industry n, the production function for firm i in industry n can be expressed as:

$$F_{ni}\left(K_{ni}, L_{ni}\right) = \left(K_{ni}\frac{\sigma_n - 1}{\sigma_n} + L_{ni}^{\frac{\sigma_n-1}{\sigma_n}}\right)^{\frac{\sigma_n}{\sigma_n-1}},$$

where σ_n is the elasticity of substitution between capital and labor. Similar to Section 4, we assume a nested structure of demand with constant elasticity at the aggregate level. This implies that the representative consumer has a constant elasticity of substitution across industries and across varieties within each industry. Under these assumptions, each firm in the industry n faces a demand curve with constant elasticity denoted by η_n. Let w and R denote the wage and rental rate, respectively. Each firm aims to maximize its own profit:

$$\text{Max} \quad P_{ni}Y_{ni} - RK_{ni} - wL_{ni},$$

subject to the production constrain $Y_{ni} = F_{ni}(K_{ni}, L_{ni})$ and the demand curve $Y_{ni} = Y_n(\frac{P_{ni}}{P_n})^{-\eta_n}$, where P_n is the price index for industry n.

The industry-level elasticity of substitution between capital and labor can be defined as the partial equilibrium response of the industry-level capital-labor ratio to a change in the relative factor price:

$$\sigma_n^N = \frac{\mathrm{d}\ln \frac{K_n}{L_n}}{\mathrm{d}\ln \frac{w}{R}}.$$

Let $\alpha_{ni} = \frac{RK_{ni}}{RK_{ni}+wL_{ni}}$ and $\alpha_n = \frac{RK_n}{RK_n+wL_n}$ denote the cost shares of capital for firm i and industry n, respectively. The firm-level and industry-level elasticities of substitution are closely related to the changes in these capital shares:

$$\sigma_{ni} - 1 = \frac{\mathrm{d}\ln \frac{RK_{ni}}{wL_{ni}}}{\mathrm{d}\ln \frac{w}{R}} = \frac{\mathrm{d}\ln \frac{\alpha_{ni}}{1-\alpha_{ni}}}{\mathrm{d}\ln \frac{w}{R}} = \frac{1}{\alpha_{ni}\left(1-\alpha_{ni}\right)}\frac{\mathrm{d}\alpha_{ni}}{\mathrm{d}\ln \frac{w}{R}} \tag{F.1}$$

$$\sigma_n^N - 1 = \frac{\mathrm{d}\ln \frac{RK_n}{wL_n}}{\mathrm{d}\ln \frac{w}{R}} = \frac{\mathrm{d}\ln \frac{\alpha_n}{1-\alpha_n}}{\mathrm{d}\ln \frac{w}{R}} = \frac{1}{\alpha_n\left(1-\alpha_n\right)}\frac{\mathrm{d}\alpha_n}{\mathrm{d}\ln \frac{w}{R}}. \tag{F.2}$$

We can express the industry-level cost share of capital as the average of firm capital shares, weighted by size:

$$\alpha_n = \sum_{i \in I_n} \alpha_{ni}\theta_{ni},$$

where $\theta_{ni} = \frac{RK_{ni}+wL_{ni}}{RK_n+wL_n}$ is firm $i's$ share of industry $n's$ expenditure on capital and labor. To find the industry-level elasticity of substitution, we differentiate the equation above to obtain the following:

$$\frac{\mathrm{d}\alpha_n}{\mathrm{d}\ln\frac{w}{R}} = \sum_{i \in I_n} \frac{\mathrm{d}\alpha_{ni}}{\mathrm{d}\ln\frac{w}{R}}\theta_{ni} + \sum_{i \in I_n} \alpha_{ni}\frac{\mathrm{d}\ln\theta_{ni}}{\mathrm{d}\ln\frac{w}{R}}.$$

Combining equations F.1 and F.2 with the previous expression, we can rewrite it as:

$$\sigma_n^N - 1 = \frac{1}{\alpha_n\left(1-\alpha_n\right)}\sum_{i \in I_n}\alpha_{ni}\left(1-\alpha_{ni}\right)\left(\sigma_{ni}-1\right)\theta_{ni} + \frac{1}{\alpha_n\left(1-\alpha_n\right)}\sum_{i \in I_n}\alpha_{ni}\theta_{ni}\frac{\mathrm{d}\ln\theta_{ni}}{\mathrm{d}\ln\frac{w}{R}}.$$

The first term on the right-hand side shows how much the substitution effect is related to factor intensity, holding the firm's size fixed. The firm-level elasticity of substitution (σ) determines the extent to which a firm changes its input of capital and labor in response to changes in factor prices. Meanwhile, the second term on the right-hand side describes the reallocation effects, which measure how much a firm changes its size in response to relative factor prices. In our case, when the cost of capital decreases, capital-intensive firms gain a relative cost advantage. Consumers respond to changes in relative input prices by shifting consumption toward capital-intensive goods. Note that consumers will respond more to changing relative prices if the demand is more elastic.

With the assumptions described above, we can manipulate equations F.1 and F.2 (detailed proof available in Oberfield and Raval (2021)) to derive the expression for the industry-level elasticity of substitution in the main text (equation 10):

$$\sigma_n^N = \left(1-\chi_n\right)\sigma_n + \chi_n\xi_n,$$

where $\chi_n \equiv \sum_{i \in I_n}\frac{\left(\alpha_{ni}-\alpha_n\right)^2}{\alpha_n\left(1-\alpha_n\right)}\theta_{ni}$. χ_n is the heterogeneous index for industry n. A larger value of χ_n indicates greater variation in capital intensities within the industry and a more significant role in the reallocation of production inputs compared to within-firm substitution. Thus, we can conclude that the industry-level elasticity of substitution is a convex combination of the firm-level elasticity of substitution in that industry and the elasticity of demand of the corresponding industry.

Appendix G Aggregate-Level Elasticity of Substitution

We will now utilize the approach developed by Oberfield and Raval (2021) to derive the aggregate-level elasticity of substitution between capital and labor based on the industry-level elasticity of substitution that we have calculated.

Oberfield and Raval (2021) demonstrate that the aggregate-level elasticity parallels the industry elasticity. In other words, the aggregate-level capital-labor elasticity of substitution consists of substitution within each industry and reallocation across industries. The aggregate-level elasticity of substitution can be expressed as:

$$\sigma^{\text{agg}} = \left(1 - \chi^{\text{agg}}\right) \bar{\sigma}^{N} + \chi^{\text{agg}} \xi.$$

Recall that the production function is

$$F_{ni}\left(K_{ni}, L_{ni}\right) = \left(K_{ni}^{\frac{\sigma_n - 1}{\sigma_n}} + L_{ni}^{\frac{\sigma_n - 1}{\sigma_n}}\right)^{\frac{\sigma_n}{\sigma_n - 1}}.$$

In addition to the cost shares of capital for industry n defined in Appendix F, we define α as the economy-wide capital cost share, where $\alpha \equiv \frac{RK}{RK+wL}$. The aggregate heterogeneous index is defined as $\chi^{\text{agg}} \equiv \sum_{n \in N} \frac{(\alpha_n - \alpha)^2}{\alpha(1-\alpha)} \theta_n$. Similarly, the aggregate heterogeneous index, together with the weighted average of the industry-level elasticity of substitution ($\bar{\sigma}^{N} = \sum_{n \in N} \frac{\alpha_n (1-\alpha_n) \theta_n}{\sum_{n' \in N} \alpha_{n'} (1-\alpha_{n'}) \theta_{n'}} \sigma_n^N$) measures the degree to which the aggregate-level capital-labor elasticity of substitution reflects the within-industry substitution and the cross-industry demand elasticity captures the substitution across industries of varying capital intensity.

Appendix H Incorporating Entry and Exit

In this appendix, we adopt the method developed by Oberfield and Raval (2021) to extend our theoretical model to account for the entry and exit of firms since a change in factor prices may cause some firms to exit and others to enter. It is reasonable to assume that the degree of adjustment may vary across plants. Thus, the responses of a firm on the margin of entering or exiting to the changes in factor prices are likely to differ from those of an infra-marginal firm.

Consider an economy with a continuum of entrepreneurs. Each entrepreneur can randomly draw a technology τ from an exogenous distribution with cumulative distribution function $T(\tau)$ by paying an entry cost of f^E units of the final output. After observing the draw, the owner of a firm can operate the firm with the production function $F_\tau(K, L)$. We assume that each production function F_τ exhibits constant returns to scale.

We define the indicator function E_τ to represent whether firm τ chooses to operate. For a firm that enters, we use α_τ and θ_τ to represent its capital share and its expenditure on capital and labor relative to the average expenditure, respectively. Then, we can express the aggregate capital share as $\alpha = \int \alpha_\tau E_\tau dT(\tau)$.

Now the aggregate-level elasticity can be written as

$$\sigma^{\text{agg}} = (1-\chi)\left[\sigma + \frac{\int (\alpha_\tau - \alpha)\frac{dE_\tau}{dl_R}\theta_\tau dT(\tau)}{\int \alpha_\tau (1-\alpha_\tau)\theta_\tau dT(\tau)}\right] + \chi\eta.$$

We have added an additional term in the first equation on the right-hand side to capture the impact of the entry and exit of firms on the change in aggregate factor shares. The interpretation of this expression is similar to that in Appendix F or Appendix G. The term in the bracket measures the response of firms' capital shares to the change in the relative cost of inputs from both the intensive and extensive margins, which includes within-firm substitution and contributions from the entry and exit of firms. In our case, the VAT reform results in a decrease in the cost of capital, causing labor-intensive firms to exit the market while capital-intensive firms tend to enter. The second term captures the reallocation of resources between capital-intensive and labor-intensive firms, where a decrease in capital cost causes capital-intensive firms to expand relative to labor-intensive firms.

Having derived the expression in the previous section, we can now demonstrate that our estimation of the aggregate-level elasticity of substitution in the main text likely represents a lower bound of its actual value. Our estimation is based on a balanced panel of firms over a seven-year period, which does not account for changes due to entry and exit (the second term in the bracket). As a result, our estimates only capture the relationship between the average capital share and the capital cost, reflecting only the intensive margin. However, a decrease in capital cost induces labor-intensive firms to exit and capital-intensive firms to enter, meaning that marginal firms are more likely to be capital-intensive, causing a downward bias in our estimates. Therefore, our balanced-panel estimates provide a conservative lower bound for the true aggregate-level elasticity of substitution in the Chinese manufacturing sector.

Appendix I Connecting Substitution Elasticity and Growth

As discussed in our main text, China's sustained high economic growth over the past few decades has been the subject of intense research. However, few studies addressed the theory proposed by de La Grandville (1989), which argues that a high aggregate-level elasticity of substitution could be a powerful engine of growth. In this section, we derive the positive connection between the elasticity of capital-labor substitution and economic growth.

Recall that we have assumed that the production function is:

$$Y = F(K, L) = \left(K^{\frac{\sigma-1}{\sigma}} + L^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}.$$

To see that the output is an increasing function of the elasticity of capital-labor substitution, we first transform the production function in terms of efficient labor units as follows:

$$y = f(k) = \left(k^{\frac{\sigma-1}{\sigma}} + 1\right)^{\frac{\sigma}{\sigma-1}},$$

where $y = \frac{Y}{L}$ and $k = \frac{K}{L}$. Accordingly, in growth terms, we shall have the following:

$$\frac{\dot{y}}{y} = \frac{1}{1 + k^{\frac{\sigma-1}{\sigma}}} \times \frac{\dot{k}}{k} = g(\sigma) \times \frac{\dot{k}}{k}$$

Differentiating the equation above with the elasticity of substitution between capital and labor arrives:

$$\frac{\partial\left(\frac{\dot{y}}{y}\right)}{\partial\sigma} = g(\sigma)\frac{\partial\left(\frac{\dot{k}}{k}\right)}{\partial\sigma} + \frac{\dot{k}}{k}\frac{\partial g(\sigma)}{\partial\sigma} > 0.$$

Here, we need to note that as implied by the neoclassical growth model, $\frac{\partial\left(\frac{\dot{k}}{k}\right)}{\partial\sigma} = \frac{s}{k}\frac{\partial f(k)}{\partial\sigma}$,[32] and assuming $k > 1$, this term is positive. Then, with $\frac{\dot{k}}{k}$, both terms on the right-hand side are positive, and, hence, the growth rate of output also depends positively on the elasticity of capital-labor substitution. In other words, the higher the aggregate-level capital-labor elasticity, the higher the economy will grow. This conclusion aligns with the rapid growth of China's economy we observed in the past decades. The intuition is straightforward, the easier factor substitution - higher elasticity of substitution between the factors - helps to overcome diminishing returns. Thus, it leads to a higher level of output. Interestingly, since our estimation of China's aggregate-level elasticity of substitution is much higher than that estimated for many other developed countries, this helps explain China's rapid economic growth in the past decades.

[32] Here, s refers to the saving rate.

Appendix J Connecting Substitution Elasticity and Labor Share

J.1 Elasticity of Substitution and Labor Share

In Capital in the Twenty-First Century, Piketty pointed out the relationship between the decline in economic growth and the labor share. In this section, we will show how a decline in economic growth would affect the capital share. Our derivation closely follows Piketty (2014), which in turn follows the growth model of Solow (1956).

Following Piketty (2014), we defined $\beta = \frac{K}{Y}$ as the capital-output ratio at the steady state, and he also assumed that the net saving rate is a constant s fraction of net output. On a balanced growth path, both capital K_t and output Y_t grow at a constant rate g over time. Thus, we have:

$$\beta = \frac{K}{Y} = \frac{s}{g},$$

the capital share of income is defined as: $\alpha = \frac{RK}{Y} = R\beta$.

With a CES production function:

$$Y_t = \left[K_t^{\frac{\sigma-1}{\sigma}} + L_t^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}},$$

the marginal product of capital, and thus the rental price R, is:

$$R = \beta^{-\frac{1}{\sigma}}.$$

Then after substituting this equation into the expression of capital share, we can obtain the following:

$$\alpha = \frac{RK}{Y} = \left(\frac{s}{g}\right)^{\frac{\sigma-1}{\sigma}}.$$

With the assumption that s is the same for the whole time, when the elasticity of substitution σ is above one, the fall in g will also increase the capital share α(decrease labor cost share).

J.2 Decomposition of Labor Share

Following Oberfield and Raval (2021), we decompose the labor share as follows:

$$ds^{v,L} = \underbrace{\frac{\partial s^{v,L}}{\partial \ln \frac{w}{R}} d\ln\frac{w}{R}}_{\text{factor price effect}} + \underbrace{\left(ds^{v,L} - \frac{\partial s^{v,L}}{\partial \ln \frac{w}{R}} d\ln\frac{w}{R}\right)}_{\text{bias of technical change}},$$

where $s^(v, L)$ is the labor's share of value added.

We also use the discrete approximation to approximate the equation above. For any x, define:

$$\bar{x} = \frac{x_{t+1} - x_t}{2}$$
$$\Delta x = \frac{x_{t+1} + x_t}{\bar{x}}.$$

We can derive two useful equations as follows:

$$\Delta\left(s^{v,K} + s^{v,L}\right) = \frac{\bar{s}^{v,K}}{\bar{s}^{v,K} + \bar{s}^{v,L}}\Delta s^{v,K} + \frac{\bar{s}^{v,L}}{\bar{s}^{v,K} + \bar{s}^{v,L}}\Delta s^{v,L}.$$

Define the biases of technical change:

$$\phi_{k,l} = \Delta RK - \Delta wL - (1 - \sigma^{agg})\,\Delta\frac{R}{w}.$$

This equation can also be written as:

$$\phi_{k,l} = \Delta s^{v,K} - \Delta s^{v,L} - (1 - \sigma^{agg})\,\Delta\frac{R}{w}.$$

The labor share can then be decomposed as:

$$\begin{aligned}\Delta s^{v,L} = \Delta s^{v,L} - \Delta\left(s^{v,K} + s^{v,L}\right) &= \Delta s^{v,L} - \frac{\bar{s}^{v,K}}{\bar{s}^{v,K} + \bar{s}^{v,L}}\Delta s^{v,K} - \frac{\bar{s}^{v,L}}{\bar{s}^{v,K} + \bar{s}^{v,L}}\Delta s^{v,L} \\ &= \frac{\bar{s}^{v,K}}{\bar{s}^{v,K} + \bar{s}^{v,L}}\left(\Delta s^{v,L} - \Delta s^{v,K}\right).\end{aligned}$$

Using the definition of $\phi_{k,l}$ we have:

$$\Delta s^{v,L} = \frac{\bar{s}^{v,K}}{\bar{s}^{v,K} + \bar{s}^{v,L}}\left(\sigma^{agg} - 1\right)\Delta\frac{R}{w} - \frac{\bar{s}^{v,K}}{\bar{s}^{v,K} + \bar{s}^{v,L}}\phi_{k,l}.$$

In the decomposition, we then have:

$$s^{v,L}_{t+1} - s^{v,L}_t = \bar{s}^{v,L}\left(1 - \bar{s}^{v,L}\right)\left(\sigma^{agg} - 1\right)\Delta\frac{R}{w} - \bar{s}^{v,L}\left(1 - \bar{s}^{v,L}\right)\phi_{k,l}.$$

Thus, if the information on the change of relative input price ratio is available, with the aggregated elasticity of substitution we estimated, we can gauge how much of the change of labor is contributed by the factor price change.

Appendix K Minimum Wage Shock

As we discussed in Section 3, we have estimated the employment and capital stock effects of the VAT reform and used the estimation to obtain the firm-level capital-labor elasticity of substitution. In this Appendix, we present detailed empirical evidence elucidating the impact of the minimum wage on both employment and capital stock. Subsequently, we leverage the observed change in labor cost to compute the capital-labor elasticity at the firm level.

K.1 Background of Minimum Wage Policy

China implemented its minimum wage policy in July 1994, following the introduction of a new labor law that mandated the establishment of a minimum wage system. Due to varying living standards across Chinese provinces, the country does not have a unified national minimum wage. Each province, municipality, autonomous region, and district has the autonomy to set its own minimum wage based on local conditions and national guidelines (Mayneris et al. (2018)). During the 1990s in China, the increment of minimum wages was relatively slow, and not all workers were encompassed by these wage regulations. In March 2004, the Ministry of Labor and Social Security introduced a policy reform aimed at promoting a standardized implementation of minimum wage policies. After that the minimum wage coverage encompassed a greater number of workers, while the frequency of minimum wage adjustments increased, occurring at least once every two years.

K.2 Data

The firm-level data in our study comes from the Annual Survey of Industry Firms (ASIF), which is conducted by the National Bureau of Statistics (NBS) in China. The data includes all industrial firms that are either state-owned or non-state firms with sales above 5 million RMB (Brandt et al. (2012)). We focus on manufacturing firms, and our sample used for analysis spans from 1998 to 2007. The summary statistics can be found in Appendix Table K1. The minimum wage data used in this subsection is provided by the Ministry of Human Resources and Social Security and the China Academy of Labor and Social Security; it records the minimum wage from 1994 to 2012.

Table K1: Summary Statistics of Firm-Level Characteristics

	(1) Mean	(2) S.D.	(3) Observation
Capital (1,000 yuan)	24,789.35	252,540.59	1,390,848
Employment	288.52	1,037.72	1,390,848
Earning per Worker (1,000 yuan)	12.96	68.11	1,390,848

Notes: This table reports the summary statistics of firm characteristics. The sample contains manufacturing firms spans in the Annual Survey of Industrial Firms from 1998 to 2007. Wage and earnings per worker are deflated to the 1998 level with the consumer price index.

K.3 Empirical Strategy

One limitation of the data is that the worker-level wage information is not available. Following the literature, we use the average wage as the proxy for the percentage of employees likely to be affected by the minimum wage (Mayneris et al. (2018);Hau et al. (2020)).To be more specific, we defined treated firms as those whose average wage at $t-1$ was below the local minimum wage set at time t.Our baseline specification can be written as follows:

$$Y_{i,k,t} = \gamma\ Treated_{i,t} + \mu_i + \kappa_{k,t} + \epsilon_{i,k,t}, \tag{K.1}$$

The outcome variable $Y_{i,k,t}$ for firm i are employment and capital stock in sector k at time t. $Treated_{i,t}$ is a dummy for firm i being exposed to the minimum wage at time t, and for each firm i we set the dummy variable to be one after its first exposure to the minimum wage. $\kappa_{k,t}$ is a industry by year fixed effects and μ_i is the firm fixed effects. Our coefficient of interest is γ, which measures the effects of minimum wage on firms' performance in terms of employment and capital stock. The results are shown in Table K2. According to our findings, the minimum wage does not have a significant impact on capital stock. However, it has been observed to result in a decrease in employment by approximately 10%.

K.4 Estimation of σ_{KL} from Minimum Wage Changes

Similar to section 4, we are able to characterize the effects of the minimum wage on the firms' demand for labor input and capital input as follows:

$$\gamma^L = (\underbrace{-S_L\eta}_{\substack{\text{Scale}\\ \text{Effect}}} \quad \underbrace{-S_K\sigma_{KL}}_{\substack{\text{Substitution}\\ \text{Effect}}}) \times \underbrace{\Gamma}_{\Delta \text{ Cost of Labor}} \tag{K.2}$$

Table K2: The Effects of Minimum Wage on Firms' Employment and Capital Stock

	(1)	(2)	(3)
Panel A: Log Capital Stock			
Expose	-0.011	-0.007	-0.010
	(0.011)	(0.010)	(0.010)
Observations	1,291,892	1,291,892	1,291,878
R-square	0.865	0.865	0.867
Panel B: Log Employment			
Expose	-0.110***	-0.108***	-0.106***
	(0.008)	(0.008)	(0.007)
Observations	1,291,892	1,291,892	1,291,878
R-square	0.909	0.909	0.912
Firm FE	Yes	Yes	Yes
Year FE	Yes	No	No
Industry × Year FE	No	Yes	Yes
Firm Controls	No	No	Yes

Notes: We use the ASIF data to estimate the effects of the Minimum Wage reform on firm outcomes. The data covers the 1998-2007 period. Columns (1)-(3) report the results from estimating the difference-in-differences model outlined above. Column (1) includes firm fixed effects and year fixed effects. Column (2) includes firm fixed effects and 2-digit industry-by-year fixed effects. Column (3) includes firm fixed effects, 2-digit industry-by-year fixed effects, and firm-level controls, which include registration type dummy and firm age dummy. Standard errors, shown in parentheses, are clustered at the city level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

$$\gamma^K = (\underbrace{-S_L\eta}_{\substack{\text{Scale}\\\text{Effect}}} \quad \underbrace{+S_L\sigma_{KL}}_{\substack{\text{Substitution}\\\text{Effect}}}) \times \underbrace{\Gamma}_{\Delta\text{ Cost of Labor}} , \tag{K.3}$$

The minimum wage increases the user cost of labor, which we denote by $\Gamma = \frac{\partial log(Cost\ of\ Labor)}{\partial Minimum\ Wage} > 0$. We provide a detailed derivation of the model in the Appendix L. When combing equation K.2 and equation K.3 the elasticity of capital-labor substitution, σ_{KL}, can be written as

$$\sigma_{KL} = \eta \left(1 - \frac{1}{S_K + S_L\frac{\gamma^L}{\gamma^K}}\right). \tag{K.4}$$

Based on our DD estimates of γ^L and γ^K (reported in Column (1) of Table K2), along with NBS's estimates of S_L and S_K (0.39 and 0.61, respectively) and an η of 4.0 estimated by Li (2018). The resulting estimate of σ_{KL} is 3.18, which is quite close to our estimation in section 4. Appendix Table K3 shows that the estimation is robust to different sets of parameters.

Table K3: Estimation of the Firm-Level Elasticity of Capital-Labor Substitution

	(1) NBS S_K	(2) S_K=0.5	(3) Low η	(4) High η
Estimates of Average σ_{KL} ($\beta^K = -0.011$; $\beta^L = -0.110$, from DD)				
Average σ_{KL}	3.11	3.27	2.33	3.89
Cost Shares:				
Labor	0.39	0.5	0.39	0.39
Capital	0.61	0.5	0.61	0.61
Demand Elasticity	4.00	4.00	3.00	5.00

Notes: This table presents several results relating our reduced-form estimations of the effects of minimum wage to the model outcomes across several alternative settings of cost share and demand elasticity η. In column (1), we approximate labor cost share by labor share provided by NBS. In column (2), we set the labor cost share to 0.5. In column (3) and column (4), we change the value of η. For long difference σ_{KL}, we use the coefficient of the last term to calculate the σ_{KL} based on our model.

So far, we estimate the capital-labor elasticity by taking advantage of capital cost shock (VAT reform) and labor cost shock (exposure to minimum wage). The findings from both estimations consistently suggest a high degree of substitutability between capital and labor within the context of China.

Appendix L Labor Cost Shock: Minimum Wage Changes

With the same assumption on firms' production function proposed in Section 4. After taking the logarithm and differentiating with respect to w, we get the following equation:

$$\frac{\partial \log[p(\omega)]}{\partial w} = \frac{C_w}{C} + \frac{\partial \log \mu}{\partial w},$$

As the markup μ is a constant, the second term on the right-hand side is 0. By Shephard's Lemma ($L = q \cdot C_w$), the elasticity of production prices with respect to labor cost is equal to the share of labor cost in the total cost (S_L):

$$\frac{\partial \log[p(\omega)]}{\partial \log w} = \frac{C_w w}{C} = \frac{wL}{cq} = S_L.$$

It is therefore straightforward to derive the effects of any change in the cost of labor on total revenue:

$$\frac{\partial \log[p(\omega) \cdot q(\omega)]}{\partial \log w} = \frac{\partial \log[p(\omega)]}{\partial \log w} + \underbrace{\frac{\partial \log[q(\omega)]}{\partial \log[p(\omega)]}}_{-\eta} \frac{\partial \log[p(\omega)]}{\partial \log w} = S_L - \eta S_L.$$

The scale effect, ηS_L, depends on the extent to which exposure to minimum wage impacts the quantity sold ($q(\omega)$) by a particular firm.

Similarly, here we denoted the labor cost increased by the minimum wage as $\Gamma = \frac{\partial \log(\text{CostofLabor})}{\partial \text{MW}} > 0$.

The equation above can be rewritten as:

$$\frac{\partial \log[p(\omega) \cdot q(\omega)]}{\partial \text{MW}} = (1 - \eta) S_L \times \Gamma$$

Let's now examine the impact of exposure to minimum wage on the input decisions of affected firms. Using Shephard's Lemma, we can determine the optimal choice of each input based on the optimal output quantity and the first-order derivative of the cost function. To be precise, taking the logarithm of Shephard's Lemma ($L = C_w \cdot q$) and differentiating with respect to w, we get the following equation:

$$\frac{\partial \log[L(\omega)]}{\partial w} = \frac{C_{ww}}{C_w} + \frac{\partial \log q(\omega)}{\partial w}. \tag{L.1}$$

Note that $w = \frac{\partial w}{\partial \log w}$. By multiplying both sides of the equation and substituting the derived expression for the capital cost share, we obtain:

$$\frac{\partial \log[L(\omega)]}{\partial \log w} = w\frac{C_{ww}}{C_w} - \eta S_L.$$

Again, based on Shephard's Lemma and a production function with constant returns to scale, we can derive the following equations:

$$qc(w,R) = wL + RK = wC_w q + RC_R q$$
$$C(w,R) = C_R R + C_w w.$$

Taking the derivative of the equation above with respect to the cost of labor gives:

$$C_w = C_{ww}w + C_w + C_{wR}r$$
$$w\frac{C_{ww}}{C_w} = -r\frac{C_{wR}}{C_w} = -\frac{RK}{qC}\cdot\frac{CC_{wR}}{C_R C_w} = -S_K\sigma_{KL}.$$

Combining the above equation with equation (L.1) gives:

$$\frac{\partial \log[L(\omega)]}{\partial \log w} = -\eta S_L - S_K\sigma_{KL}.$$

Again, letting $\Gamma = \frac{\partial \log(\text{CostofLabor})}{\partial \text{MW}} > 0$, we get:

$$\frac{\partial \log[L(\omega)]}{\partial \text{MW}} = \left(-\eta S_L - S_K\sigma_{KL}\right)\Gamma.$$

Following the same procedure, we can derive the effects of exposure to minimum wage on the optimal capital input for the affected firms. By taking the logarithm of Shephard's Lemma, $K = C_R \cdot q$, and differentiating with respect to w, we obtain the following equation:

$$\frac{\partial \log[K(\omega)]}{\partial w} = \frac{C_{wR}}{C_w} + \frac{\partial \log q(\omega)}{\partial w}.$$

The above equation can be rewritten as:

$$\frac{\partial \log[K(\omega)]}{\partial \log w} = \frac{RC_R}{C}\cdot\frac{CC_{wR}}{C_R C_w} - \eta S_L = \left(\sigma_{KL} - \eta\right)S_L.$$

Together with $\Gamma = \frac{\partial \log(\text{CostofLabor})}{\partial \text{MW}} > 0$, we obtain

$$\frac{\partial \log[K(\omega)]}{\partial \text{MW}} = \left(\sigma_{KL} - \eta\right)S_L\Gamma.$$