Can Investment Incentives Crowd Out Innovation? Evidence from China

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Abstract

We analyze the spillover effect of fixed asset investment tax credits on firm innovation. We estimate this effect by exploring China's value-added tax reform in 2004. The results of difference-in-difference-in-differences (DDD) estimation show that the reform significantly reduces firm innovation, by 9.51%. Moreover, the crowding out effect appears only in firms with intermediate-level financial constraints, consistent with the prediction of our simple model with heterogeneous production technologies and financial constraints. A similar non-monotonic effect also appears in other firm decisions, such as labor input. As innovation is a major driver of economic growth with a positive externality, our results suggest that the fiscal policy of investment incentives may have unintended consequences.

JEL Classifications: O31, O32, G31.

Keywords: Value-added tax reform; innovation; capital expenditure; financial constraints; China

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1. Introduction

How to stimulate long-term economic growth is at the center of economic policy making. Economists and policymakers have long recognized that investment and innovation are two key drivers of economic growth. Therefore, many fiscal policies implemented around the world have been designed to encourage firms to invest more and/or conduct more innovation activities (e.g., Hall and Jorgenson, 1967; Bloom et al., 2002; Zwick and Mahon, 2017; Guceri and Liu, 2019). In this study, we document a crowding out effect: investment tax incentives may lead to an unintended reduction in firm innovation. Moreover, the effect is non-monotonic in terms of the level of financial constraints of firms. It is well established that firm innovation has a positive externality on the productivity of other firms, and thus on economic growth, through technology spillovers (see, for example, Romer, 1986; Griliches, 1991; Jones and Williams, 1998; Bloom et al., 2013). Therefore, the crowding-out effect on firms' innovation may lead to a negative externality on economic growth that firms do not internalize as they maximize profits.

In particular, we investigate the effect of a value-added tax (VAT) reform in China in 2004, aimed to stimulate firms' fixed asset investment, on firm innovation. Over the last 20 years, China has experienced rapid economic growth, believed to be driven by increased investment.[1] Indeed, the Chinese government has used strong fiscal stimuli to encourage investment. One important stimulus is the VAT reform of 2004, designed to encourage firms to invest in fixed assets, especially machinery and equipment, by avoiding double taxation under the previous tax policy when purchasing these assets.

We analyze the effect of investment tax credits in a simple model, in which firms have heterogeneous production technologies and financial constraints and can choose to upgrade their technology. However, advanced technology is associated with additional operating costs. The VAT reform reduces the costs of machinery and equipment and makes it more attractive to upgrade to capital-intensive advanced technology. Nevertheless, not all firms prefer to upgrade. Firms with tight financial constraints will not find upgrading beneficial, as the additional costs associated with advanced technology leave insufficient funds for production. Firms with loose financial constraints can afford advanced technology, regardless of whether the reform reduces costs. In contrast, firms with intermediate-level financial constraints will take advantage of the VAT reform to upgrade. However, to afford the additional operating costs associated with advanced technology, innovation will be crowded out. It should be noted that while firms want to

[1] For example, on July 6, 2011, *The New York Times* article "China's Reliance on Investment-driven Growth" by Michael Pettis (https://www.nytimes.com/roomfordebate/2011/07/06/chinas-debt-monster/chinas-reliance-on-investment-driven-growth/) argues that China's investment-driven growth has persisted for many years and is likely to continue for at least another two years.

reduce innovation to maximize their profits, this reduction will have a negative externality on economic growth that firms do not take into consideration. In addition to this non-monotonic crowding out effect on innovation, our theoretical analysis predicts how the VAT reform affects fixed asset expenditure and labor costs, and provides a unified explanation for previous empirical studies, including Liu and Lu (2015), Zhang et al. (2018), Cai and Harrison (forthcoming), and Liu and Mao (2019).

We empirically examine the effect of the 2004 VAT reform on firm innovation. The reform targets firms in six industries in three northeastern provinces of China. This allows us to use difference-in-difference-in-differences (DDD) estimation for identification. In other words, we first compare the before–after difference between industries targeted by the reform with those not targeted by the reform in these northeastern provinces (difference-in-differences or DID). Next, we compare the results of this DID estimation between these northeastern provinces and other provinces in China. Using the number of patents as the primary measure of innovation activities, we find that the VAT reform has a significant negative effect on firm innovation. Following the model's prediction, we examine the heterogeneous effects of the VAT reform on innovation in terms of financial constraints. We find that the VAT reform has a negative effect on innovation only for firms with an intermediate level of financial constraints. This result is robust to alternative measures of financial constraints.

We conduct a series of robustness tests to justify our main results. We first exclude other explanations for the crowding out effect of the VAT reform on innovation, such as the removal of the Multifiber Arrangement (MFA), the implementation of stricter environmental policies, and China's entry into the World Trade Organization (WTO). We also find that the non-monotonic effect (based on the level of financial constraints) of the VAT reform cannot be explained by different firm behaviors during different stages of the business life cycle. Second, we test the validity of our identification: (1) we show that the difference in time trends of firm innovation between affected and unaffected industries is the same across provinces before the VAT reform; (2) we verify that firms could not predict the policy and change their behavior in advance; (3) we use the propensity score matched sample to re-estimate the effect, and the results are robust; (4) we conduct permutation tests to show that our results are not driven by random factors; (5) we show that neither trans-province production nor firm entry/exit drives our main results. Third, we find that our results are robust to alternative samples and innovation measures. Fourth, we address concerns about the quality of patents in China by using information on the patents filed by Chinese firms but granted by the World Intellectual Property Organization (WIPO) and the economic value of the patents measured by the stock price reaction to patent grants following Kogan et al. (2017).

Finally, we show that the non-monotonic effect of the reform is not limited to innovation: firms' labor costs are also non-monotonically (based on the level of financial constraints) affected by the VAT reform, consistent with the model. In addition, we find that the effect of the reform on fixed asset expenditure is not significant, which is consistent with our model's prediction that the effect of the reform on fixed asset expenditure depends on the parameters of the production functions of firms. Specifically, as a firm upgrades its technology, the crowding out effect on fixed asset expenditure due to the additional costs associated with advanced technology and the increase in capital intensity coexist, but these two forces act in opposite directions.

Our study makes three contributions. First, it contributes to the literature on the effects of tax credits. Both investment tax credits and R&D tax credits are commonly used around the world. Previous studies (e.g., Hall and Jorgenson, 1967; Abel, 1982; Brock, 1988; Sen and Turnovsky, 1990; Goolsbee, 1998; House and Shapiro, 2008; Zwick and Mahon, 2017) on the investment tax credit focus mainly on its direct effect on firm investment. In addition, other studies examine the direct effect of R&D subsidies on firms' R&D expenditure (e.g., Hall and Van Reenen, 2000; Bloom et al., 2002; Thomson, 2017; Dechezleprêtre et al., 2016; Rao, 2016; Chen et al., 2018; Agrawal et al., 2019; Guceri and Liu, 2019). Our study adds to the literature by examining the spillover effect of investment tax credits on firm innovation.

Second, this study contributes to the literature on the role of financial constraints in firm investment decisions. The argument that financial constraints restrict firms' investment and production has long attracted research attention (e.g., Fazzari et al., 1988; Campello et al., 2010; Buera et al., 2011; Banerjee and Duflo, 2014). Thus, tax reforms may affect firm investment differently when firms face different financial constraints. Tax reforms may increase firm investment by relaxing financial constraints. For example, Cai et al. (2018) examine the effects of corporate income taxes on firm innovation by exploiting a tax collection reform, which increases firms' after-tax profits and alleviates their financial constraints. Zwick and Mahon (2017) study the effect of tax policy on firms' investment behavior. They show that the effect of fiscal incentives on investment is stronger for firms with tighter financial constraints. Liu and Mao (2019) also find that financial constraints can reinforce the effects of VAT reforms on firm investment in fixed assets. Our study focuses on a tax reform affecting the relative cost of capital. We add to this literature by highlighting that the effect of investment tax credits on firm innovation and other activities are non-monotonic based on the level of financial constraints of firms.

Finally, this study is part of the literature on the effects of VAT reforms in China. Zhang et al. (2018) find that the 2004 VAT reform increases the fixed investment of eligible firms. Cai and Harrison (forthcoming) show that the 2004 VAT reform encourages eligible firms to reduce their labor force and therefore to become more capital intensive. Liu and Mao (2019) focus on VAT reforms during the 2005–2009 period, showing that these reforms increase the R&D expenditure per employee of eligible firms. We contribute to this literature by focusing on innovation. In addition, our model provides a unified framework for synthesizing the current empirical findings on the effect of VAT reform. Moreover, our results highlight the non-monotonic nature of the effect through financial constraints, which is not recognized in previous studies.

The rest of this paper is organized as follows. Section 2 presents the institutional background of China's VAT reform in 2004. Section 3 describes our theoretical framework. Sections 4 and 5 discuss the data and the empirical strategy, respectively. Section 6 and 7 present the empirical results and those of the robustness tests, respectively. Section 8 examines the effect of the reform on firms' outcomes other than innovation. Finally, Section 9 concludes the study.

2. Institutional Background of the 2004 VAT Reform in China

More than 130 countries around the world have adopted VAT reforms. VAT is a tax levied on the value added at each stage of production, transaction, and labor services. It represents the difference between gross sales and the value of intermediate purchases.[2] China adopted its VAT system in 1994. It specified that certain intermediate purchases (excluding fixed assets) could be deducted from gross sales for the current period when VAT was levied.[3] When the VAT system was adopted, the government believed that the economy was overheating. It discouraged investment by making the costs of fixed assets non-deductible from sales revenues when calculating VAT liabilities. Under this policy, fixed assets were taxed twice: on producers of fixed assets as their sales products and on buyers of fixed assets. VAT was the most important tax source in China between 1994 and 2004 and accounted for 35% to 45% of national tax revenue.[4] A decade later, the government believed that the economy was no longer overheating and wanted to encourage production automation and technology improvement (e.g., Liu and Lu, 2015). Fiscal revenues had also increased since 1994.[5] Therefore, the original VAT policy was considered unsuitable.

[2] Metcalf (1995) provides a comprehensive explanation of the functioning of value-added taxation and the evolution of VAT policies around the world.

[3] For a certain period, if the output tax, which corresponds to the amount of sales multiplied by the VAT rate, is lower than the input tax, which corresponds to the purchasing price multiplied by the VAT rate, the excess input tax could be carried forward for compensation in subsequent periods. For more information, see the website of the State Taxation Administration of China: http://www.chinatax.gov.cn/chinatax/jibenfa/jibenfa0101.htm (accessed May 5, 2019).

[4] Source: China Statistical Yearbook in 2005.

[5] The payment of VAT was levied by the central government after the reform in 1994. In 1994, mainland China implemented a tax-sharing

In September 2004, the Chinese government implemented a pilot VAT reform by allowing firms in six industries located in three northeastern provinces (Heilongjiang, Jilin, and Liaoning) to deduct the costs of fixed assets (excluding real estate assets) from sales revenue when calculating VAT liabilities.[6] The 2004 pilot VAT reform applies to all transactions made after July 1, 2004. The definition of eligible industries is based on the Chinese Industrial Classification (CIC) code.[7] The six eligible industries are the following: (1) equipment manufacturing;[8] (2) automobile manufacturing;[9] (3) petroleum, chemical, and pharmaceutical manufacturing;[10] (4) agricultural product processing;[11] (5) metallurgy;[12] and (6) shipbuilding.[13] The deduction is based on the one-time purchase prices of the machines rather than their annual depreciation.

After the VAT reform, the costs of investment in fixed assets have been significantly reduced. VAT deductions include the following categories: (1) the purchase of fixed assets (including donations and physical investments); (2) the costs of materials and labor to manufacture, modify, or install fixed assets; (3) fixed assets acquired through lease if the lessor has paid VAT in accordance with the regulations; and (4) the cost of transportation of fixed asset purchases.

The 2004 VAT reform is one of the preferential policies implemented by the government to revitalize the old industrial base of the northeastern region of China.[14] With a large number of SOEs, this region was the center of China's heavy industries, growing from the 1950s during the planned economy period. Since the late 1970s, with the rapid evolution of technology and the economic transition to a market system,

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reform. The reform determines the distribution rule of tax income between the central and local governments based on the type of tax.

[6] Real estate assets (e.g., buildings) cannot be deducted from the VAT base before and after the 2004 VAT reform. For more details on the 2004 pilot VAT reform, see the website of the State Taxation Administration of China: http://www.chinatax.gov.cn/n810341/n810765/n812193/n812983/c1202351/content.html (accessed May 5, 2019).

[7] The industry classification and industry codes were converted in the system from GB/T 4754–1994 to GB/T 4754–2002 after 2002 in the Annual Survey of Industrial Firms database used in this study. We adjust all firm industry codes to the new classification codes as the eligible industries of the 2004 VAT reform were defined based on the new classification system.

[8] The 2-digit (3-digit) equipment manufacturing industries include ordinary machinery manufacturing (35); special equipment manufacturing (36); railway transport equipment manufacturing (371); aerospace and aeronautical equipment manufacturing (376); other transportation equipment manufacturing (379); electrical machinery and apparatus manufacturing (39); computer and communications equipment manufacturing (40); and instruments, culture and office machinery manufacturing (41).

[9] The 2-digit (3-digit) automobile manufacturing industries include automobile manufacturing (372).

[10] The 2-digit (3-digit) petroleum, chemical, and pharmaceutical manufacturing industries include refined petroleum products (251); nuclear fuel processing (253); chemical raw materials and chemical products (26); medical and pharmaceutical products (27); chemical fibers (28); rubber products (29); and plastic products (30).

[11] The 2-digit (3-digit) industries of agricultural product processing include smelting and pressing of ferrous metals (32) and smelting and pressing of non-ferrous metals (33).

[12] The 2-digit (3-digit) metallurgy industries include agricultural and by-product processing (13); food production (14); beverage production (15); textiles (17); garment manufacture (18); leather, furs, down, and related products (19); timber processing, bamboo, and straw products (20); furniture manufacturing (21); paper making and paper products (22); and crafts and other manufacturing (42).

[13] The 2-digit (3-digit) industries of shipbuilding include ships and floating equipment manufacturing (375).

[14] "Advocates of the Chinese Communist Party Central Committee and State Council for the Implementation of Strategies to Revitalize the Old Industrial Base of the Northeastern Region," October 5, 2003. For more details, see: http://www.chinalawedu.com/falvfagui/fg22016/873.shtml (accessed September 12, 2019).

the old industrial base has faced a sharp reduction in investment to upgrade technology and adjust the structure of SOEs. Therefore, the region has experienced a decline in its traditional economy, lagging behind coastal areas with more new private firms. Under these circumstances, investment tax credits have been designed to facilitate the adoption of new technologies by eligible firms by alleviating their tax burden and reducing the cost of machinery investment.

In 2007, the VAT reform was extended to 26 cities in six provinces of central China[15] and finally to all industries of the country in early 2009.[16]

3. A Theory of Motivation

In this section, we discuss a simple model for analyzing the effects of the VAT reform, or more generally, investment tax credits. Our empirical analysis follows the findings of this model. The details of the model are provided in Appendix 1.

The VAT reform reduces the price of machinery and equipment, affecting firms with different percentages of machinery and equipment differently. Therefore, we consider a stylized model with two types of firm that maximize profits, given the price of output and the prices of factors of production.

As a benchmark, without innovation, suppose that the production function of a firm takes the Cobb–Douglas form $AK^{\alpha}L^{\beta}$, in which A is the firm's technology, K represents the fixed assets affected by the VAT reform, and L represents labor. For simplicity, for the analysis, fixed assets refer only to machinery, equipment, and other non-structural assets affected by the VAT reform. Suppose that innovation, denoted by R, increases the firm's output through technological advances. That is, the firm's production function is $\tilde{A}(R)K^{\alpha}L^{\beta}$. The function $\tilde{A}(R)$ represents the firm's technology. Innovation may lead to stochastic outputs, in which case the production function is understood as the expected output. As a useful benchmark, suppose that $\tilde{A}(R)$ is a power function, so that the production function is the Cobb–Douglas production function.

Firms with a higher percentage of machinery and equipment often have better technology (see, for example, Wolff, 1991; Midrigan and Xu, 2014). Therefore, we assume that a high-type firm has a higher

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[15] In addition to the industries affected by the 2004 VAT reform, the 2007 VAT reform includes the mining and electricity industries as eligible industries. The 2-digit (3-digit) codes of the added industries are mining (06, 08, 09, 10, and 11) and electricity (441 and 442). For more details on the 2007 VAT reform, see the website of the State Taxation Administration of China: http://www.chinatax.gov.cn//n810341/n810765/n812176/n812783/c1194518/content.html (accessed May 11, 2019).

[16] For more details on the 2009 VAT reform, see the website of the State Taxation Administration of China: http://www.chinatax.gov.cn//n810341/n810765/n812171/n812675/c1190447/content.html (accessed May 11, 2019).

output elasticity of fixed assets and better technology than a low-type firm. Of course, different types of firms face different types of costs. High-type firms may or may not face a higher cost per unit of fixed assets than low-type firms. High-type production may need more expensive machinery than low-type production, but the cost per unit also depends on the definition of a unit, for example. In any case, this does not affect our results and we simply allow both types to have potentially different costs per unit of fixed assets. A more important assumption is that to be a high-type firm, some additional operating costs must be incurred, such as the cost of training workers, buying more suitable but expensive software, and additional construction and management costs related to high-type manufacturing procedures, operations, organization, and quality control (see, for example, Teece, 1977; Acemoglu and Finkelstein, 2008).[17]

Next, we introduce the second source of firm heterogeneity in our model, financial constraints. Financial constraints are crucial for firm production, and fiscal policies often affect firms with different financial constraints differently (e.g., Howell, 2017; Zwick and Mahon, 2017). Suppose that each firm is associated with a constant $I > 0$ that measures the capital available for the firm to purchase production factors. A firm with a high (low) I is financially less (more) constrained or face loose (tight) financial constraints.[18]

The level of financial constraints is given exogenously. Firms cannot choose it. The additional operating costs of being a high-type firm are also fixed for each firm, but can be different for firms with different Is. In this section, to facilitate the explanation of our model, the additional operating costs of being a high-type firm are identical across firms (see Appendix 1 for the general model with heterogeneous operating costs). In contrast, regardless of the level of financial constraints, a firm can choose to be high type or low type, depending on which type yields more profits.

The claims we make below are based on the standard profit maximization of the Cobb–Douglas production function, except that we need to first prove that under our assumptions, there is a unique cutoff I^*, such that the firm whose I is greater than I^* will choose the high type; and otherwise the low type.

The first result is our main finding. Although the VAT reform encourages firms to upgrade, it discourages internal technological improvement through innovation, and more importantly, innovation will be crowded out only for firms with an intermediate level of financial constraints.

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[17] The role of additional operating costs is discussed by Hopenhayn (1992), Melitz (2003), Buera et al. (2011), and Midrigan and Xu (2014), among others. In our model, we do not consider additional operating costs as one-time expenses incurred only at the time of the upgrade. In a more realistic dynamic setting, technology embedded in high-type fixed assets requires constant updating and maintenance, and high-type firms must pay these operating costs in each period.

[18] In our model, we assume that I is constant for each firm. In practice, I may change in the long run. If we allow I to change in the long run, the effect of the reform on firm behavior, including innovation, may be different in the long run. However, we do not discuss long-term effects in our theoretical and empirical analysis, because these long-term effects are difficult to identify.

Result 1. *There are two cutoffs* $I^{**} < I^{*}$*. Before and after the VAT reform, a firm with* $I > I^{*}$ *is a high-type firm, a firm with* $I < I^{**}$ *is a low-type firm, and neither changes its optimal innovation. A firm with* $I^{**} < I < I^{*}$ *is a low-type firm before the VAT reform and becomes a high-type firm after, and its optimal innovation decreases after the VAT reform.*

After the VAT reform reduces the relative price of fixed assets, firms with an intermediate level of financial constraints switch from low type to high type. As high-type firms have a higher percentage of fixed assets, the VAT reform reduces the cost of being a high-type firm. However, after switching to high type, part of their capital must cover the additional operating costs of being a high-type firm, crowding out innovation. As mentioned earlier, under the VAT reform, although it is in the interest of these firms to reduce innovation (to maximize profits), reducing innovation will have a negative externality on economic growth that they do not internalize.

Heavily financially constrained firms do not want to become high type, because if they upgrade and pay the additional operating costs, they will have little capital left to produce enough output. In contrast, less financially constrained firms are able to upgrade without the help of the VAT reform. Note that the production function of firms is the Cobb – Douglas production function. Therefore, firms that do not change their type allocate a fixed fraction of capital to fixed assets, labor, and innovation. Therefore, changing the price of fixed assets has no effect on firms' optimal innovation.

Our main focus is innovation, but the observation that firms with different financial constraints are affected non-monotonically applies to other optimal decisions made by firms.

Result 2. *After the VAT reform, for any firm with* $I > I^{*}$ *or* $I < I^{**}$*, the optimal labor and optimal fixed asset expenditure do not change, and for any firm with* $I^{**} < I < I^{*}$*, the optimal labor decreases, but the change in the optimal fixed asset expenditure depends on the production function.*

From Result 1, we know that firms with $I > I^{*}$ or $I < I^{**}$ do not change their type and therefore do not change their labor and fixed asset expenditure under the Cobb–Douglas production function. The optimal amount of fixed assets may change because the price of fixed assets is affected by the VAT reform.

The optimal labor of a firm that upgrades its type decreases for two reasons. First, as innovation, it is crowded out by the additional operating costs of being a high-type firm. Second, a high-type firm has a lower percentage of labor compared with a low-type firm. How fixed asset expenditure is affected by the VAT reform for a firm that changes its type depends on the details of the production function. First, becoming a high-type firm implies that the firm's percentage of fixed assets increases. Second, the additional operating costs of being a high-type firm limits the capital available to purchase fixed assets.

Several studies examine the effects of the VAT reform on labor and fixed assets. Result 2 is consistent with the empirical findings of Liu and Lu (2015), Zhang et al. (2018), Cai and Harrison (forthcoming), and Liu and Mao (2019), although none of them discuss the non-monotonic nature of the effect. Liu and Lu (2015) and Zhang et al. (2018) show that the firms affected by the VAT reform increase their fixed investment on average. In terms of labor, Cai and Harrison (forthcoming) find that these firms experience a decline in employment and an increase in capital intensity of production. In addition, Liu and Mao (2019) find an increase in firms' total factor productivity and innovation expenditure per employee after the VAT reform, while Cai and Harrison (forthcoming) find no significant increase in productivity. In Appendix 1 we provide additional results to show how our model rationalizes these findings in detail.

4. Data

4.1 Firm Sample

Our data come from the Annual Survey of Industrial Firms (ASIF). The survey is conducted by the National Bureau of Statistics (NBS) of China. It includes all state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) whose annual sales exceed RMB 5 million (approximately US$625,000).[19] The data cover information on firm characteristics and financial balance sheets collected at the end of each calendar year. By the end of 2007, the ASIF had collected information from more than 330,000 manufacturing firms, accounting for about 95% of the nation's industrial output. Thus, it is the most comprehensive firm-level panel dataset of Chinese manufacturing firms and is widely used in research, such as Liu and Lu (2015), Liu and Qiu (2016), and Brandt et al. (2017). As the pilot VAT reform was implemented in 2004, we use a sample from 2001 to 2007, including the years before and after the regulatory shock.[20] Our estimation focuses only on the short-term effect of the VAT reform, although it may last in the long run. In the long term, there may be more confounding effects, so the identification is not as clear as in the short term.

To obtain a final sample for the regressions, we first eliminate all firms with error values, such as zero or negative values, in output or sales. Then we exclude all firms that changed their location or industry during the sampling period to avoid sample selection bias. Next, we restrict our sample to all firms present

[19] During the period from 2001 to 2007, the exchange rate between the Chinese renminbi and the U.S. dollar was approximately RMB8 = US$1.

[20] The sampling period is the period used to collect data on our independent variables. As we lag our independent variables by one year, we actually use patent information from 2002 to 2008 for our dependent variables. In a robustness test, we use patent information for year $t + 2$, so the patent data for this test extend from 2003 to 2009.

at least once in the pre- and post-reform period.[21] Finally, following Zhang et al. (2018), we exclude all firms located in the 26 cities of central China and all firms in the mining and electricity sectors to avoid the effect of the 2007 VAT reform. To reduce the effect of outliers, we winsorize all continuous variables at the top and bottom 1% by replacing values above the top 1% and below the bottom 1% with the values at the top and bottom 1%, respectively. Our final sample consists of 722,855 firm-year observations associated with 151,050 firms. Table 1 shows the distribution of firms by year, region, and industry. In the three northeastern provinces, on average, 83.13% of the firms are affected by the VAT reform.

[Insert Table 1 Here]

4.2 Innovation Variables

Following the recent innovation literature (e.g., Aghion et al., 2013; Fang et al., 2014; Seru, 2014), we use the number of successful patent filings to measure firm innovation outcome. We obtain the patent data from Baiten.[22] The information on the Baiten website comes from the Chinese National Intellectual Property Administration (CNIPA), the official institution responsible for managing patent applications in China.[23] By searching for firm names in Baiten, we can obtain information on all patents granted to firms, including the application date, grant date, and type of patent.

We construct the measure of firm innovation as the logarithm of one plus the total number of patent applications filed (and eventually granted) by firm i in year t, $LnPat_t$.[24] We obtain information on patents granted by the end of 2014. As the time lag between the application date and the grant date varies from five months to about three years for different patents, patents granted by the government at the same time may be produced by different innovation inputs at different times. Following the innovation literature, we set the patent counts to zero for firms without available patent information in the CNIPA database.

We use patent data rather than innovation input data, such as R&D expenditure, for two reasons. First, R&D expenditure is available in the ASIF database only between 2005 and 2007 and is therefore not suitable for our study due to the lack of data before the 2004 reform.[25] Second, Chinese firms have incentives to manipulate accounting information on R&D expenditure to obtain subsidies from the government, as some subsidy programs target eligible high-tech firms with high R&D expenditure (e.g.,

[21] The results are robust if we extend the sample to include all firms appearing in the dataset at least once during the period.
[22] For more information, see the Baiten website: http://www.baiten.cn/ (accessed May 11, 2019).
[23] For more information, see the CNIPA website: http://www.sipo.gov.cn/ (accessed May 11, 2019).
[24] We use the number of successful patent applications (eventually granted in the following years) rather than the number of patents granted in a given year for two reasons. First, the application year is the year when a firm produces the innovation output, thus it better captures the real time of innovation (e.g., Griliches et al., 1988; Hall et al., 2001). Second, it takes time for the government to approve patent applications and the approval time varies between patent application types.
[25] Despite the shortcoming of R&D data for manufacturing firms, we use R&D data during the 2005–2007 period to examine the effect of the 2007 VAT reform as a robustness test. The results are consistent with our main findings.

Chen et al., 2018).

Some studies show that patents granted in China are less valuable than those granted by international institutions (see, for example, Zhang and Chen, 2012; Dang and Motohashi, 2015; Hu et al., 2017). Indeed, patent-friendly policies and the weak patent examination process in China encourage and enable firms to counterfeit patents. Firms have non-innovation motivations for acquiring patents, including building reputation, advertising products, obtaining government subsidies or tax benefits, and manipulating their market value. For instance, Hu et al. (2017) show a weak correlation between patents and R&D in China. To address this potential concern, in one robustness test, we use patents granted by an international organization of the United Nations.

4.3 Summary Statistics

Table 2 presents the summary statistics for the key variables used in the study. Appendix 2 provides the definition of the variables. All monetary variables are deflated using the provincial Consumer Price Index, with 1998 as the base year. The firms in our sample applied for an average of 0.049 patents per year during the 2001–2007 period ($Pat_{i,t}$), including 0.032 invention and utility model patents and 0.017 design patents.

We also report the summary statistics of other patent-based variables and R&D-related variables, which are proxies for innovation in the robustness tests. The firm-year patent stock is 0.340 on average and the number of patents granted by WIPO is 0.007 on average. Then, we present the summary statistics of other outcome variables used in our study, such as R&D-based innovation measures, market value of patents, total wages, and fixed investment rate.

In addition, we present the summary statistics of the firm-year control variables. On average, a firm in our sample has a book value of assets = RMB58.675 million (in 1998 renminbi), ROA = 0.065, firm age = 10.772, foreign share = 0.187, and state share = 0.056.[26]

[Insert Table 2 Here]

5. Empirical Strategy

The 2004 pilot VAT reform applies to firms in six industries located in three provinces in northeastern China, which facilitates the use of the DDD strategy. First, we can compare the before–after change of firms in different industries. However, some industry-level time-varying variables may be correlated with

[26] The mean values of foreign and state ownership in our sample are in line with those in Zhang et al. (2018), in which state-owned enterprises and foreign-invested firms represent respectively 7.01% and 17.45% on average.

the outcome variables and regressors at the same time, leading to bias in our estimates. In light of this concern, we exploit the fact that the 2004 reform only applies to firms in three provinces in China. In other words, we combine three types of variation: time variation (i.e., before and after the 2004 VAT reform), provincial variation (i.e., northeastern provinces versus non-northeastern provinces), and industrial variation (i.e., industries affected by the reform versus industries not affected by the reform). The following regression is estimated:

$$y_{ijp,t+1} = \beta * NE_p * Eind_j * Post2004_t + \mu_i + \gamma_{pt} + \tau_{jt} + \varepsilon_{ijpt}. \tag{1}$$

where the subscript i indicates the firm, t indicates a given year, j indicates the 3-digit industry, and p indicates the province. The dependent variable $y_{ijp,t+1}$ represents firm innovation, measured by the logarithm of one plus the total number of patents ($LnPat_{ijp,t+1}$) filed by firm i in year $t+1$ (and eventually granted). As innovation activities take time, due to the time lag between firms' R&D investment and patent applications, we investigate the effects of the VAT reform on the number of patents filed by a firm one year after their grant date (e.g., Hsu et al., 2014; Liu and Qiu, 2016; Acharya and Xu, 2017). In the robustness tests, we repeat our analysis based on the number of patents filed by a firm with a two-year lag.

In Equation (1), NE_p is an indicator equal to one for the three provinces in the northeastern part of China (Heilongjiang, Jilin, and Liaoning), and zero otherwise. $Eind_j$ is an indicator equal to one for the six industries targeted by the reform, and zero otherwise. $Post2004_t$ is also an indicator equal to one for the 2005–2007 period, and zero for the 2001–2004 period.[27] The coefficient of the triple interaction term ($NE_p * Eind_j * Post2004_t$) β is the main interest. ε_{ijpt} is the error term with a mean equal to zero. To address heteroscedasticity and serial correlation, all standard errors are clustered at the firm level. We also cluster standard errors at the province-industry level as a robustness test and the results are consistent.

Using the DDD strategy allows us to include the full set of firm fixed effects μ_i, province-year fixed effects γ_{pt}, and industry-year fixed effects τ_{jt}. In doing so, we control for time-invariant and time-varying provincial characteristics and industrial characteristics, and time-invariant differences between industries across provinces. Firms did not change their location or industry during our sampling period. Therefore, we do not control for NE_p, $Eind_j$, and $Post2004_t$ separately and the double interactions between them, as they are absorbed by the fixed effects mentioned above. Note that some province-

[27] The reform was implemented in September 2004. As the purchase of fixed assets is time consuming, we use 2005 as the first post-reform year. To address the potential concern about the noise of the effect of the reform in 2004, we delete all observations in 2004 in the robustness test in Section 7.

industry time-varying variables remain, which may lead to bias in our estimates. We address this concern by controlling for the interactions between time dummies and pre-reform average firm characteristics in Section 6.1 and for the confounding effects of some concurrent events in Section 7.1.

We further verify the validity of this empirical design in Section 7. We first examine other explanations related to confounding events, such as the removal of the MFA, the implementation of a stricter environmental policy, and China's WTO entry, and firms' life cycle in Section 7.1. In addition, one pre-assumption for the validity of DDD needs to hold. That is, the difference in pre-existing time trends between targeted industries and non-targeted industries in the northeastern provinces must be identical to that of other provinces. We verify this in Section 7.2. Furthermore, we rule out the effects of firms' location choice of their factories, expectation effect, non-random selection of the pilot VAT reform, and random factors in Section 7.2.

6. Empirical Results

6.1 Main Results

Table 3 presents the main results of the effect of the 2004 VAT reform on firm innovation. The dependent variable is the logarithm of one plus the total number of patents.

[Insert Table 3 Here]

Overall, the results reported in Table 3 show that the 2004 VAT reform has a significantly negative effect on firm innovation. We can see in column (1) that the coefficient of the triple interaction term $NE_p * Eind_j * Post2004_t$ is -0.0082 and statistically significant at the 5% level. Compared with other provinces, the difference between the before – after growth rate of patents developed by firms in targeted industries and non-targeted industries in the northeastern provinces is 9.51% lower.[28]

Note that some province-industry time-varying variables that cannot be absorbed by the fixed effects may exist. To address this concern, we add a vector of firm-level time-varying variables, including firm size, firm profitability, firm age, state ownership, and foreign ownership. The results reported in column (2) show that the coefficient of the triple interaction term remains the same. However, these controls may be endogenous to the 2004 VAT reform. Therefore, we do not include them in our baseline specification, but we include them as a robustness test.

[28] Specifically, $\frac{d[ln(1+y)]}{dx} = \frac{1}{1+y}\frac{dy}{dx}$, where x is the interaction between NE_p, $Eind_j$, and $Post2004_t$. When we increase x from zero to one, $dy = (1+y)ln(1+y)$. The change in the number of patents (dy) based on its mean value (0.0944) between 2002 and 2008 is then equal to $0.0082 \times (1 + 0.0944) = 0.0090$, representing 9.51% of the mean value of the total number of patents.

The Chinese government did not randomly choose the six industries in the northeastern provinces for the pilot reform. Indeed, as stated in the official document,[29] the government chose these pilot reform firms, mainly state-owned in a traditional industrial base and less profitable, to stimulate their upgrade by reducing their tax burden. In addition, Cai and Harrison (forthcoming) focus on the same VAT reform and show that firms affected by the 2004 VAT reform are larger and younger than other firms. They also find that firms with less foreign investment and more state ownership were more likely to be selected for the 2004 pilot VAT reform. Their findings suggest that the goal of the 2004 VAT reform is consistent with the facts: some firm characteristics, such as firm size, firm profitability, firm age, state ownership, and foreign ownership, differ between affected and unaffected firms.

This non-random selection raises concerns that these characteristics may lead to a different change in patents over time for the firms involved, causing bias in our estimates. To address this issue, in columns (3) and (4), we control for the interactions between time dummies and firm characteristics measured during the pre-reform period (averaged over the 2001–2004 period). We interact the $Post2004$ dummy with the pre-reform controls (in column (3)), and interact the full set of year dummies with the pre-reform controls (in column (4)). The estimated coefficients of $NE_p * Eind_j * Post2004_t$ remain unchanged in both columns (3) and (4).

In summary, these results show that the 2004 VAT reform has on average a crowding out effect on firm innovation.

6.2 Quality of Innovation

Our main results show that VAT has a negative spillover effect on innovation, measured by the total number of patent applications by a firm (and eventually granted). However, different patents are associated with different qualities. Fewer patents may not necessarily mean that firms innovate less, as firms may focus on high quality innovations, which require more R&D inputs and more time for development. To address this issue, in this section, we examine the effect of the 2004 VAT reform on the number of patents with different innovative qualities.

China's Patent Law classifies patents into three types: invention patents, utility model patents, and design patents. Invention patents must show significant technological improvement, go through a complex approval process, have the longest protection period, and thus represent the highest quality. Utility model patents can be granted for new applications of existing technologies. Design patents focus on new designs

[29] See "Advocates of the Chinese Communist Party Central Committee and State Council for the Implementation of Strategies to Revitalize the Old Industrial Base of the Northeastern Region," October 5, 2003. For more information, see: http://www.chinalawedu.com/falvfagui/fg22016/873.shtml (accessed September 12, 2019).

in the shape, color, and graphic pattern of products, and are therefore the least innovative and under the shortest period of protection.[30]

[Insert Table 4 Here]

Table 4 reports the results of the estimated effect of the 2004 VAT reform on the number of different types of patents. The dependent variable in column (1) is the logarithm of one plus the sum of the number of invention patents and utility model patents, recognized as having a higher degree of innovation. In column (2), the dependent variable is the logarithm of one plus the number of design patents, considered to have a lower degree of innovation. We can see that the coefficients of the triple interaction term $NE_p * Eind_j * Post2004_t$ are -0.0066 (column (1)) and -0.0021 (column (2)). These results suggest that the magnitude of the negative effect of the reform is greater for high-quality innovation than low-quality innovation, implying that the negative effects of the VAT reform on the total number of patents do not disappear with innovation quality improvement.

6.3 Non-monotonic Effect on Innovation in Terms of Financial Constraints

Our theory predicts that the crowding out effect of investment tax credits on innovation is significant only for firms with an intermediate level of financial constraints. Many studies also show that firms with different financial constraints are affected by fiscal policies differently (e.g., Howell, 2017; Zwick and Mahon, 2017). In this section, we analyze how firms with varying levels of financial constraints respond to the VAT reform.

We follow Hadlock and Pierce (2010) to construct a variable of firms' financial constraints, called the size‑age (SA) index.[31] The SA index is given by $-0.737 * Size + 0.043 * Size^2 - 0.040 * Age$, where $Size$ is the logarithm of the inflation-adjusted book value of assets[32] and Age is firm age, defined by subtracting the year of creation of a firm from the observation year.[33] A firm with a higher SA index is financially more constrained.[34] We use this index as the main financial constraint measure for

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[30] For more information on Chinese patent categories, see China's Patent Law on the CNIPA website: http://www.sipo.gov.cn/zcfg/zcfgflfg/flfgzl/fl_zl/1063508.htm (accessed July 5, 2019).

[31] Hadlock and Pierce (2010) find that firm size and age, two relatively exogenous firm characteristics, are particularly useful predictors of financial constraint levels. They propose a measure of financial constraints based solely on firm size and age, which performs better than other traditional financial constraint measures, such as the KZ index (Kaplan and Zingales, 1998) and the WW index (Whited and Wu, 2006).

[32] Following Hadlock and Pierce (2010), the book asset statistics are calculated in millions of inflation adjusted in 2004 renminbi and are winsorized at 1% and 95% levels.

[33] In the original SA index in Hadlock and Pierce (2010), Age is defined as the current year minus the first year the firm has a non-missing stock price. Most firms in our sample are not publicly listed firms, thus we modify the definition of Age by subtracting the year of creation of a firm from the observation year. Following previous studies (see Cabral and Mata, 2003; Angelini and Generale, 2008; Hall, 2008; Howell, 2017), younger firms are more likely to face financial constraints due to higher information asymmetry and lack of collateral compared with older firms. Therefore, the modified definition of Age is more meaningful and suitable for our dataset. To ensure the robustness of our results, we re-estimate the results using the original SA index and find similar results.

[34] A higher SA index corresponds to a lower I in the model of Section 3.

three reasons. First, the SA index is not based on endogenous variables, such as cash flow or leverage. Second, the variables used to construct the SA index are available for non-listed firms. Third, the SA index relies solely on firm size and firm age, which vary slowly, reflecting the stickiness of firm-level financial constraints over time. Thus, the SA index is better adapted to capture the cross-sectional variation in financial constraints than the time variation. Although originally estimated with U.S. firm data, scholars show that the SA index is a good proxy for the level of financial constraints of firms in various contexts (see Hadlock and Pierce, 2010; Berkowitz et al., 2015). Previous research also confirms that smaller firms and younger firms face tighter financial constraints in China, further indicating that the SA index is a reasonable proxy for financial constraints in China (see Cull and Xu, 2005; Liu and Mao, 2019).

[Insert Table 5 Here]

We divide the sample into deciles based on the average SA index during the pre-reform period (2001–2004) and construct three subsamples based on the top three, middle four, and bottom three deciles.[35] We then estimate Equation (1) using these three subsamples separately. The results are reported in Table 5, with columns (1) to (3) representing firms with a high, intermediate, and low SA index, respectively. We can see that for firms with tight (column (1)), intermediate-level (column (2)), and loose (column (3)) financial constraints, the coefficients of the triple interaction term $NE_p * Eind_j * Post2004_t$ are 0.0039, -0.0127, and -0.0123, respectively. More importantly, only the coefficient for firms in the middle group is statistically significant, with a value of -0.0127. This indicates that compared with other provinces, the difference between the before–after growth rate of patents developed by firms with intermediate-level financial constraints in targeted industries and non-targeted industries is 23.24% lower in the northeastern provinces.[36]

Finally, as complementary evidence, we construct two indicators, $Intermediate$ and $Loose$, based on the SA index to identify firms with intermediate-level and loose financial constraints, respectively. Specifically, $Intermediate$ is equal to one for firms belonging to the middle four deciles, and zero otherwise. $Loose$ is equal to one for firms belonging to the bottom three deciles, and zero otherwise. We then include the interaction terms $NE * Eind * Post2004 * Intermediate$ and $NE * Eind * Post2004 * Loose$ and their triple and double interactions that are not absorbed by the fixed effects. The results are presented in column (4) of Table 5. They are consistent with columns (1) to (3) in

[35] In our sample, the SA index for firms with loose financial constraints is below -2.203 while the SA index for firms with tight financial constraints is greater than -1.416.

[36] For firms with an intermediate level of financial constraints, the change in the number of patents based on the mean value (0.0578) of the number of patents for this subsample during the 2002–2008 period is equal to $0.0127 \times (1 + 0.0578) = 0.0134$, representing 23.24% of the mean value of the total number of patents for firms with intermediate-level financial constraints.

Table 5. The estimated coefficient of $NE * Eind * Post2004 * Intermediate$ is negative and statistically significant, while the estimated coefficient of $NE * Eind * Post2004 * Loose$ is not significant. This suggests that the negative effect of the reform on firms with an intermediate level of financial constraints is greater than that of other firms.

These findings are consistent with our expectations. Innovation in firms with an intermediate level of financial constraints will be crowded out by the VAT reform. However, this effect will not occur in more financially constrained and less financially constrained firms.

6.4 Ownership and the Effect of the VAT Reform

Poncet et al. (2010) show that in China, firms with different types of ownership face different financial constraints. Specifically, SOEs have easier access to bank loans because of political connections or other types of government support (e.g., Allen et al., 2005; Cai and Liu, 2009; Jin et al., 2019). Foreign-invested firms are also less likely to face tight financial constraints, as foreign firms are more likely to obtain external financing (e.g., Ayyagari et al., 2011). In addition, to attract foreign investors, the Chinese government offers several financial benefits (e.g. lower corporate tax rates) to foreign-invested firms during our sampling period. In contrast, domestic private firms do not receive any of these benefits and are more likely to face tight financial constraints (e.g., Poncet et al., 2010). In this section, we investigate whether the effect of the VAT reform on innovation differs for firms with different ownership structures, as additional evidence of the prediction of our model.

[Insert Table 6 Here]

We divide all of the firms into three groups: SOEs, foreign-invested firms, and domestic private firms. Following Dollar and Wei (2007) and Guariglia et al. (2011), we use the ratio of paid-in capital contributed by different types of investors in 2004 to identify firm ownership. A firm is considered an SOE (domestic private firm, foreign-invested firm) if the state (domestic private shareholder, foreign investors) owns the largest share of the firm's total paid-in capital. In this analysis, firms with two or three shareholders with the same largest share are eliminated, as their ownership cannot be clearly defined. We then estimate Equation (1) using these three subgroups separately.

Table 6 shows the results. We can see that the estimated coefficient of the triple interaction term $NE_p * Eind_j * Post2004_t$ is significant only in column (2) (domestic private firms), with a value of -0.0086. The same estimated coefficients in column (1) (SOEs) and column (3) (foreign-invested firms) are not significant. These results show that the VAT reform has a negative effect on innovation in domestic private firms, but not in SOEs or foreign-invested firms.

7. Robustness Tests

In this section, we conduct a series of robustness tests to partial out alternative explanations for our results, justify our empirical identification, and test the robustness of our results to alternative samples and measurements.

7.1 Alternative Explanations

There are other potential explanations for our empirical results. In this section, we provide evidence that these alternative explanations cannot rationalize our results.

[Insert Table 7 Here]

A. Confounding Policies

Around the same time as the VAT reform, three important policies may have induced a similar effect on innovation.

Removal of the Multifiber Arrangement (MFA). Under the MFA, textile and clothing exports from China and other developing countries to the U.S., the European Union, and Canada were subject to quotas. These quotas were removed on January 1, 2005, stimulating textile clothing exports (see Khandelwal et al., 2013). If increased exports encourage firms to innovate less (because they have to pay fixed costs to enter foreign markets (Melitz, 2003)), removing the MFA may have similar negative results to those of the VAT reform, as there are fewer textile and clothing industries in the three provinces in the northeastern region. To address this issue, we remove all firms in the textile and clothing industries and re-estimate equation (1). The results presented in column (1) in Table 7 are consistent with our main results.

Environmental Policies. Stricter environmental policies may increase production costs and reduce profits, leading to reduced R&D investment. Therefore, we check whether our main results are driven by an environmental policy enacted during the sampling period. During the period of the eleventh Five-Year Plan (2006–2010), the Chinese government implemented a strict environmental policy setting a pollution reduction target for each province, which may have reduced firm innovation. As the six industries affected by the VAT reform are heavy industries, which tend to be pollution intensive, they are more likely to have been affected by the environmental policy of the eleventh Five-Year Plan. To verify whether our results are driven by this environmental policy, following Shi and Xu (2018), we include an additional control variable measuring the effect of the environmental policy, $LnTarget_p * Post2005_t * lnSO_{2_j}$, where $LnTarget_p$ is the log of the provincial pollution reduction target (%), which is the required percentage of SO_2 emission reduction at the provincial level.[37] $Post2005_t$ is a dummy variable equal to one for the 2006–2007 period and zero for the 2001–2005 period. $lnSO_{2_j}$ is the log of the average industrial SO_2 emissions (in 10,000 tons) from 2003 to 2005. The results reported in column (2) of Table 7 show that our main results are unchanged.

WTO Entry. China entered WTO at the end of 2001. On the one hand, it reduced China's import tariffs, which facilitates the import of foreign advanced machines (e.g., Liu and Qiu, 2016). It might also crowd out firms' innovation. Moreover, more foreign products flowing into China's domestic market due to lower import tariffs improved domestic competition level, leading to lower profits earned by firms. It may also lead to less innovation. However, the reductions of import tariffs varied across industries, which can be absorbed by the industry-year fixed effects included in our baseline regression. One the other hand, China's entry into WTO also made it easier for Chinese firms to export. If firms in the VAT reform targeted industries in the northeastern provinces happened to export more to those countries whose tariffs on China's products reduced more, then our estimates would be contaminated since firms with more exports might earn higher profits and therefore have more money to spend on innovation. To address this concern, we further include the firm-level time-variant export intensity and an exporter dummy in our baseline regression. Export intensity is measured by the ratio of export to sales in each firm and the exporter dummy is equal to one if a firm is an exporter in a given year and zero otherwise. The result shown in column (3) of Table 7 is similar with our main result, suggesting that China's entry into WTO is not a concern.

B. Life Cycle

Firms in the intermediate stage of their life cycle are more likely to upgrade their technology, either as originally planned or as encouraged by policies. If these firms are concentrated in the six affected industries in the northeastern provinces of China, we should observe a similar effect even without the VAT reform.

To address this issue, we check whether firms in the intermediate stage of their life cycle are concentrated in the six affected industries in northeastern China. We use firm age to determine their life cycle stage and divide the sample into deciles based on the average age during the pre-reform period. We construct a dummy variable, $Middle\text{-}stage\ Dummy$, to indicate intermediate-stage firms, which is

[37] Pollution reduction targets at the provincial level are defined by negotiation between the central government and the provinces (Shi and Xu, 2018), and listed in the document, "Reply to Pollution Control Plan During the Eleventh Five-Year Plan," published by the State Council of China in 2006. For more details on this document, see: http://www.gov.cn/gongbao/content/2006/content_394866.htm (accessed September 12, 2019).

equal to one if a firm belongs to the middle four deciles, and zero otherwise. We run a cross-sectional regression using $Middle\text{-}stage\ Dummy$ as the dependent variable and $NE * Eind$ as the main independent variable. The results reported in column (4) of Table 7 show that the coefficient of $NE * Eind$ is not significant, suggesting that intermediate-stage firms are not concentrated in the affected industries in the northeastern provinces.

7.2 Justification of the Validity of the DDD Estimation Strategy

We conduct several tests to justify the validity of the DDD estimation strategy.

Pre-existing Time Trends. For a valid DDD estimation, one pre-assumption needs to hold. That is, the difference in time trends of firm innovation between affected and unaffected industries should be the same across provinces without the VAT reform.

Figure 1 shows the dynamic effect of the 2004 VAT reform on the number of patents of firms over a 7-year window (2001–2007), ranging from three years before the reform to three years after the reform. We run a regression of the number of successful patent filings in year $t + 1$ on a set of interactions between $NE * Eind$ (indicating the affected firms by the 2004 VAT reform) and annual year dummies (excluding 2003) after controlling for the entire set of province-year fixed effects, industry-year fixed effects, and firm fixed effects. The omitted time category is $Year2003$, so that the estimated effect is relative to one year before the 2004 VAT reform. Thus, the coefficient estimate of $NE * Eind * Year_t$ indicates the relative mean value of $\left(Pat_{NE=1,Eind=1} - Pat_{NE=1,Eind=0}\right) - (Pat_{NE=0,Eind=1} - Pat_{NE=0,Eind=0})$ in year $t + 1$, a DDD estimator of the effect of the 2004 VAT reform after controlling for the full set of fixed effects. The dashed lines represent the 95% confidence interval, adjusted for clustering at the firm level.

[Insert Figure 1 Here]

The figure shows that the effect of the reform during the pre-reform period (2001–2003) is rather weak. It becomes stronger during the 2006–2007 period (post-reform period), significant at the 5% level. This minor pre-reform effect indicates the non-existence of pre-existing time trends, providing evidence that the pre-assumption of the DDD strategy holds.

[Insert Table 8 Here]

As an additional test, we remove all post-reform observations and replace the variable $NE_p * Eind_j * Post2004_t$ in Equation (1) with an interaction term between NE, $Eind$, and pre-reform year dummies. The year before the 2004 VAT reform, 2003, is set as the base year. We re-estimate Equation (1) using this pre-reform sample. The results presented in column (1) in Table 8 show that none of the estimated coefficients of the triple interactions are significant, which also justifies the pre-assumption of the DDD estimation.

Expectation Effect. To check whether firms changed their innovation behavior in anticipation of the coming VAT reform, we add to the regression another control ($NE_p * Eind_j * Year2004_t$), an interaction term between $NE * Eind$, and the dummy indicating one year before the reform. This anticipation can make the affected and unaffected firms ex ante incomparable and bias our estimates. The results reported in column (2) of Table 8 show that the coefficient of $NE_p * Eind_j * Year2004_t$ is not significant, indicating a negligible anticipation effect, but the coefficient of our main independent variable ($NE_p * Eind_j * Post2004_t$) remains significantly negative.

Propensity Score Matched Sample. Are firms in the affected industries in the northeastern provinces significantly different from other firms? To answer this question, in addition to examining pre-existing time trends, we use the propensity score matched sample of affected and unaffected firms to re-estimate the results. We use the nearest neighbor matching of the propensity score matching approach introduced by Rosenbaum and Rubin (1983). The detailed matching process is described in Appendix 3. The estimation results using the matched samples shown in column (3) in Table 8 are robust.

Location Choice of Factories. Another concern is that ineligible firms establish factories or production lines in the affected industries in the northeastern region of China to enjoy the benefits of the VAT reform, leading to bias in our estimates. As firms located near the affected provinces are more likely to establish factories there, we eliminate all firms located in provinces within 500 miles of the affected provinces, including Anhui (about 470 miles), Beijing (about 200 miles), Hebei (0 mile), Henan (about 430 miles), Inner Mongolia (0 mile), Jiangsu (about 350 miles), Shaanxi (about 500 miles), Shandong (about 300 miles), Shanxi (about 500 miles), and Tianjin (about 150 miles), and re-estimate the main results. The results reported in column (4) in Table 8 are robust, ruling out the concern that our results are driven by trans-province production.

Permutation Tests. To ensure that our results are not driven by random effects, we conduct several permutation tests. We first construct a "placebo treatment," $(NE * Eind)_{Random} * Post2004$, consisting of a randomly selected set of province-industry cells $(NE * Eind)_{Random}$, and a true post-reform dummy. We estimate Equation (1) by replacing the true treatment dummy with this randomly generated interaction variable, $(NE * Eind)_{Random} * Post2004$. We repeat this exercise 500 times.[38] We further conduct two

[38] The same exercise is conducted in Chetty et al. (2009) and La Ferrara et al. (2012).

similar exercises. First, we randomly assign the value of $Post2004$ and estimate Equation (1) using this randomly generated variable, $NE * Eind * Post2004_{random}$, 500 times. Second, we randomly assign both the affected province-industry groups and the affected years, and run the regression in Equation (1) using the placebo triple interaction $(NE * Eind)_{Random} * Post2004_{Random}$, 500 times.

Panels A, B, and C in Figure 2 show the probability distributions of the estimated coefficients of the triple interaction term for these three tests, respectively. The vertical line in each figure represents the coefficient of the triple interaction term in column (1) in Table 3. This vertical line is in the lower tail of the estimated placebo effects, regardless of how we randomly assign the treatment dummy. Taken together, the results in Figure 2 reinforce our confidence that our main results are not driven by random factors.

[Insert Figure 2 Here]

7.3 Alternative Samples

We use three alternative samples to test the robustness of our main results. First, as the VAT reform started in July 2004, 2004 mixes pre- and post-reform information. We eliminate all observations in 2004 and re-estimate Equation (1). Second, in 2007, the VAT reform was extended to 26 cities in 6 other provinces of central China. Although we remove all firms in these cities from our main sample, the behavior of firms in other cities could also be affected in 2007, as they may have expected the 2004 reform to extend to their cities. To address this concern, we eliminate all observations in 2007 and re-estimate equation (1). Third, the 2004 VAT reform may encourage firms to enter or exit the market. For example, if new entrants have more incentives to upgrade and more firms enter the market in the northeastern regions, our results may be overestimated by capturing both the selection effect and the true effect of the VAT reform on innovation. To eliminate the bias caused by firms' entry and exit, we use a balanced sample, which includes all of the firms operating throughout the sampling period (from 2001 to 2007) to estimate equation (1). The results of these tests reported in Table 9 are all robust.

[Insert Table 9 Here]

7.4 Alternative Measures

In this section, we conduct several tests using alternative measures of outcome and explanatory variables to investigate the robustness of our main results.

[Insert Table 10 Here]

Alternative Measures of Innovation. First, we construct two alternative patent-based measures following Liu and Qiu (2016) and Fang et al. (2017). The first measure is $\ln\left[Pat_{ijpt} + \left(Pat_{ijpt}^2 + 1\right)^{1/2}\right]$, where Pat_{ijpt} is the total number of patents filed by firm i in industry j in province p in year t. This measure enables us to eliminate the potential bias caused by the use of the log-like transformation in the main results. The second measure is the patent stock of a firm, which better captures the long-term nature of patent assets. Following Fang et al. (2017), the patent stock is given by $Patent\_Stock_{ijpt} = (1-\theta)Patent\_Stock_{ijp,t-1} + r_{ijpt}$.[39]

Second, we assume that there is a one-year lag between innovation investment and successful patent applications in the main results. We extend this time lag to two years. Specifically, we use the natural logarithm of the number of patents measured two years later ($LnPat_{t+2}$) as the dependent variable to estimate the results.

Third, although information on R&D expenditure is not available in the ASIF database before 2004, firms were required to report their R&D expenditure during the 2005–2007 period. As the 2004 VAT reform was extended to 26 cities in 6 provinces of central China,[40] affecting the mining and electricity sectors, we use R&D data between 2005 and 2007 and exploit the VAT reform in 2007 to investigate the effect of the 2007 VAT reform on R&D expenditure.[41] The specification is as follows:

$$y_{ijct} = \beta * Mid_c * Eind_j * Year2007_t + \mu_i + \gamma_{ct} + \tau_{jt} + \varepsilon_{ijct}, \qquad (2)$$

where y_{ijct} is R&D expenditure divided by lagged total assets or lagged total sales in year t for firm i. Mid_c is an indicator equal to one for the 26 selected cities, and zero otherwise. $Eind_j$ is an indicator for eligible industries.[42] $Year2007_t$ is an indicator for the post-2007 period as the 2007 VAT reform was implemented on July 1, 2007.[43] We control for firm, city-year, and 3-digit industry-year fixed effects. Standard errors are clustered at the firm level.

The results of these tests shown in columns (1) to (5) of Table 10 are all robust, further supporting

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[39] Here, $Patent\_Stock_{ijpt}$ is the patent stock of firm i in industry j in province p in year t, θ is the depreciation rate of the patent stock (set to 15%, following previous work), and r_{ijpt} is the number of granted patents filed by firm i in industry j in province p in year t. The patent stock measure in year t is constructed using a declining balance formula and patent history with a 15% depreciation. For firm i established in year t_0, $Patent_{Stock_{ijp,t_0}} = r_{ijp,t_0}$, where $Patent_{Stock_{ijp,t_0}}$ is the patent stock of firm i in year t_0 and r_{ijp,t_0} is the number of granted patents filed by firm i in year t_0. The patent data of r_{ijpt} in the CNIPA database begin in 1985. For firms established before 1985, the effect of the missing initial condition, such as patents prior to 1985, should be negligible for the patent stock variable.

[40] The 26 cities affected by the 2007 VAT reform are Taiyuan, Datong, Yangquan, and Changzhi in Shanxi province; Hefei, Maanshan, Bengbu, Wuhu, and Huainan in Anhui province; Nanchang, Pingxiang, Jingdezhen, and Jiujiang in Jiangxi province; Zhengzhou, Luoyang, Jiaozuo, Pingdingshan, and Kaifeng in Henan province; Wuhan, Huangshi, Xiangfan, and Shiyan in Hubei province; and Changsha, Zhuzhou, Xiangtan, and Hengyang in Hunan province.

[41] To make the results comparable to those of the baseline estimation, we construct a sample of manufacturing firms following the description in Section 4.1. The differences in data processing between the baseline analysis and this section are the following. First, as the pilot reform involves the city-industry level for the 2007 VAT reform, we exclude all firms that changed their city or (3-digit) industry during the sampling period to avoid sample selection bias. We include all firms located in the 26 cities affected by the 2007 VAT reform. We also delete 136 observations with missing R&D expenditure data. As the sampling period in this analysis covers only 2005 to 2007, we keep a balanced sample of firms present in the sample during these three years.

[42] The mining and electricity sectors are not included in our sample, so the definition of $Eind_j$ here is the same as in Equation (1).

[43] R&D data are not available after 2008, so we can only consider 2007 as the post-reform year, capturing the partial effect of the 2007 VAT reform.

our main results.

Quality of Patent Data in China. Patents granted in China are often criticized for their low quality (e.g., Zhang and Chen, 2012; Hu et al., 2017). The fact that some firms may counterfeit patents is flagrant in China because of its ill-prepared legal system, especially in the early 2000s (e.g., Hu and Jefferson, 2009). Hu et al. (2017) show that the correlation between patents and R&D expenditure in China is weak, suggesting that patents granted by the CNIPA can be manipulated or acquired through bribery. If the VAT reform discourages the affected firms from manipulating patents, our results may be biased. In addition, the VAT reform may reduce the number of granted patents but enhance the economic value of each patent. If so, the overall effect of the VAT reform on firm innovation is unclear. To address these issues, we use two proxies to capture the value of patents, patents granted outside China and the economic value of patents based on the stock market reaction to patent grants.

First, we use patents granted abroad as a proxy for innovation (e.g., Holmes et al., 2015). We collect information on patents applied by Chinese firms and granted by WIPO.[44] We merge the WIPO dataset with our ASIF dataset and find that firms in ineligible industries have few global patents granted by WIPO, making it difficult to conduct the DDD analysis. Due to data limitations, we only use firms in the six affected industries[45] to compare the before–after change of firms in the three northeastern provinces with firms in other parts of China. The following regression is estimated:

$$y_{ip,t+1} = \beta * NE_p * Post2004_t + \mu_i + \gamma_t + \varepsilon_{ipt}, \tag{3}$$

where $y_{ip,t+1}$ is the logarithm of the number of patent applications filed (and eventually granted by WIPO) by firm i in year $t+1$. NE_p is a dummy indicating the three provinces affected by the 2004 VAT reform. $Post2004_t$ is a dummy equal to one for the 2005–2007 period and zero for the 2001–2004 period. μ_i and γ_t are firm and year fixed effects. Standard errors are clustered at the firm level. Columns (6) and (7) in Table 10 show the results. The estimated coefficient of $NE * Post2004$ is still negative but not precisely estimated, which may be due to the small sample size.

Second, we use Kogan et al.'s (2017) measure as an alternative proxy for the quality of innovation. The basic idea of this measure is to use the stock price movements related to the value of patents after patent issuance events to capture the economic importance of patents. Kogan et al. (2017) estimate the value of a patent as the product of a firm's idiosyncratic rate of return around a 3-day window after the patent issuance event and market capitalization on the trading day preceding the issuance announcement.

[44] WIPO is an international organization of the United Nations and provides intellectual property services.
[45] The eligible industries of the 2004 VAT reform are described in Section 2.

Compared with other measures of the quality of innovation (for instance, patent citations), the stock market response to patent issuance events has several advantages: (i) it requires only ex ante information by using forward-looking asset prices; (ii) it captures the economic (as opposed to the scientific) value of a patent and is therefore more useful for analyzing firms' profit maximization decisions; and (iii) it is based on the value of innovation and is thus comparable across different periods and industries.

Due to the lack of stock price information for firms in the ASIF dataset, we estimate the economic value of innovation for a sample of firms publicly listed on the A-share stock market. To make the results comparable to the baseline results, we further restrict the sample to manufacturing firms, obtaining a sample of 868 firms. Following Kogan et al. (2017), we examine a firm's stock price reaction to measure the economic value of its patents.

Specifically, we calculate the increase in the market value of a firm related to the value of its patents over a 3-day widow starting from the patent grant date. We first construct the firm's abnormal return, defined as the raw return minus the return on the market portfolio. Then we estimate the anticipation-adjusted economic value of each patent applied in a given year that is eventually granted by adjusting the unconditional probability of a successful patent application[46] and the abnormal return component unrelated to the patent. Finally, we add the value of all patents applied by a given firm in a given year that were eventually granted as the total value of innovation produced by that firm in that year. To avoid scale effects, we normalize the value of innovation with firm size, measured by the book value of assets (in thousands of renminbi) following Kogan et al. (2017).

We report the results in column (8) in Table 10. Overall, these results suggest that the 2004 VAT reform reduces the economic value of the patents generated by the affected firms. We find that compared with non-NE provinces, the difference between the before–after growth rate of the standardized shareholder value added by the granted patents developed by firms in eligible industries and ineligible industries is significantly lower by 0.22 in the northeastern provinces.

Alternative Financial Constraint Measures. We use the SA index as a proxy for financial constraints in the main analysis. However, the SA index is constructed based on a sample of U.S. listed firms (Hadlock and Pierce, 2010), which may not be suitable for Chinese firms. To address this concern, we follow Liu and Mao (2019) and use firm size and the cash flow ratio as alternative proxies. Firm size and the cash flow ratio are defined as the average value of assets (in 1998 renminbi) and the average ratio of cash flow

[46] The success rate of a patent application was about 56% between 1985 and 2011. For more details, see: http://www.cnipa.gov.cn/tjxx/jianbao/year2011/a/a1.html.

to total assets during the pre-reform period, respectively. Based on each measure, we divide the sample into three groups: the bottom three (tight), the middle four (intermediate), and the top three (loose) deciles. We then re-estimate Equation (1) using these subsamples separately.

[Insert Table 11 Here]

As indicated in Table 11, firms with an intermediate level of financial constraints are the most responsive to the VAT reform, while the other two groups have negligible and statistically non-significant coefficients. These results are consistent with our main results. We also construct two indicators, $Intermediate$ and $Loose$, for each alternative financial constraint measure. We include the interaction terms $NE * Eind * Post2004 * Intermediate$ and $NE * Eind * Post2004 * Loose$ and their triple and double interactions that are not absorbed by the fixed effects. The results presented in Appendix 5 are consistent with those in Table 11.

8. Non-monotonic Effect on Other Firm Decisions by Financial Constraints

Our theory also suggests that other decisions made by firms may be affected by the VAT reform non-monotonically, based on the level of financial constraints. For example, the labor input of firms with an intermediate level of financial constraints should also be crowded out. Conversely, the effect of the VAT reform on fixed assets may go both ways depending on the parameters of the production technology. In other words, we should also observe the non-monotonic effect of the VAT reform on firms' labor input, but we may or may not observe it on investment decisions. Below, we present the response of labor and fixed asset investment to the 2004 VAT reform as supplementary evidence.

We use the log of total wages (in 1998 renminbi) and fixed asset investment as the dependent variables and estimate equation (1), respectively. Following Zhang et al. (2018), we use gross fixed asset investment in year t (GFI_t) normalized by the net fixed asset stock in year $t-1$ ($NFAS_{t-1}$),[47] as a proxy for firm fixed asset investment ($Rgfinv_t$):

$$Rgfinv_t = \frac{(1-VAT\ \ tax\ \ rate)GFI_t/FIPI_t}{NFAS_{t-1}/FIPI_{t-1}}, \tag{4}$$

where $FIPI_t$ is the fixed asset investment price index in year t based on 1998 renminbi from the Statistic Yearbook of China, to adjust inflation.[48] This measure is slightly different from that of Zhang et al. (2018), as we multiply it by $(1 - VAT\ \ tax\ \ rate)$ to eliminate the benefits of the VAT deduction, where the VAT rate is equal to 17%.

[47] In the ASIF dataset, the net asset value is measured at different acquisition prices and we add them to obtain $NFAS_t$.

[48] We simply use $FIPI_{t-1}$ to deflate $NFAS_{t-1}$ because of the low level of inflation in the 1990s.

[Insert Table 12 Here]

Table 12 reports the results. We find a statistically significant negative effect of the 2004 VAT reform on labor costs only for firms with an intermediate level of financial constraints, consistent with our main results (see Section 3 and Appendix 1). Firms with an intermediate level of financial constraints switch from low type to high type after the reform. After becoming a high-type firm, the firm reduces its percentage of labor input and pays additional operating costs. Both effects reduce the labor input of firms after the VAT reform.

For fixed asset investment, none of the three groups of firms with different levels of financial constraints significantly responds to the VAT reform. This does not contradict our model. In our model, firms upgrading their technology after the VAT reform increase their percentage of fixed assets, while facing additional operating costs that can crowd out fixed asset expenditure. Thus, the VAT reform can have two opposite effects on fixed asset investment and the net effect can go either way.

9. Conclusions

We examine the effect of investment tax credits on firm innovation, focusing on the 2004 pilot VAT reform in six industries in the northeastern region of China. This reform switches from production-type VAT to consumption-type VAT by allowing the costs of fixed assets to be deducted, reducing the relative price of machinery and equipment.

Our model indicates that this change in the relative price of machinery and equipment leads to a decline in innovation for firms with an intermediate level of financial constraints. Using the DDD approach, consistent with the model's prediction, we show that the 2004 VAT reform has a negative effect on firm innovation. Firms facing different financial constraints are affected differently by the reform. Specifically, the 2004 VAT reform has a negative effect on innovation only for firms with intermediate-level financial constraints. These results are robust to a series of robustness tests.

To conclude, our study suggests that investment tax credits may have an unintended negative effect on firm innovation (which in turn has a negative externality on economic growth). It also deepens our understanding of the role of financial constraints in this problem. We acknowledge that our results may be more relevant shortly after the reform, as the financial constraints of firms can change in the long term. Over time, with improved performance and external financing, more capital will be available for firms to produce. In this case, the negative effect of the reform on innovation may be mitigated. Nevertheless, our findings on the crowding out effect of investment tax credits on innovation are of interest to policymakers designing optimal fiscal policies to improve innovation and boost economic growth. This is particularly important for a country like China. Even with its rapid economic growth, China has long been criticized for its insufficient innovation. Promoting healthy economic growth motivated by innovation is essential for stable long-term economic growth.

References

Abel, A. B. (1982). Dynamic effects of permanent and temporary tax policies in a *q* model of investment. *Journal of Monetary Economics 9* (3): 353–373.

Acemoglu, D. and A. Finkelstein (2008). Input and technology choices in regulated industries: Evidence from the health care sector. *Journal of Political Economy 116* (5): 837–880.

Acharya, V. and Z. Xu (2017). Financial dependence and innovation: The case of public versus private firms. *Journal of Financial Economics 124* (2): 223–243.

Aghion, P., J. Van Reenen, and L. Zingales (2013). Innovation and institutional ownership. *American Economic Review 103* (1): 277–304.

Agrawal, A., C. Rosell, and T. S. Simcoe (2019). Tax credits and small firm R&D spending. National Bureau of Economic Research Working Paper 20615.

Allen, F., J. Qian, and M. Qian (2005). Law, finance, and economic growth in China. *Journal of Financial Economics 77* (1): 57–116.

Angelini, P. and A. Generale (2008). On the evolution of firm size distributions. *American Economic Review 98* (1): 426–438.

Ayyagari, M., A. Demirgüç-Kunt, and V. Maksimovic (2011). Firm innovation in emerging markets: The role of finance, governance, and competition. *Journal of Financial and Quantitative Analysis 46* (6): 1545–1580.

Banerjee, A. V. and E. Duflo (2014). Do firms want to borrow more? Testing credit constraints using a directed lending program. *Review of Economic Studies 81* (2): 572–607.

Berkowitz, D., C. Lin, and Y. Ma (2015). Do property rights matter? Evidence from a property law enactment. *Journal of Financial Economics 116* (3): 583–593.

Bloom, N., M. Schankerman, and J. Van Reenen (2013). Identifying technology spillovers and product market rivalry. *Econometrica 81* (4): 1347–1393.

Bloom, N., R. Griffith, and J. Van Reenen (2002). Do R&D tax credits work? Evidence from a panel of countries 1979–1997. *Journal of Public Economics 85* (1): 1–31.

Brandt, L., J. Van Biesebroeck, L. H. Wang, and Y. F. Zhang (2017). WTO accession and performance of Chinese manufacturing firms. *American Economic Review 107* (9): 2784–2820.

Brock, P. L. (1988). Investment, the current account, and the relative price of non-traded goods in a small open-economy. *Journal of International Economics 24* (3–4): 235–253.

Buera, F. J., J. P. Kaboski, and Y. Shin (2011). Finance and development: A tale of two sectors. *American Economic Review 101* (5): 1964–2002.

Cabral, L. S. M. B. and J. Mata (2003). On the evolution of the firm size distribution: Facts and theory. *American Economic Review 93* (4): 1075–1090.

Cai, H. B. and Q. Liu (2009). Competition and corporate tax avoidance: Evidence from Chinese industrial firms. *Economic Journal 119* (537): 764–795.

Cai, J., Y. Chen, and X. Wang (2018). The impact of corporate taxes on firm innovation: Evidence from the corporate tax collection reform in China. National Bureau of Economic Research Working Paper 25146.

Cai, J. and A. Harrison (forthcoming). Industrial policy in China: Some intended or unintended consequences. *Industrial and Labor Relations Review.*

Campello, M., J. R. Graham, and C. R. Harvey (2010). The real effects of financial constraints: Evidence from a financial crisis. *Journal of Financial Economics 97* (3): 470–487.

Chen, Z., Z. Liu, J. C. Suárez Serrato, and D. Y. Xu (2018). Notching R&D investment with corporate income tax cuts in China. National Bureau of Economic Research Working Paper 24749.

Chetty, R., A. Looney, and K. Kroft (2009). Salience and taxation: Theory and evidence. *American*

Economic Review 99 (4): 1145–1177.
Cull, R. and L. C. Xu (2005). Institutions, ownership, and finance: The determinants of profit reinvestment among Chinese firms. *Journal of Financial Economics 77* (1): 117–146.
Dang, J. and K. Motohashi (2015). Patent statistics: A good indicator for innovation in China? Patent subsidy program impacts on patent quality. *China Economic Review 35*: 137–155.
Dechezleprêtre, A., E. Einiö, R. Martin, K.–T. Nguyen, and J. Van Reenen (2016). Do tax incentives for research increase firm innovation? An RD design for R&D. National Bureau of Economic Research Working Paper 22405.
Dollar, D. and S.–J. Wei (2007). Das (wasted) kapital firm ownership and investment efficiency in China. National Bureau of Economic Research Working Paper 13103.
Fang, L. H., J. Lerner, and C. P. Wu (2017). Intellectual property rights protection, ownership, and innovation: Evidence from China. *Review of Financial Studies 30* (7): 2446–2477.
Fang, V. W., X. Tian, and S. Tice (2014). Does stock liquidity enhance or impede firm innovation? *Journal of Finance 69* (5): 2085–2125.
Fazzari, S. M., R. G. Hubbard, and B. C. Petersen (1988). Financing constraints and corporate investment. National Bureau of Economic Research Working Paper 2387.
Goolsbee, A. (1998). Investment tax incentives, prices, and the supply of capital goods. *Quarterly Journal of Economics 113* (1): 121–148.
Griliches, Z. (1991). The search for R&D spillovers. National Bureau of Economic Research Working Paper 3768.
Griliches, Z., A. Pakes, and B. H. Hall (1988). The value of patents as indicators of inventive activity. National Bureau of Economic Research Working Paper 2083.
Guariglia, A., X. X. Liu, and L. Song (2011). Internal finance and growth: Microeconometric evidence on Chinese firms. *Journal of Development Economics 96* (1): 79–94.
Guceri, I. and L. Liu (2019). Effectiveness of fiscal incentives for R&D: Quasi-experimental evidence. *American Economic Journal: Economic Policy 11* (1): 266–291.
Hadlock, C. J. and J. R. Pierce (2010). New evidence on measuring financial constraints: Moving beyond the KZ index. *Review of Financial Studies 23* (5): 1909–1940.
Hall, B. and J. Van Reenen (2000). How effective are fiscal incentives for R&D? A review of the evidence. *Research Policy 29* (4–5): 449–469.
Hall, B. H. (2008). *The financing of innovation*. Oxford: Blackwell.
Hall, B. H., A. B. Jaffe, and M. Trajtenberg (2001). The NBER patent citation data file: Lessons, insights and methodological tools. National Bureau of Economic Research Working Paper 8498.
Hall, R. E. and D. W. Jorgenson (1967). Tax policy and investment behavior. *American Economic Review 57* (3): 391–414.
Holmes, T. J., E. R. McGrattan, and E. C. Prescott (2015). Quid pro quo: Technology capital transfers for market access in China. *Review of Economic Studies 82* (3): 1154–1193.
Hopenhayn, H. A. (1992). Entry, exit, and firm dynamics in long-run equilibrium. *Econometrica 60* (5): 1127–1150.
House, C. L. and M. D. Shapiro (2008). Temporary investment tax incentives: Theory with evidence from bonus depreciation. *American Economic Review 98* (3): 737–768.
Howell, S. T. (2017). Financing innovation: Evidence from R&D grants. *American Economic Review 107* (4): 1136–1164.
Hsu, P. H., X. Tian, and Y. Xu (2014). Financial development and innovation: Cross-country evidence. *Journal of Financial Economics 112* (1): 116–135.
Hu, A. G. and G. H. Jefferson (2009). A great wall of patents: What is behind China's recent patent explosion? *Journal of Development Economics 90* (1): 57–68.

Hu, A. G. Z., P. Zhang, and L. Zhao (2017). China as number one? Evidence from China's most recent patenting surge. *Journal of Development Economics 124*: 107–119.

Jin, M., S. N. Zhao, and S. C. Kumbhakar (2019). Financial constraints and firm productivity: Evidence from Chinese manufacturing. *European Journal of Operational Research 275* (3): 1139–1156.

Jones, C. I. and J. C. Williams (1998). Measuring the social return to R&D. *Quarterly Journal of Economics 113* (4): 1119–1135.

Kaplan, S. N. and L. Zingales (1997). Do investment-cash flow sensitivities provide useful measures of financing constraints? *Quarterly Journal of Economics 112* (1): 169–215.

Khandelwal, A. K., P. K. Schott, and S. J. Wei (2013). Trade liberalization and embedded institutional reform: Evidence from Chinese exporters. *American Economic Review 103* (6): 2169–2195.

Kogan, L., D. Papanikolaou, A. Seru, and N. Stoffman (2017). Technological innovation, resource allocation, and growth. *Quarterly Journal of Economics 132* (2): 665–712.

La Ferrara, E., A. Chong, and S. Duryea (2012). Soap operas and fertility: Evidence from Brazil. *American Economic Journal: Applied Economics 4* (4): 1–31.

Liu, Q. and L. D. Qiu (2016). Intermediate input imports and innovations: Evidence from Chinese firms' patent filings. *Journal of International Economics 103*: 166–183.

Liu, Q. and Y. Lu (2015). Firm investment and exporting: Evidence from China's value-added tax reform. *Journal of International Economics 97* (2): 392–403.

Liu, Y. and J. Mao (2019). How do tax incentives affect investment and productivity? Firm-level evidence from China. *American Economic Journal: Economic Policy 11* (3): 261–291.

Melitz, M. J. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica 71* (6): 1695–1725.

Metcalf, G. E. (1995). Value-added taxation: A tax whose time has come? *Journal of Economic Perspectives 9* (1): 121–140.

Midrigan, V. and D. Y. Xu (2014). Finance and misallocation: Evidence from plant-level data. *American Economic Review 104* (2): 422–458.

Poncet, S., W. Steingress, and H. Vandenbussche (2010). Financial constraints in China: Firm-level evidence. *China Economic Review 21* (3): 411–422.

Rao, N. (2016). Do tax credits stimulate R&D spending? The effect of the R&D tax credit in its first decade. *Journal of Public Economics 140*: 1–12.

Romer, P. M. (1986). Increasing returns and long-run growth. *Journal of Political Economy 94* (5): 1002–1037.

Rosenbaum, P. R. and D. B. Rubin (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika 70* (1): 41–55.

Sen, P. and S. J. Turnovsky (1990). Investment tax credit in an open-economy. *Journal of Public Economics 42* (3): 277–299.

Seru, A. (2014). Firm boundaries matter: Evidence from conglomerates and R&D activity. *Journal of Financial Economics 111* (2): 381–405.

Shi, X. Z. and Z. F. Xu (2018). Environmental regulation and firm exports: Evidence from the eleventh Five-Year Plan in China. *Journal of Environmental Economics and Management 89*: 187–200.

Teece, D. J. (1977). Technology-transfer by multinational firms: The resource cost of transferring technological know-how. *Economic Journal 87* (346): 242–261.

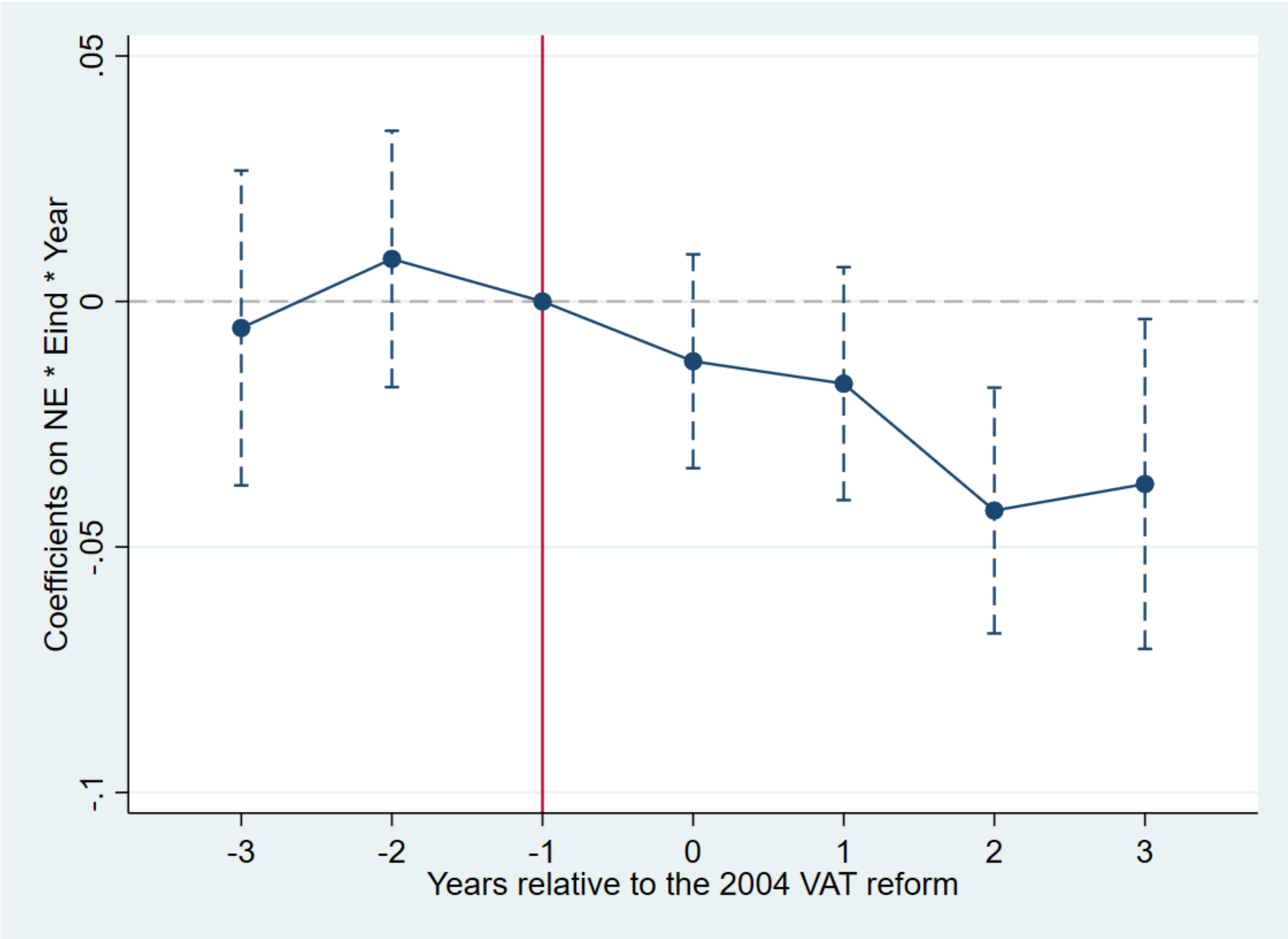
Thomson, R. (2017). The effectiveness of R&D tax credits. *Review of Economics and Statistics 99* (3): 544–549.

Whited, T. M. and G. J. Wu (2006). Financial constraints risk. *Review of Financial Studies 19* (2): 531–559.

Wolff, E. N. (1991). Capital formation and productivity convergence over the long-term. *American*

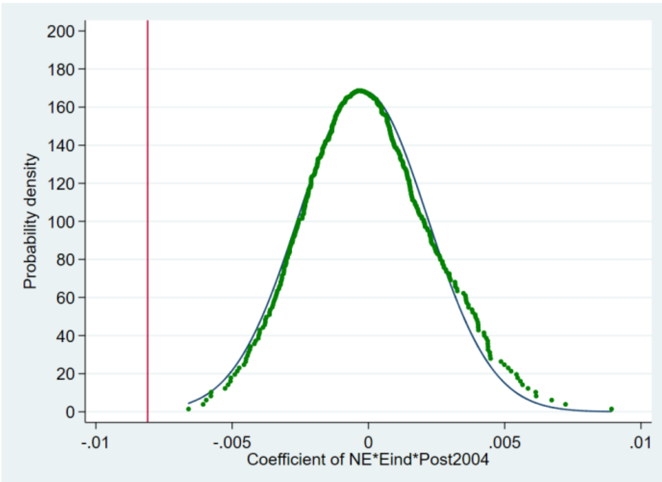
Economic Review 81 (3): 565–579.
Zhang, G. and X. Chen (2012). The value of invention patents in China: Country origin and technology field differences. *China Economic Review 23* (2): 357–370.
Zhang, L., Y. Y. Chen, and Z. Y. He (2018). The effect of investment tax incentives: Evidence from China's value-added tax reform. *International Tax and Public Finance 25* (4): 913–945.
Zwick, E. and J. Mahon (2017). Tax policy and heterogeneous investment behavior. *American Economic Review 107* (1): 217–248.

Figure 1. The Dynamic Effect of the 2004 VAT Reform on the Number of Patents of Firms.

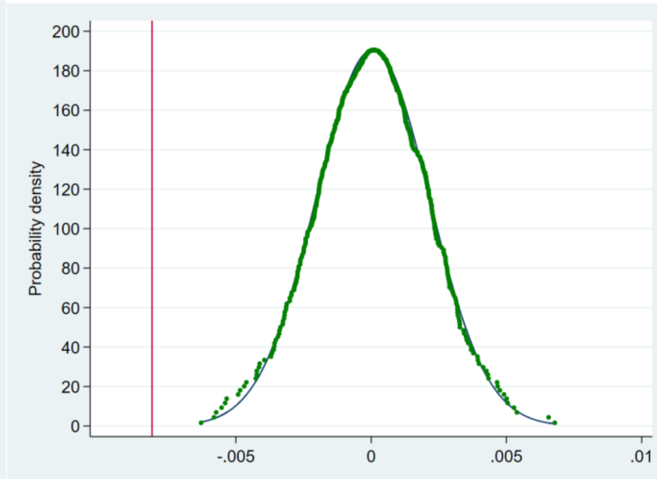


Note. This figure shows the dynamic effect of the 2004 VAT reform on the number of patents of firms over a 7-year window (2001–2007), ranging from three years before the reform to three years after the reform. Specifically, the figure plots the estimated coefficients based on a regression of the total number of successful patent filings in year $t+1$ on a set of interactions between $NE * Eind$ (indicating the affected firms by the 2004 VAT reform) and annual year dummies (excluding 2003). Province-year, industry-year, and firm fixed effects are included in the regression. The omitted time category is $Year2003$, so that the estimated effect is relative to one year before the 2004 VAT reform. Thus, the coefficient estimate of $NE * Eind * Year_t$ indicates the relative mean value of $\left(Pat_{NE=1,Eind=1} - Pat_{NE=1,Eind=0}\right) - \left(Pat_{NE=0,Eind=1} - Pat_{NE=0,Eind=0}\right)$ in year $t+1$, a DDD estimator of the effect of the 2004 VAT reform after controlling for the full set of fixed effects. The dashed lines represent the 95% confidence interval, adjusted for clustering at the firm level.

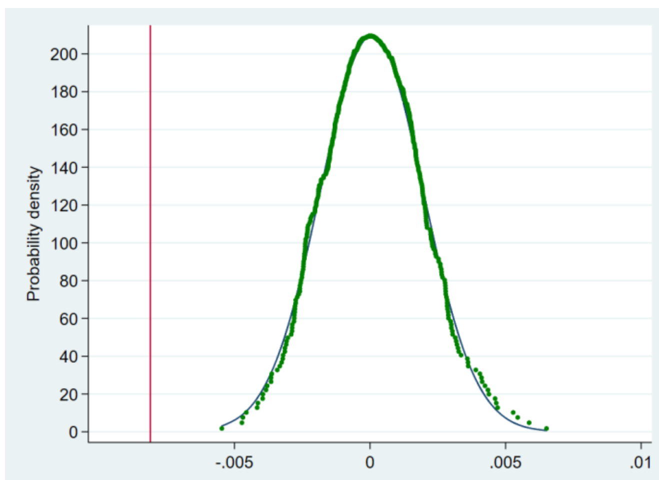
Figure 2. Probability Density Function of the Placebo Estimates.



Panel A. Using $(NE * Eind)_{Random} * Post2004$



Panel B. Using $NE * Eind * Post2004_{Random}$



Panel C. Using $(NE * Eind)_{Random} * Post2004_{Random}$

Note: These figures plot three empirical distributions of the placebo effects for firm innovation. For each figure, the probability distribution function is constructed from 500 placebo estimates of β using the specification in column (1) of Table 3. Panels A, B, and C use the three placebo interaction variables constructed by randomly assigning affected province-industry groups ($(NE * Eind)_{Random} * Post2004$), affected years ($NE * Eind * Post2004_{Random}$), and both affected province-industry groups and affected years ($(NE * Eind)_{Random} * Post2004_{Random}$), respectively. The vertical lines show the treatment effect estimates reported in column (1) of Table 3.

Table 1. Annual Sample Distribution.

Year	Total	Northeastern (NE) Region		
		Total	Number of Firms in Eligible Industries	Percentage of Firms in Eligible Industries (%)
2001	45,534	2,584	2,109	81.62
2002	55,649	3,276	2,698	82.36
2003	74,316	4,505	3,733	82.86
2004	145,567	8,014	6,688	83.45
2005	143,760	7,926	6,594	83.19
2006	133,457	7,421	6,180	83.28
2007	124,572	6,906	5,775	83.62
Total	722,855	40,632	33,777	83.13

Note: This table presents the annual distribution of observations for the 2001–2007 period by region and industry in our sample. The northeastern region includes Heilongjiang, Jilin, and Liaoning provinces. Eligible industries include equipment manufacturing; automobile manufacturing; petroleum, chemical, and pharmaceutical manufacturing; agricultural product processing; metallurgy; and shipbuilding. The sample excludes all firms located in the 26 cities of central China to eliminate the effect of the VAT reform in 2007. The sample also excludes all firms that changed their location or industry during the sampling period to avoid sample selection bias. The sample excludes all firm-year observations with missing or error values. Finally, the sample includes only firms with at least one observation both before and after the 2004 VAT reform.

Table 2. Summary Statistics.

	Mean	*SD*	Min	Median	Max	Count
			Innovation variables			
Pat	0.049	0.397	0.000	0.000	17.000	722,855
Pat_inv_utl	0.032	0.270	0.000	0.000	10.000	722,855
Pat_des	0.017	0.232	0.000	0.000	13.000	722,855
Pat_stock	0.340	2.096	0.000	0.000	60.907	722,855
WIPO patents	0.007	2.426	0.000	0.000	1,544.000	722,855
R&D/Assets	0.009	0.039	0.000	0.000	1.695	445,161
R&D/Sales	0.009	0.035	0.000	0.000	0.913	445,161
Patent value/Firm size (thousands)	0.304	1.186	0.000	0.000	21.607	4,750
			Other outcome variables			
Total Wage	3,569.148	7,484.104	29.290	1,385.940	234,399.900	722,855
ln(Total Wage)	7.359	1.199	-0.001	7.234	16.667	722,855
Fixed investment ratio	0.583	5.104	-184.267	0.063	1,064.867	587,813
			Characteristics			
Assets (in millions)	58.675	164.567	0.511	15.120	8,964.640	722,855
Firm Age (years)	10.772	10.977	0.000	7.000	88.000	722,855
ROA	0.065	0.148	-1.187	0.026	7.140	722,855
Foreign Share	0.187	0.362	0.000	0.000	1.000	722,855
State Share	0.056	0.215	0.000	0.000	1.000	722,855

Note: This table presents the summary statistics of the main variables, whose definitions are given in Appendix 2. All of the continuous variables are winsorized at the 1st and 99th percentiles. Data period: 2001–2007.

Table 3. Effect of the 2004 VAT Reform on the Total Number of Patents.

Dependent Variable	$\ln(1+Pat_{t+1})$			
	(1)	(2)	(3)	(4)
NE*Eind*Post2004	-0.0082	-0.0081	-0.0083	-0.0081
	(0.0038)	(0.0038)	(0.0039)	(0.0039)
LnAssets		0.0162		
		(0.0007)		
Firm Age		0.0073		
		(0.0012)		
ROA		0.0019		
		(0.0027)		
Foreign Share		-0.0106		
		(0.0031)		
State Share		0.0162		
		(0.0007)		
Firm FE	Yes	Yes	Yes	Yes
Year-province FE	Yes	Yes	Yes	Yes
Year-industry FE	Yes	Yes	Yes	Yes
Pre-reform Average Controls*Post2004	No	No	Yes	No
Pre-reform Average Controls*Year FE	No	No	No	Yes
Observations	722,855	722,855	722,855	722,855
R-squared	0.533	0.534	0.535	0.533
N (affected group)	7,044	7,044	7,044	7,044
N (control group)	144,006	144,006	144,006	144,006
Mean of dep. var.	0.0393	0.0393	0.0393	0.0393
Std. dev. of dep. var.	0.2338	0.2338	0.2338	0.2338
Change of level variable	-0.0090	-0.0089	-0.0086	-0.0089
% effect relative to level mean	-9.51%	-9.39%	-9.62%	-9.39%

Note: This table provides evidence of the effect of the 2004 VAT reform on the total number of patents filed by a firm that were eventually granted by the CNIPA. The dependent variable is the log of one plus the total number of patents filed by a firm in year $t+1$ that were eventually granted by the CNIPA. Column (1) estimates the basic effect of the 2004 VAT reform on firm innovation. Column (2) controls for a set of firm-level time-variant variables. The average values of these controls are calculated for all firms in the pre-reform period. Column (3) interacts the $Post2004$ dummy with the pre-reform controls. Column (4) fully controls for the interactions between year dummies and pre-reform controls. Standard errors are clustered at the firm level and reported in brackets. Definitions of all of the control variables can be found in Appendix 2.

Table 4. Effect of the 2004 VAT Reform on Different Types of Patents.

Dependent Variable	$\ln(1+Pat\_inv\_utl_{t+1})$	$\ln(1+Pat\_des_{t+1})$
	(1)	(2)
NE*Eind*Post2004	-0.0066	-0.0021
	(0.0034)	(0.0006)
Firm FE	Yes	Yes
Year-province FE	Yes	Yes
Year-industry FE	Yes	Yes
Observations	722,855	722,855
R-squared	0.509	0.478
N (affected group)	7,044	7,044
N (control group)	144,006	144,006
Mean of dep. var.	0.0267	0.0093
Std. dev. of dep. var.	0.1753	0.1022
Change of level variable	-0.0070	-0.0021
% effect relative to level mean	-13.04%	-11.69%

Note: This table provides evidence of the effect of the 2004 VAT reform on the number of patents with different qualities. The dependent variables are the log of one plus the sum of the number of invention patents and utility model patents (in column 1) and the log of one plus the number of design patents (in column 2), all of which are filed by a firm in year $t + 1$ and eventually granted by the CNIPA. Robust standard errors are clustered at the firm level and reported in brackets.

Table 5. Heterogeneity: Financial Constraints.

Dependent Variable	ln(1+Pat$_{t+1}$)			
Sample	Tight	Intermediate	Loose	All
	(1)	(2)	(3)	(4)
NE*Eind*Post2004	0.0039	-0.0127	-0.0123	0.0040
	(0.0044)	(0.0050)	(0.0075)	(0.0044)
NE*Eind*Post2004*Intermediate				-0.0196
				(0.0066)
NE*Eind*Post2004*Loose				-0.0131
				(0.0086)
Post2004*Intermediate				0.0020
				(0.0018)
NE*Post2004*Intermediate				0.0097
				(0.0059)
Post2004*Eind*Intermediate				0.0048
				(0.0021)
Post2004*Loose				0.0141
				(0.0029)
NE*Post2004*Loose				-0.0139
				(0.0069)
Post2004*Eind*Loose				0.0144
				(0.0033)
Firm FE	Yes	Yes	Yes	Yes
Year-province FE	Yes	Yes	Yes	Yes
Year-industry FE	Yes	Yes	Yes	Yes
Observations	188,033	287,147	247,611	722,855
R-squared	0.475	0.461	0.558	0.534
N (affected group)	1,767	2,677	2,600	7,044
N (control group)	43,548	57,743	42,715	144,006
Mean of dep. var.	0.0787	0.0250	0.0093	0.0393
Std. dev. of dep. var.	0.3297	0.1835	0.1112	0.2338
Change of level variable	0.0051	-0.0134	-0.0246	-
% effect relative to level mean	1.65%	-23.24%	-2.46%	-

Note: This table presents the heterogeneous effects of the 2004 VAT reform on the total number of patents based on the financial constraint index (SA index). The dependent variable is the log of one plus the total number of patents filed by a firm in year $t+1$ that were eventually granted by the CNIPA. The average SA index (Hadlock and Pierce, 2010) measured during the pre-reform period is used to divide the sample into deciles and define the top three deciles as tight financial constraints, the middle four deciles as intermediate-level financial constraints, and the bottom three deciles as loose financial constraints. $Intermediate$ and $Loose$ are two dummy variables based on the SA index to identify firms with an intermediate level and a loose level of financial constraints, respectively. $Intermediate$ is equal to one for firms belonging to the middle four deciles when the firms in the sample are divided based on the SA index, and zero otherwise. $Loose$ is equal to one for firms belonging to the bottom three deciles when the firms in the sample are divided based on the SA index, and zero otherwise. Definitions of all of the variables can be found in Appendix 2. Robust standard errors are clustered at the firm level and reported in brackets.

Table 6. Heterogeneity: Ownership.

Dependent Variable	$\ln(1+Pat_{t+1})$		
Subsample	SOE	Domestic private	Foreign
	(1)	(2)	(3)
NE*Eind*Post2004	-0.0058	-0.0086	-0.0043
	(0.0142)	(0.0042)	(0.0109)
Firm FE	Yes	Yes	Yes
Year-province FE	Yes	Yes	Yes
Year-industry FE	Yes	Yes	Yes
Observations	37,364	533,750	125,246
R-squared	0.600	0.524	0.552
N (affected group)	644	5,186	807
N (control group)	6,232	107,747	24,315
Mean of dep. var.	0.0564	0.0359	0.0499
Std. dev. of dep. var.	0.2742	0.2221	0.2677
Change of level variable	-0.0066	-0.0093	-0.0048
% effect relative to level mean	-5.00%	-11.03%	-3.90%

Note: This table presents the heterogeneous effects of the 2004 VAT reform on innovation based on ownership. The dependent variable is the log of one plus the total number of patents filed by a firm in year $t+1$ and eventually granted by the CNIPA. Columns (1) to (3) report the results using the subsamples of SOEs, domestic private firms, and foreign-invested firms, respectively. The nature of ownership is defined based on information in 2004. A firm is considered an SOE (domestic private firm) if the state (domestic private shareholder) owns the largest share of the firm's total paid-in capital. A firm is defined as a foreign-invested firm if foreign investors own the largest share of its total paid-in capital. In this analysis, firms with two or three shareholders with the same largest share are eliminated, as their ownership cannot be clearly defined. Definitions of all of the variables can be found in Appendix 2. Robust standard errors are clustered at the firm level and reported in brackets.

Table 7. Robustness Test: Other Explanations.

Dependent Variable	$\ln(1+Pat_{t+1})$			Middle-stage Dummy
Specification/Sample	Excluding MFA-Affected Industries	Controlling for Pollution Reduction	Controlling for the Impact of WTO Entry	Excluding Life-Cycle Theory
	(1)	(2)	(3)	(4)
NE*Eind*Post2004	-0.0090	-0.0077	-0.0123**	
	(0.0040)	(0.0038)	(0.0052)	
LnTarget*Post2005*$\ln SO_2$		0.0008		
		(0.0005)		
Export/Sales			-0.0041	
			(0.0028)	
Exporter			0.0104***	
			(0.0023)	
NE*Eind				0.0194
				(0.0170)
Firm FE	Yes	Yes	Yes	No
Year-Province FE	Yes	Yes	Yes	No
Year-Industry FE	Yes	Yes	Yes	No
Province FE	No	No	No	Yes
Industry FE	No	No	No	Yes
Observations	610,712	722,855	568,755	151,050
R-squared	0.537	0.533	0.559	0.012
N (affected group)	6,415	7,044	6,677	7,044
N (control group)	120,915	144,006	135,840	144,006
Mean of dep. var.	0.0447	0.0393	0.0426	0.3833
Std. dev. of dep. var.	0.2482	0.2338	0.2459	0.4862
Change on level variable	-0.0100	-0.0084	-0.0138	0.0194
% effect relative to level mean	-9.33%	-8.93%	-13.20%	5.06%

Note: Columns (1), (2), and (3) rule out the confounding effects of the removal of the MFA, the environmental policy on SO_2 emissions, and the WTO entry. The dependent variable in columns (1) – (3) is the log of one plus the total number of patents filed by a firm in year $t+1$ and eventually granted by the CNIPA. Column (1) eliminates all observations in the textile and clothing industries, which are MFA-affected industries. Column (2) controls for the influence of an environmental policy setting a pollution reduction target for each province. In column (2), $lnTarget$ is the log of the provincial pollution reduction target (%). $Post2005$ is a dummy variable equal to one for the 2006–2007 period and zero for the 2001–2005 period. $lnSO_2$ is the log of the average industrial SO_2 emissions (in 10,000 tons) from 2003 to 2005. Column (3) controls the impact of WTO entry by including firm-level time-variant export intensity and exporter as control variables. Export intensity is measured by the ratio of export to sales in each firm and exporter is a dummy variable equal to one if a firm is an exporter in a given year and zero otherwise. Column (4) uses the pre-reform average to construct a cross-sectional sample to check if the proportion of intermediate-stage firms in the affected group is disproportionally larger than that of other firms. The dependent variable in column (3) is $Middle\text{-}stage\ \ Dummy$, a binary variable equal to one for firms in the intermediate stage of their life cycle and zero for other firms. All firms in our sample are divided into deciles based on their annual average age before the 2004 VAT reform, with firms in the middle four deciles defined as being in the intermediate stage of their life cycle. Definitions of all of the variables can be found in Appendix 2. Robust standard errors are clustered at the firm level and reported in brackets.

Table 8. Robustness Test: Justification of the Empirical Strategy.

Dependent Variable	$LnPat_{t+1}$			
Specification/Sample	2001–2004	Excluding Expectation Effect	PSM Sample	Distant Provinces as Control Group
	(1)	(2)	(3)	(4)
NE*Eind*Year2001	-0.0041			
	(0.0085)			
NE*Eind*Year2002	0.0008			
	(0.0070)			
NE*Eind*Year2004	-0.0069	-0.0073		
	(0.0062)	(0.0051)		
NE*Eind*Post2004		-0.0118	-0.0334	-0.0097
		(0.0049)	(0.0144)	(0.0040)
Firm FE	Yes	Yes	Yes	Yes
Year-province FE	Yes	Yes	Yes	Yes
Year-industry FE	Yes	Yes	Yes	Yes
Observations	245,357	722,855	122,529	551,765
R-squared	0.6216	0.533	0.5201	0.538
N (affected group)	7,044	7,044	7,044	7,044
N (control group)	144,006	144,006	18,325	114,874
Mean of dep. var.	0.0361	0.0393	0.0459	0.0446
Std. dev. of dep. var.	0.2147	0.2338	0.2447	0.2515
Change of level variable	-	-0.0129	-0.0369	-0.0108
% effect relative to level mean	-	-13.68%	-35.52%	-9.83%

Note: This table reports the results of several tests to justify the validity of the assumptions of the DDD estimation strategy. The dependent variable in columns (1) to (4) is the log of one plus the total number of patents filed by a firm in year $t+1$ and eventually granted by the CNIPA. Column (1) eliminates all post-reform observations and uses the interactions of NE, $Eind$, and the pre-reform year dummies ($Year2001$, $Year2002$, and $Year2004$) as the main independent variables. Column (2) controls for an additional interaction term, $NE * Eind * Year2004$, to check whether firms changed their behavior in anticipation of the 2004 VAT reform. Column (3) uses the propensity score matched sample, in which the control group is constructed using a one-to-three nearest neighbor matching (with replacement) of the propensity score matching approach. Column (4) uses the firms affected by the 2004 VAT reform and the control firms located in the provinces distant from the northeastern region of China. Distant provinces are defined as provinces whose minimum distance from the northeastern provinces is greater than 500 miles. Definitions of all of the variables can be found in Appendix 2. Robust standard errors are clustered at the firm level and reported in brackets.

Table 9. Robustness Test: Alternative Samples.

Dependent Variable	$LnPat_{t+1}$		
Sample	Delete Sample in 2004	Delete Sample in 2007	Balanced Sample
	(1)	(2)	(3)
NE*Eind*Post2004	-0.0122	-0.0073	-0.0140
	(0.0052)	(0.0038)	(0.0084)
Firm FE	Yes	Yes	Yes
Year-province FE	Yes	Yes	Yes
Year-industry FE	Yes	Yes	Yes
Observations	568,755	596,746	217,007
R-squared	0.559	0.573	0.519
N (affected group)	7,044	7,044	1,350
N (control group)	144,006	144,006	29,652
Mean of dep. var.	0.0426	0.0353	0.0557
Std. dev. of dep. var.	0.2459	0.2165	0.2715
Change of level variable	-0.0135	-0.0079	-0.0158
% effect relative to level mean	-12.91%	-9.72%	-12.22%

Note: This table shows the results of the robustness tests using alternative samples to examine the effect of the 2004 VAT reform on firm innovation. The dependent variable in columns (1) to (3) is the log of one plus the total number of patents filed by a firm in year $t+1$ and eventually granted by the CNIPA. Columns (1) and (2) remove all observations in 2004 and 2007, respectively. Column (3) uses a balanced sample of firms operating continuously over all seven years. Definitions of all of the variables can be found in Appendix 2. Robust standard errors are clustered at the firm level and reported in brackets.

Table 10. Robustness Test: Alternative Measures of Innovation.

Dependent Variable	ln (Pat+(Pat^2+1)$^{1/2}$)	LnPat_stock$_{t+1}$	LnPat$_{t+2}$	R&D$_t$/Assets$_t$	R&D$_t$/Sales$_t$	ln (WIPO patents+1)		Patent Value /Firm Size
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NE*Eind*Post2004	-0.0104	-0.0128	-0.0096					-0.2216
	(0.0050)	(0.0055)	(0.0044)					(0.1274)
Mid*Eind*Year2007				-0.0020	-0.0023			
				(0.0012)	(0.0011)			
NE*Post2004						-0.0003	-0.1036	
						(0.0002)	(0.0771)	
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-province FE	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Year-industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-city FE	No	No	No	Yes	Yes	No	No	No
Observations	722,855	722,855	722,855	445,161	445,161	583,311	1,091	4,750
R-squared	0.532	0.845	0.534	0.506	0.535	0.583	0.583	0.615
N (affected group)	7,044	7,044	7,044	5,894	5,894	7,044	11	49
N (control group)	144,006	144,006	144,006	142,493	142,493	115,406	199	819
Mean of dep. var.	0.0507	0.1027	0.0473	0.0093	0.0086	0.0006	0.3145	0.3036
Std. dev. of dep. var.	0.3008	0.4153	0.2649	0.0391	0.0351	0.0345	0.7325	1.1861
Change of level variable	-0.0114	-0.0172	-0.0108	-0.0020	-0.0023	-0.0003	-0.5768	-0.2216
% effect relative to level mean	-12.06%	-5.04%	-8.88%	-21.51%	-26.74%	-3.56%	-12.63%	-72.99%

Note: This table reports the results of robustness tests using alternative measures of innovation as dependent variables. The dependent variable in column (1) is $\ln(Pat + (Pat^2 + 1)^{\frac{1}{2}})$, a patent-based measure using another log-like transformation. The dependent variable in column (2) is $LnPat\_stock_{t+1}$, a patent stock measure constructed following Fang et al. (2017). Column (3) uses the dependent variable $LnPat_{t+2}$, the log of one plus the total number of patents filed by a firm in year $t+2$ and eventually granted by the CNIPA. Columns (4) and (5) investigate the effect of the 2007 VAT reform on R&D expenditure. Mid_c is an indicator equal to one for the 26 cities affected by the 2007 VAT reform, and zero otherwise. The sample in columns (4) and (5) include all firms located in the 26 cities affected by the 2007 VAT reform and constitutes a balanced sample for the 2005–2007 period. As the pilot reform involves the city-industry level for the 2007 VAT reform, firms changing their city or (3-digit) industry during the sampling period are excluded. Columns (6) and (7) examine the effect of the VAT reform on patent quality, proxied by the number of patents filed by Chinese firms in year $t+1$ and granted by WIPO. Following Kogan et al. (2017), column (8) examines the effect of the 2004 VAT reform on patent quality, proxied by the total value of patents filed by Chinese firms in year $t+1$ and granted by the CNIPA, standardized by firm size, proxied by the book value of assets (in thousands of renminbi). Definitions of all of the variables can be found in Appendix 2. Robust standard errors are clustered at the firm level and reported in brackets.

Table 11. Robustness Test: Alternative Measures of Financial Constraints.

Dependent Variable	$\ln(1+Pat_{t+1})$					
Financial constraint measures	Cash flow/assets			Firm size		
Subsample	Tight	Intermediate	Loose	Tight	Intermediate	Loose
	(1)	(2)	(3)	(4)	(5)	(6)
NE*Eind*Post2004	0.0027	-0.0168	-0.0114	-0.0022	-0.0116	-0.0093
	(0.0068)	(0.0060)	(0.0073)	(0.0038)	(0.0047)	(0.0081)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year-province FE	Yes	Yes	Yes	Yes	Yes	Yes
Year-industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	207,980	299,625	215,215	188,974	290,492	243,334
R-squared	0.520	0.529	0.558	0.453	0.459	0.557
N (affected group)	2,986	2,431	1,627	1,736	2,711	2,597
N (control group)	42,329	57,989	43,688	43,579	57,709	42,718
Mean of dep. var.	0.0340	0.0428	0.0397	0.0084	0.0232	0.0825
Std. dev. of dep. var.	0.2159	0.2426	0.2380	0.1059	0.1760	0.3374
Change of level variable	0.0029	-0.0185	-0.0125	-0.0022	-0.0122	-0.0112
% effect relative to level mean	3.62%	-18.17%	-12.86%	-11.74%	-22.92%	-5.53%

Note: This table provides evidence of the heterogeneous effects of the VAT reform on firm innovation using subsamples based on alternative measures of financial constraints: the cash flow ratio (columns (1) to (3)) and total assets (columns (4) to (6)). The dependent variable in columns (1) to (6) is the log of one plus the total number of patents filed by a firm in year $t+1$ and eventually granted by the CNIPA. The financial constraint measures are constructed using the average values of the cash flow ratio and total assets during the pre-reform period for each firm. All firms in our sample are divided into deciles based on these two measures. The bottom three, the middle four, and the top three deciles are defined as firms with tight, intermediate-level, and loose financial constraints, respectively. Columns (1) to (3) are the results of the heterogeneous effects of the VAT reform on firm innovation based on financial constraints proxied by the ratio of cash flow to total assets. Columns (4) to (5) are the results of the heterogeneous effects of the VAT reform on firm innovation based on financial constraints proxied by total assets. Definitions of all of the variables can be found in Appendix 2. Robust standard errors are clustered at the firm level and reported in brackets.

Table 12. Response of Labor and Capital to the 2004 VAT Reform.

Dependent Variable	ln(Total Wage)		
Subsample	Tight	Intermediate	Loose
	(1)	(2)	(3)
NE*Eind*Post2004	0.0554	-0.0582	-0.0292
	(0.0393)	(0.0275)	(0.0288)
Firm FE	Yes	Yes	Yes
Year-province FE	Yes	Yes	Yes
Year-industry FE	Yes	Yes	Yes
Observations	188,033	287,147	247,611
R-squared	0.776	0.793	0.875
N (affected group)	1,767	2,677	2,600
N (control group)	43,548	57,743	42,715
Mean of dep. var.	6.6359	7.1197	8.1751
Std. dev. of dep. var.	0.8218	0.9003	1.1894
Change of level variable	63.1716	-107.8597	-211.9406
% effect relative to level mean	5.70%	-5.65%	-2.88%
Dependent Variable	Fixed Investment Rate		
Subsample	Tight	Intermediate	Loose
	(4)	(5)	(6)
NE*Eind*Post2004	0.0798	-0.0569	0.0692
	(0.2249)	(0.0853)	(0.0645)
Firm FE	Yes	Yes	Yes
Year-province FE	Yes	Yes	Yes
Year-industry FE	Yes	Yes	Yes
Observations	133,546	226,203	216,333
R-squared	0.310	0.263	0.249
N (affected group)	1,464	2,420	2,438
N (control group)	37,077	52,777	40,853
Mean of dep. var.	0.6262	0.4490	0.3021
Std. dev. of dep. var.	1.9132	1.5036	1.2011
Change of level variable	0.0798	-0.0569	0.0692
% effect relative to level mean	12.74%	-12.67%	22.91%

Note: This table provides evidence of the heterogeneous effects of the 2004 VAT reform on labor costs and the growth rate of fixed assets at the firm level in terms of financial constraints proxied by the SA index. The dependent variables are the log of total wages (in 1998 renminbi) in columns (1) to (3) and the fixed investment rate in columns (4) to (6). The three subsamples with different levels of financial constraints are constructed as in Table 5. Definitions of all of the variables can be found in Appendix 2. Robust standard errors are clustered at the firm level and reported in brackets.

For Online Publication

Appendix 1: The Model

In this section, we provide the details of our model described in the text. The model explains (i) how innovation is affected by the VAT reform; (ii) how the effect is related to financial constraints; and (iii) how the empirical findings of previous studies on the VAT reform can also be rationalized in this simple framework.

We consider an economy with firm output as the final good and three factors of production, fixed assets, labor, and innovation. As explained in Section 3, a firm's production function takes the form of $\tilde{A}(R)K^{\alpha}L^{\beta}$. Each firm is associated with a constant $I > 0$ that measures the capital available for the firm to purchase production factors.

In terms of production technology, there are two types of firms: firms with high-type (only) fixed assets K_h, called high-type firms, and firms with low-type (only) fixed assets K_l, called low-type firms. Following Wolff (1991) and Midrigan and Xu (2014), we assume that a high-type firm has a higher output elasticity of fixed assets and better technology. In addition, a high-type firm must pay additional operating costs, as described in Section 3.

Specifically, the production function of a high-type firm is $\tilde{A}_h(R)K_h^{\alpha_h}L^{\beta_h}$, and that of a low-type firm is $\tilde{A}_l(R)K_l^{\alpha_l}L^{\beta_l}$. For simplicity, we assume that $\tilde{A}_h(R) = A_h R^{\gamma}$, $\tilde{A}_l(R) = A_l R^{\gamma}$, $\alpha_h > \alpha_l$, and $\alpha_h + \beta_h + \gamma = \alpha_l + \beta_l + \gamma = 1$, in which $A_h > A_l$. Note that both types of firms have constant returns to scale and share the same output elasticity of innovation, γ.[1]

The additional operating costs of being a high-type firm may differ between firms. We assume that the additional operating costs of being a high-type firm correspond to a function $\theta(I)$, such that $\theta(I) > 0$, $\left(\frac{\theta(I)}{I}\right)' \leq 0$, and $\lim_{I \to +\infty} \theta'(I) = 0$. The ratio of the additional operating costs $\theta(I)$ to the total amount of capital I is decreasing, and the rate of change of $\theta(I)$ eventually approaches zero. Note that $\theta(I)$ is allowed to be increasing or decreasing or to change non-monotonically with I. However, under our assumptions, even if $\theta(I)$ is increasing, a firm with a higher I will be more comfortable covering the additional operating costs of being a high-type firm than a firm with a lower I. Our assumptions also

[1] Remember that we omit all real estate assets, such as factories and buildings that are not affected by the VAT reform, from the production functions. Our findings below will not be affected if we bring these assets back to the production functions, or if we leave them out but assume that the production functions have decreasing returns to scale (because a factor of production is left out).

allow $\theta(I)$ to be constant: firms may face identical additional operating costs of being a high-type firm. Below is a consequence of the assumptions on $\theta(I)$, which will be used later.

Lemma 1. *For any* $\lambda \in (0,1)$, $\theta(I) = \lambda I$ *has a unique solution.*

Proof. Set an arbitrary $\lambda \in (0,1)$. When $I = 0$, $\theta(0) > \lambda I = 0$ because $\theta(I) > 0$. Therefore, $I = 0$ is not the solution to $\theta(I) = \lambda I$ for any λ. Consider $I > 0$. Let $g(I) = \frac{\theta(I)}{I}$. We know that $g^{'}(I) < 0$ according to our assumptions, and we want to prove that $g(I) = \lambda$ has a unique strictly positive solution.

Because $\lim_{I \to 0+} g(I) = +\infty$, when I is sufficiently small, $g(I) > 1$. If $\theta(I)$ is bounded from above, we must have $\lim_{I \to +\infty} \frac{\theta(I)}{I} = 0$. Otherwise, as I goes to infinity, $\theta(I)$ also goes to infinity. In this case, L'Hospital's rule can be applied to $g(I)$:

$$\lim_{I \to +\infty} \frac{\theta(I)}{I} = \lim_{I \to +\infty} \frac{\theta^{'}(I)}{1} = 0$$

as $\lim_{I \to +\infty} \theta^{'}(I) = 0$. This proves that $g(I) > 1$ when I is sufficiently small and $\lim_{I \to +\infty} g(I) = 0$. In addition, $g(I)$ is a continuous and strictly decreasing function. Thus, based on the intermediate value theorem, there exists a unique $\tilde{I} > 0$ such that $g(\tilde{I}) = \frac{\theta(\tilde{I})}{\tilde{I}} = \lambda$. ■

A low-type firm with I faces the following profit maximization problem:

$$\max_{K_l, L, R} A_l K_l^{\alpha_l} L^{\beta_l} R^{\gamma} - c_{K_l} K_l - c_L L - c_R R \tag{A1}$$

subject to

$$c_{K_l} K_l + c_L L + c_R R \leq I,$$

and a high-type firm with I faces the following profit maximization problem:

$$\max_{K_h, L, R} A_h K_h^{\alpha_h} L^{\beta_h} R^{\gamma} - c_{K_h} K_h - c_L L - c_R R - \theta(I) \tag{A2}$$

subject to

$$c_{K_h} K_h + c_L L + c_R R \leq I - \theta(I).$$

In the profit maximization problems (A1) and (A2) above, c_i is the relative price of production factor i,

$i \in \{K_h, K_l, L, R\}$, with the price of the final good normalized to 1. Presumably, c_{K_h} may be greater than c_{K_l}, but this is not important for our results and we do not need to assume it. The VAT reform will only affect c_{K_h} and c_{K_l}.[2]

The first-order conditions of this maximization problem (A1) are

$$\alpha_l A_l K_l^{\alpha_l - 1} L^{\beta} R^{\gamma} - (1+\mu)c_{K_l} = 0,$$
$$\beta_l A_l K_l^{\alpha_l} L^{\beta_l - 1} R^{\gamma} - (1+\mu)c_L = 0,$$
$$\gamma A_l K_l^{\alpha_l} L^{\beta_l} R^{\gamma - 1} - (1+\mu)c_R = 0,$$

and

$$c_{K_l} K_l + c_L L + c_R R - I = 0.$$

Combining the four first-order conditions above, we have the optimal choices of firms:

$$(K_l^*, L^*, R^*) = \left(\frac{\alpha_l I}{c_{K_l}}, \frac{\beta_l I}{c_L}, \frac{\gamma I}{c_R}\right).$$

The optimal profit of a low-type firm is

$$\pi_l = A_l \left(\frac{\alpha_l I}{c_{K_l}}\right)^{\alpha_l} \left(\frac{\beta_l I}{c_L}\right)^{\beta_l} \left(\frac{\gamma I}{c_R}\right)^{\gamma} - I. \quad \text{(A3)}$$

If $I \geq \theta(I)$, similar to the solution to (A1), we derive the optimal choices of the three types of inputs in (A2):

$$(K_h^*, L^*, R^*) = \left(\frac{\alpha_h(I-\theta(I))}{c_{K_h}}, \frac{\beta_h(I-\theta(I))}{c_L}, \frac{\gamma(I-\theta(I))}{c_R}\right).$$

In this case, the optimal profit of a high-type firm is

$$\pi_h = A_h \left(\frac{\alpha_h(I-\theta(I))}{c_{K_h}}\right)^{\alpha_h} \left(\frac{\beta_h(I-\theta(I))}{c_L}\right)^{\beta_h} \left(\frac{\gamma(I-\theta(I))}{c_R}\right)^{\gamma} - I. \quad \text{(A4)}$$

If $I < \theta(I)$, the firm cannot afford to be a high-type firm.

So far, we make no assumptions about the relationship between a firm's type and its financial constraint I. Our next two assumptions will imply that low-type firms must also be more financially constrained.

Assumption 1. *Each firm compares the profits in equations (A3) and (A4) (if possible) and chooses the type with higher profits.*

[2] Some studies find that fixed asset prices will change after certain tax reforms (see, for example, Goolsbee, 1998). This change will not affect our results qualitatively.

Assumption 2. $A_l \left(\frac{\alpha_l}{c_{K_l}}\right)^{\alpha_l} \left(\frac{\beta_l}{c_L}\right)^{\beta_l} < A_h \left(\frac{\alpha_h}{c_{K_h}}\right)^{\alpha_h} \left(\frac{\beta_h}{c_L}\right)^{\beta_h}$.

The first assumption is straightforward: a firm can compare the profits of being a high-type firm with those of being a low-type firm and decide which type it wants to be. As $\alpha_h + \beta_h + \gamma = \alpha_l + \beta_l + \gamma$, the second assumption is equivalent to

$$A_l \left(\frac{\alpha_l I}{c_{K_l}}\right)^{\alpha_l} \left(\frac{\beta_l I}{c_L}\right)^{\beta_l} \left(\frac{\gamma I}{c_R}\right)^{\gamma} < A_h \left(\frac{\alpha_h I}{c_{K_h}}\right)^{\alpha_h} \left(\frac{\beta_h I}{c_L}\right)^{\beta_h} \left(\frac{\gamma I}{c_R}\right)^{\gamma}. \tag{A5}$$

Note that the left-hand side of (A5) represents the profits of being a low-type firm, while the right-hand side of (A5) represents the profits of being a high-type firm if the additional operating costs were zero ($\theta(I) = 0$). Thus, the second assumption means that without the additional operating costs, a firm prefers to be a high-type firm.

The two terms in Assumption 2 will become useful soon. Let us define $\phi_l \coloneqq A_l \left(\frac{\alpha_l}{c_{K_l}}\right)^{\alpha_l} \left(\frac{\beta_l}{c_L}\right)^{\beta_l}$ and $\phi_h := A_h \left(\frac{\alpha_h}{c_{K_h}}\right)^{\alpha_h} \left(\frac{\beta_h}{c_L}\right)^{\beta_h}$.

Lemma 2. *Let I^* be the unique solution to $I^* = \frac{\phi_h}{\phi_h - \phi_l}\theta(I)$. Thus, (a) if $I < I^*$, the firm must be a low-type firm, (b) if $I > I^*$, the firm must be a high-type firm, and (c) if $I = I^*$, the firm is indifferent to being of either type.*

Proof. According to Assumption 1, every firm compares π_l and π_h, then becomes the type with the highest profits. As we have

$$\frac{\pi_h}{\pi_l} = \frac{\phi_h(I-\theta(I))}{\phi_l I} = \frac{\phi_h}{\phi_l} - \frac{\phi_h}{\phi_l}\frac{\theta(I)}{I},$$

we can see that when $I = \frac{\phi_h}{\phi_h - \phi_l}\theta(I)$, $\pi_h = \pi_l$. Based on Assumption 2, $\phi_h > \phi_l$, thus $\frac{\phi_h - \phi_l}{\phi_h} \in (0, 1)$. According to Lemma 1, $I = \frac{\phi_h}{\phi_h - \phi_l}\theta(I)$ has a unique solution, denoted by I^*. Moreover, as $\left(\frac{\phi_h}{\phi_l} - \frac{\phi_h}{\phi_l}\frac{\theta(I)}{I}\right)' > 0$, if $I \leq I^*$, $\pi_h \leq \pi_l$ and the firm chooses to be a low-type firm, and vice versa. ■

The intuition behind this lemma is simple. For a firm with a low I, $I - \theta(I)$ may be too low for the firm to purchase enough production factors, thus the firm prefers to be a low-type firm. For example, remember that our assumptions allow the additional operating costs $\theta(I)$ to be constant. In this case, firms with a low I cannot even afford $\theta(I)$. In contrast, because $\lim_{I \to +\infty} \theta'(I) = 0$, $\theta(I)$ is negligible for a firm with a high I, in which case Assumption 2 follows: the firm prefers to be a high-type firm.

Finally, the VAT reform reduces c_{K_j} to τc_{K_j} with $0 < \tau < 1$, $j \in \{h, l\}$.[3] The proposition below summarizes how the VAT reform affects innovation in firms with different financial constraints non-monotonically.

Proposition 1. *Let* I^{**} *be the unique solution to* $I = \frac{\phi_h}{\phi_h - \phi_l \tau^{\alpha_h - \alpha_l}} \theta(I)$. *Thus,* $I^{**} < I^*$. *Moreover,*

a) *before and after the VAT reform, a firm with* $I > I^*$ *will be a high-type firm, a firm with* $I < I^{**}$ *will be a low-type firm, and their profit maximization* R *will not change; and*
b) *a firm with* $I^{**} < I < I^*$ *will be a low-type firm before the VAT reform and a high-type firm after, and its profit maximization* R *decreases.*

Proposition 1 implies that after the VAT reform, profit maximization R decreases slightly for every firm. Part (b) of Proposition 1 suggests that all firms with an intermediate level of financial constraints switch from low type to high type after the VAT reform. Firms with loose financial constraints or tight financial constraints do not change their type. The intuition is explained in Section 3.

The next proposition shows how firms facing different financial constraints are affected differently by the VAT reform in terms of optimal decisions on labor and fixed assets. The intuition again can be found in Section 3.

Proposition 2. *After the VAT reform, (a) for any firm with* $I > I^*$ *or* $I < I^{**}$, *profit maximization* L *and fixed asset expenditure do not change, and (b) for any firm with* $I^{**} < I < I^*$, *profit maximization* L *decreases, and if* $\frac{\alpha_l}{\alpha_h} \leq \frac{\phi_l}{\phi_h} \tau^{\alpha_h - \alpha_l}$, *fixed asset expenditure increases.*

Proof of Propositions 1 and 2. The VAT reform reduces c_{K_j} to τc_{K_j} with $0 < \tau < 1$, $j \in \{h, l\}$. In this case,

$$\frac{\pi_h}{\pi_l} = \frac{\phi_h (I - \theta(I))}{\tau^{\alpha_h - \alpha_l} \phi_l I}.$$

[3] According to the details of the VAT reform, it may reduce the costs of high-type fixed assets more significantly. However, this will only reinforce our findings.

Let I^{**} be the unique solution to $I = \frac{\phi_h}{\phi_h - \phi_l \tau^{\alpha_h - \alpha_l}} \theta(I)$. We can see that after the VAT reform, when $I = I^{**}$, $\pi_h = \pi_l$. As τ is less than one, $\frac{\phi_h - \phi_l \tau^{\alpha_h - \alpha_l}}{\phi_h} > \frac{\phi_h - \phi_l}{\phi_h}$. In addition, because $g(I) = \frac{\theta(I)}{I}$ is continuous and decreasing, $I^{**} < I^*$.

In Lemma 2, we prove that before the VAT reform, a firm is considered a high-type firm if $I > I^*$. As $\frac{\pi_h}{\pi_l}\Big|_{I=I^*} = \frac{\phi_h(I^* - \theta(I^*))}{\tau^{\alpha_h - \alpha_l}\phi_l I^*} = \frac{\phi_h}{\tau^{\alpha_h - \alpha_l}\phi_l}\left(1 - \frac{\theta(I^*)}{I^*}\right) > \frac{\phi_h}{\phi_l}\left(1 - \frac{\theta(I^*)}{I^*}\right) = 1$, every firm with $I > I^*$ remains a high-type firm after the VAT reform. Therefore, before and after the VAT reform, profit maximization L and R and fixed asset expenditure do not change.

Similarly, every firm with $I < I^*$ is considered a low-type firm before the VAT reform. If $I < I^{**}$, the firm will still be a low-type firm after the VAT reform. Profit maximization L and R and fixed asset expenditure do not change before and after the VAT reform.

However, every firm with $I^{**} < I < I^*$ switches from low type to high type after the VAT reform. Profit maximization L will decrease from $\frac{\beta_l I}{c_L}$ to $\frac{\beta_h(I - \theta(I))}{c_L}$. Similarly, profit maximization R will decrease from $\frac{\gamma I}{c_R}$ to $\frac{\gamma(I - \theta(I))}{c_R}$. The profit maximization of fixed asset expenditure will change from $\alpha_l I$ to $\alpha_h(I - \theta(I))$. Thus, if $I^{**} \geq \frac{\alpha_h}{\alpha_h - \alpha_l}\theta(I^{**})$, as $\frac{\theta(I)}{I}$ is decreasing, the fixed asset expenditure of every firm with $I^{**} < I < I^*$ increases. That is, we will observe that fixed asset expenditure increases if $\frac{\alpha_l}{\alpha_h} \leq \frac{\phi_l}{\phi_h}\tau^{\alpha_h - \alpha_l}$. ■

Next, we discuss the implications of our model for firms' total factor productivity and innovation expenditure per employee. In terms of total factor productivity, according to how it is measured in previous empirical studies, we should examine $A_h R^\gamma$ for high-type firms and $A_l R^\gamma$ for low-type firms. Innovation expenditure per employee can be measured by $c_R R/L$. The result below identifies the conditions under which firms' total factor productivity and innovation expenditure per employee increase.

Proposition 3. *After the VAT reform, (a) for any firm with* $I > I^*$ *or* $I < I^{**}$, $c_R R/L$ *and total factor productivity do not change, and (b) for any firm with* $I^{**} < I < I^*$, $c_R R/L$ *increases, and if* $\left(\frac{A_l}{A_h}\right)^{1/\gamma} \leq \frac{\phi_l}{\phi_h}\tau^{\alpha_h - \alpha_l}$, *total factor productivity increases.*

Proof. For any firm with $I > I^*$ or $I < I^{**}$, its type does not change after the VAT reform, so the optimal choices for R, L, and total factor productivity do not change.

For any firm with $I^{**} < I < I^*$, it will switch from low type to high type after the VAT reform. When the firm produces as a low-type firm, $c_R R/L$ is equal to $c_L \gamma/\beta_l$. After the VAT reform, it produces as a high-type firm, thus $c_R R/L$ is equal to $c_L \gamma/\beta_h$. Because $\beta_l > \beta_h$, innovation expenditure per employee increases.

The total factor productivity of a firm is equal to $A_j R^\gamma$, $j \in \{h, l\}$. We have

$$\frac{TFP_h}{TFP_l} = \frac{A_h\big(I-\theta(I)\big)^\gamma}{A_l I^\gamma} > 1$$

if TFP_h is greater than TFP_l. As proven in Proposition 1, the firm switches its type if $I^{**} < I < I^*$. Because $\frac{\theta(I)}{I}$ is decreasing, a sufficient condition for the increase in total factor productivity for firms with $I^{**} < I < I^*$ after the VAT reform is $\frac{A_h(I^{**}-\theta(I^{**}))^\gamma}{A_l I^{**\gamma}} > 1$. That is, $\left(\frac{A_l}{A_h}\right)^{1/\gamma} \le \frac{\phi_l}{\phi_h}\tau^{\alpha_h-\alpha_l}$. ■

Proposition 3 rationalizes the empirical results of Liu and Mao (2019) and Cai and Harrison (forthcoming). Liu and Mao (2019) find that the VAT reform increases total factor productivity by improving R&D expenditure per employee, while Cai and Harrison (forthcoming) show no significant increase in productivity. The firms in the sample of these two studies come from different datasets at different times, thus they show different responses to the VAT reform. However, their findings can be simultaneously rationalized in our framework.

Appendix 2: Definitions of the Variables

Variable	Definition
Measures of innovation	
Pat	Total number of patent applications filed (and eventually granted by the CNIPA) by a firm in a given year.
Pat_inv_utl	The sum of the number of invention patent and utility model patent applications filed (and eventually granted by the CNIPA) by a firm in a given year.
Pat_des	The number of design patent applications filed (and eventually granted by the CNIPA) by a firm in a given year.
Pat_stock	Patent stock is the total number of patent applications filed (and eventually granted by the CNIPA) by a firm in a given year, plus patent history with a 15% depreciation.
WIPO patents	Total number of patent applications filed (and eventually granted by WIPO) by a firm in a given year.
LnR&D	The logarithm of one plus the R&D expenditure adjusted by the 1998 price index.
R&D/Assets	R&D expenditure in a given year divided by lagged total assets (adjusted by the Consumer Price Index).
R&D/Sales	R&D expenditure in a given year divided by lagged total sales (adjusted by the Consumer Price Index).
Patent value /Firm size (thousands)	Total value of patents standardized by firm size, proxied by the book value of assets of the firm (in thousands of renminbi). Following Kogan et al. (2017), the total value of all patents is calculated by adding the estimated value of all patents filed by Chinese firms in a given year and granted by the CNIPA. The value of a patent is measured by the excess stock market return around the 3-day period of the patent announcement related to innovation.
Other Variables	
Post2004	A dummy variable equal to one for the 2005–2007 period and zero for the 2001–2004 period.
NE	An indicator equal to one for the three provinces in the northeastern part of China (Heilongjiang, Jilin, and Liaoning), and zero otherwise.
Eind	An indicator equal to one for the six broadly defined industries targeted by the reform, and zero otherwise.
ln(Total Wage)	The logarithm of total wages (in thousands of renminbi), adjusted by the 1998 Consumer Price Index, for a firm in a given year.
Fixed investment ratio	Gross fixed asset investment in a given year normalized by the lagged net fixed asset stock.
Assets (in millions)	Total assets of a firm adjusted by the 1998 price index (in millions of renminbi).
Firm Age (years)	Firm age, defined by subtracting the year of creation from the survey year.
ROA	Return on assets, defined as operating income divided by the book value of total assets.
Foreign Share	The proportion of capital owned by foreign investors in the total paid-in capital.
State Share	The proportion of capital owned by the state in the total paid-in capital.

SA index	The SA index given by $-0.737 * Size + 0.043 * Size^2 - 0.040 * Age$, where $Size$ is the logarithm of the inflation-adjusted book value of assets, and Age is firm age, defined by subtracting the year of creation from the observation year.
Cash flow ratio	Cash flow divided by total assets.

Appendix 3: Propensity Score Matching Regression

First, we estimate a logit model to ensure that the covariates we use are valid determinants of the pilot VAT reform, using the pre-reform mean (2001–2004) of the relevant observables. Specifically, our propensity score model includes the dependent variable, $NE * Eind$, which is a dummy variable equal to one if the firm belongs to the eligible industries in the three northeastern provinces.

According to the official policy document,[4] the 2004 VAT reform is designed to facilitate the modernization of firms lagging behind in terms of development and thus lacking economic vitality. In addition, Cai and Harrison (forthcoming) document that the affected firms are younger and larger than other firms and have less foreign ownership, more state ownership, and lower profitability. Thus, we choose the following matching covariates: 2-digit industry fixed effects, firm size ($LnAssets$), profitability (ROA), firm age ($Firm\ Age$), state ownership ($State\ Share$), and foreign ownership ($Foreign\ Share$). Detailed definitions of all of the covariates are given in Appendix 2. The logit model is estimated with 124,611 firms with no missing data for all covariates before 2004, to ensure that the covariates capture the determinants of the VAT policy treatment. The results of the logit model are presented in Table A3 below, showing that the model captures a significant amount of variation in the selection variables, as indicated by a p-value less than 1% from the Chi-square test of the overall model fitness. Specifically, we find that larger and less profitable firms are more likely to be eligible firms. In addition, if firms are younger, they are more likely to be selected for the policy treatment. In terms of ownership, firms with a higher proportion of state ownership and a lower proportion of foreign ownership tend to be selected for the pilot reform.

Then, we use the propensity scores estimated by the logit regression and implement a one-to-three nearest neighbor matching with replacement to construct a control group.[5] That is, for each eligible firm, we match it with three control firms with the closest propensity score. Appendix 4 presents the difference between the treatment group and the control group in terms of firm characteristics after matching to gauge the quality of the matching procedure. The results suggest that for most firm characteristics, there is no significant difference between the two groups. The matching process eliminates the major differences between these two groups.

[4] See "Advocates of the Chinese Communist Party Central Committee and State Council for the Implementation of Strategies to Revitalize the Old Industrial Base of the Northeastern Region," October 5, 2003. For more information, see: http://www.chinalawedu.com/falvfagui/fg22016/873.shtml (accessed September 12, 2019).

[5] Because the number of ineligible firms significantly exceeds the number of eligible firms.

Table A3. Logit for Propensity Score Matching.

Dependent variable	$NE \times Eind$
LnAssets	0.0969
	(0.0098)
FirmAge	-0.0030
	(0.0014)
ROA	-1.9013
	(0.1399)
Foreign Share	-0.3707
	(0.0430)
State Share	0.6518
	(0.0532)
Constant	-3.0432
	(0.0980)
Industry FE	Yes
Observations	124,611
Pseudo R-squared	0.047
p-value for Chi2	0.000

Note: This table presents the major determinants of the implementation of the 2004 VAT reform using a logit model. The dependent variable is $NE \times Eind$, a dummy variable equal to one if the firm is located in the three northeastern provinces of China and belongs to the eligible industries, and zero otherwise. The logit regression is run at the firm level and all covariates included in the regression are the mean value of the firm characteristics, as reported during the pre-reform period (2001–2004). The model is used to generate the propensity scores for matching. Detailed definitions of all of the control variables are given in Appendix 2. Robust standard errors are clustered at the firm level and reported in brackets.

Appendix 4: Balanced Tests for Propensity Score Matching.

	Pre-match			Post-match	
	Treated	Control	Difference	Control	Difference
	(1)	(2)	(3)	(4)	(5)
LnAssets	9.7897	9.5505	-0.2392	9.8014	0.0117
			(0.000)		(0.625)
Firm Age	8.5986	7.1790	-1.4196	8.5886	-0.0100
			(0.000)		(0.957)
ROA	0.03428	0.0553	0.0210	0.0348	0.0005
			(0.000)		(0.736)
Foreign Share	0.1317	0.1904	0.0587	0.1333	0.0016
			(0.000)		(0.753)
State Share	0.1094	0.0481	-0.0613	0.1031	-0.0063
			(0.000)		(0.174)

Note: This table presents the results of the comparison of the characteristics used to match the firms in the treatment group and the control group, before and after matching. The standard errors of the comparison of means tests are reported in brackets.

Appendix 5: Heterogeneity Based on Financial Constraints with Interaction Terms.

Dependent variable	$\ln(1+Pat_{t+1})$	
Proxies for financial constraints	Firm Size	Cash Flow Ratio
	(1)	(2)
NE*Eind*Post2004*Intermediate	-0.0120	-0.0170
	(0.0062)	(0.0089)
NE*Eind*Post2004*Loose	-0.0023	-0.0135
	(0.0088)	(0.0098)
NE*Eind*Post2004	-0.0029	0.0016
	(0.0039)	(0.0067)
Post2004*Intermediate	0.0022	0.0032
	(0.0017)	(0.0025)
NE*Post2004*Intermediate	0.0063	0.0060
	(0.0054)	(0.0073)
Post2004*Eind*Intermediate	0.0038	0.0040
	(0.0019)	(0.0029)
Post2004*Loose	0.0185	0.0058
	(0.0030)	(0.0027)
NE*Post2004*Loose	-0.0196	0.0024
	(0.0071)	(0.0082)
Post2004*Eind*Loose	0.0134	0.0047
	(0.0034)	(0.0032)
Firm FE	Yes	Yes
Year-province FE	Yes	Yes
Year-industry FE	Yes	Yes
Observations	722,855	722,855
R-squared	0.534	0.533
N (affected group)	7,044	7,044
N (control group)	144,006	144,006
Mean of dep. var.	0.0393	0.0393
Std. dev. of dep. var.	0.2338	0.2338

Note: This table provides evidence of the heterogeneous effects of the 2004 VAT reform on firm innovation based on financial constraints, using two alternative measures of financial constraints: the cash flow ratio and total assets. The average financial constraints measured during the pre-reform period are used to divide our sample into deciles and compare the bottom three, the middle four, and the top three deciles. $Intermediate$ and $Loose$ are two dummy variables based on each measure of financial constraints to identify firms with intermediate-level and loose financial constraints, respectively. Taking firm size as an example, $Intermediate$ is equal to one for firms belonging to the middle four deciles when the firms in the sample are divided based on total assets, and zero otherwise. $Loose$ is equal to one for firms belonging to the top three deciles when the firms in the sample are divided based on total assets, and zero otherwise. Standard errors (in brackets) are clustered at the firm level in all regressions.