Can Investment Incentives Crowd Out Innovation? Evidence from China

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Abstract

We analyze the spillover effects of fixed asset investment tax credits on firms' innovation. We estimate the effects by exploring the value-added tax reform in China in 2004. The difference-in-difference-in-differences (DDD) estimation results show that the reform significantly reduces firms' 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. Similar non-monotonic effects also appear in other firm decisions, such as the labor input. Since innovation is an important economic growth engine, our findings suggest that fiscal investment incentive policy may generate unintended consequences.

JEL Classification: 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 the core of economic policies. Economists and policy makers have long recognized that investment and innovation are both crucial driving forces of economic growth. Therefore, many fiscal policies implemented around the world have been designed to encourage firms to invest more or/and conduct more innovation activities (e.g., Hall and Jorgenson, 1967; Bloom, et al., 2002; Zwick and Mahon, 2017; and Guceri and Liu, 2019). In this paper, we document a crowding-out effect—investment tax incentives may generate unintended reduction of firms' innovation. Moreover, the effect is non-monotonic in the level of financial constraints.

In particular, we investigate the effects of a 2004 value-added tax (VAT) reform in China aimed to stimulate firms' fixed asset investment on firms' innovation. Over the last 20 years China experienced rapid economic growth, which is widely believed to be driven by large amounts of investment.[1] Indeed, the Chinese government has been using strong fiscal stimulus to encourage investment. One important stimulus is the VAT reform in 2004. It was introduced to avoid double taxation due to the previous policy and to mitigate firms' tax burden. It was intended to encourage firm investment in fixed assets, especially machines and equipment.

We propose a model to analyze the impact of investment tax credits. We assume that firms have heterogeneous production technologies and financial constraints, and can choose to upgrade their technologies, but advanced technologies are associated with additional operating costs. Because the VAT reform reduces the costs of fixed assets, upgrading to the capital-intensive advanced technology becomes more appealing. Nonetheless, not all firms prefer to upgrade. Firms with tight financial constraints will not find upgrading beneficial, because the additional costs associated with advanced technologies leave them insufficient funds for production. Firms with loose financial constraints can afford advanced technologies whether there is any cost reduction from the reform. In contrast, firms with intermediate-level financial constraints will take advantage of the VAT reform to upgrade. To afford the additional operating cost associated with advanced technologies, however, innovation will be crowded out. In addition to this non-monotonic crowding-out effect on innovation, our model also provides predictions about how the VAT reform affects fixed asset investment and labor inputs and offers a unified explanation for previous empirical findings including Liu and Lu (2015); Zhang, et al.

[1] For example, the July 6, 2011, 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 existed for many years and was likely to continue for at least another two years.

(2018); Cai and Harrison (forthcoming); and Liu and Mao (2019).

We empirically examine the effects of the 2004 VAT reform on firms' innovation. The reform targeted firms in six industries located in three northeastern provinces in China, which allows us to exploit the difference-in-difference-in-differences (DDD) estimation for identification. Using the number of patents as the primary measure of innovation activities, we find that the VAT reform has significant negative effects on firms' 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 the intermediate level of financial constraints. The result is robust to the alternative measures of financial constraints.

We conduct a battery of robustness checks to justify our main results. We first preclude other explanations for the crowding-out effects of the VAT reform on innovation, such as removing the Multifiber Arrangement and implementing the environmental policies. We find that the non-monotonic impacts (in the level of financial constraints) of the VAT reform cannot be explained by different behaviors of firms during different lifecycle stages. Second, we test the validity of our identification: (1) we show that there is no difference in pre-existing time trends of the outcome variable between the affected and unaffected firms; (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 effects, 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 entries/exits drives our main results. Third, we find that our results are robust to the alternative samples and innovation measures. Fourth, we address the concern on the quality of patents in China by using the information on the patents applied by Chinese firms but granted by the World Intellectual Property Organization (WIPO).

Finally, we show that the non-monotonic effects of the reform are not limited to innovation—firms' labor expenditure is also non-monotonically (in 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 insignificant, consistent with our model's prediction that the effect of the reform on fixed asset expenditure depends on the parameters of firms' production functions. Specifically, as a firm upgrades its technology, the crowding-out effect on the expenditure of fixed assets due to the additional operating cost and the increase in capital intensity may coexist, but act in opposite directions.

Our paper makes three contributions. Our paper contributes to the literature on the effects of tax credits. Both investment tax credits and R&D tax credits are commonly used. Previous studies (e.g., Hall and Jorgenson, 1967; Abel, 1982; Brock, 1988; Sen and Turnovsky, 1990; Goolsbee, 1998; House and Shapiro, 2008; and Zwick and Mahon, 2017) examining the investment tax credit focus mainly on its direct effect on firms' investment. While other studies examine the direct effect of R&D subsidies on firms' R&D expenditures (e.g., Hall and Van Reenen, 2000; Bloom, et al., 2002; Agrawal, et al., 2014; Thomson, 2017; Dechezleprêtre, et al., 2016; Rao, 2016; Chen, et al., 2018; and Guceri and Liu, 2019). Our paper adds to the literature by examining the spillover effects of investment tax credits on firms' innovation.

Second, this paper contributes to the literature on the role of financial constraints in affecting firms' 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), and thus, tax reforms may differently affect firm investment when firms face different financial constraints. Tax reforms may increase firm investment by relaxing financial constraints. For example, Cai, et al. (2018) examine the impacts of corporate income taxes on firm innovation by exploiting a tax collection reform, which increases firms' after-tax profits and alleviates firms' financial constraints. Zwick and Mahon (2017) study the impact of the tax policy on firms' investment behavior. They show that the impact of fiscal incentives on investment is stronger on firms with tighter financial constraints. Liu and Mao (2019) also find that financial constraints would strengthen the effects of the VAT reforms on firms' investment in fixed assets. Our study focuses on a tax reform that affects the relative cost of capital. We add to this literature by highlighting that the impacts of investment tax credits on firms' innovation and other activities are non-monotonic in firms' financial constraint levels.

Finally, this paper belongs to the literature examining the impacts of the VAT reforms in China. Zhang, et al. (2018) find that the 2004 VAT reform increases eligible firms' fixed investment. Cai and Harrison (forthcoming) show that the 2004 VAT reform induces eligible firms to reduce their employment and therefore become more capital-intensive. Liu and Mao (2019) focus on the VAT reforms during the period of 2005–2009, showing that those reforms increase eligible firms' R&D expenditure per employee. We contribute to this literature by focusing on a different variable, innovation. Our results highlight the non-monotonic nature of the effects by financial constraints that is previously unrecognized. Moreover, our model provides a unified framework to synthesize the existing empirical findings about the effect of the VAT reform.

The rest of this paper is organized as follows: Section 2 introduces the 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 presents the empirical results, with results from robustness checks in Section 7. Section 8 examines the reform's impacts on firms' outcomes other than innovation, and Section 9 concludes.

2. Institutional Background of the 2004 VAT Reform in China

The VAT has been widely adopted by more than 130 countries around the world. It is a tax that is charged on the added value at each stage of production, transaction, and labor services. It is the difference between gross sales and the value of intermediate purchases.[2] China adopted the VAT in 1994; it specified that some intermediate purchases (excluding fixed assets) could be deducted from the gross sales for the current period when the VAT was levied.[3] When the VAT was adopted, the government believed that the economy was overheating; it discouraged investment by requiring that firms' cost of fixed assets were not deductible from sales revenues when calculating the VAT liabilities. Under this policy, fixed assets were taxed twice—on fixed asset producers as their sales products and on fixed asset buyers. The VAT was the most important tax source in China over the period from 1994 to 2004 and accounted for 35% to 45% of national tax revenue.[4] A decade later, the government believed that economic overheating had been reversed and wanted to encourage production automation and technology improvement (e.g., Liu and Lu, 2015). Fiscal revenues also had increased since 1994.[5] Therefore, the original VAT policy was considered unsuitable.

In September, 2004, the Chinese government enacted the VAT reform pilot by allowing firms in six industries located in three northeastern provinces (Heilongjiang, Jilin, and Liaoning) to deduct fixed asset costs (excluding real estate assets) from sales revenue when calculating the VAT liabilities.[6] The definition of eligible industries is based on the Chinese Industrial Classification (CIC) code.[7] The six

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

[3] For a period, if the output tax, which is equal to sales amount times the VAT tax rate, is less than the input tax, which is equal to purchasing price times the VAT tax rate, the excess input tax could be carried forward for set-off in the following periods. For more information, see the website of 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 VAT payment was levied by the central government after the reform in 1994. In 1994, mainland China implemented a tax sharing reform. The reform determines the distribution rule of tax income between local and central government based on the type of taxes.

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

[7] 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 we used in this study. We adjust all firm industry codes to the new classification codes because

eligible industries include: (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) ship building.[13] The 2004 VAT reform pilot program applied to any transactions completed after July 1, 2004. The deduction is based on machines' one-time purchase prices rather than their yearly depreciation.

After the VAT reform, the cost of investment in fixed assets was reduced substantially. VAT deductions include the following categories: (1) the purchase of fixed assets (including donations and physical investment); (2) the material and labor costs to manufacture, modify, or install fixed assets; (3) fixed assets acquired through lease if the lessor paid the VAT following regulations; and (4) the cost related to transportation of fixed asset purchase.

The 2004 VAT reform was one of the preferential policies implemented by the government to revitalize the old industrial base of the northeastern region of China.[14] The northeastern region with a large proportion of SOEs, was the center of China's heavy industries, which had grown up since 1950s during the planned economy period. Since the late 1970's, with the rapid technology advancement and economic transition to a market system, the old industrial base experienced a long-term absence of investments to upgrade technology and adjust SOE structure; therefore, the region suffered declines in the old, traditional economy and lagged behind the coastal areas with more new, privately-owned firms. Under these circumstances, investment tax credits were designed to facilitate eligible firms' adoption of new technologies by alleviating their tax burden and reducing the cost of machinery investment.

In 2007, the VAT reform expanded to another 26 cities in six provinces located in central China,[15]

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the eligible industries of the 2004 VAT reform were defined based on the new classification system.

[8] 2-Digit (3-digit) industries in equipment manufacturing consist of Ordinary machinery manufacturing (35); Special equipment manufacturing (36); Railway transport equipment manufacturing (371); Aerospace and aeronautic equipment manufacturing (376); Other transportation equipment manufacturing (379); Electric machines and apparatuses manufacturing (39); Computer and communication equipment manufacturing (40); and Instruments, cultural and office machinery manufacturing (41).

[9] 2-Digit (3-digit) industries in automobile manufacturing consist of Automobile manufacturing (372).

[10] 2-Digit (3-digit) industries in petroleum, chemical, and pharmaceutical manufacturing consist of Refined petroleum products (251); Nuclear fuel processing (253); Raw chemical materials and chemical products (26); Medical and pharmaceutical products (27); Chemical fibers (28); Rubber products (29); and Plastic products (30).

[11] 2-Digit (3-digit) industries in agricultural product processing consist of Smelting and pressing of ferrous metals (32) and Smelting and pressing of nonferrous metals (33).

[12] 2-Digit (3-digit) industries in metallurgy consist of Agricultural and by-product processing (13); Food production (14); Beverage production (15); Textiles (17); Garments 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 work and other manufacturing (42).

[13] 2-Digit (3-digit) industries in ship building consist of 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 of the information, see the website: http://www.chinalawedu.com/falvfagui/fg22016/873.shtml (accessed by Sep 12, 2019).

[15] In addition to the affected industries in 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 consist of Mining (06, 08, 09, 10, and 11) and Electricity (441 and 442). For more details of the 2007 VAT reform, see the website of State Taxation Administration of China:

and finally to all industries countrywide in early 2009.[16]

3. A Motivating Theory

In this section, we discuss a simple model that helps us analyze the effect of the VAT reform, or more generally, investment tax credits. Our empirical analyses follow the findings of the model. The details of the model are provided in Appendix 1.

The VAT reform lowers the price of machines and equipment, which affects firms with different percentages of machines and equipment differently. Therefore, we consider a stylized model with two types of firms that maximize profits, given the price of output and the prices of factors of production.

As a classic benchmark, without innovation, assume that a firm's production function takes the Cobb–Douglas form, $AK^{\alpha}L^{\beta}$, in which A captures the firm's technology, K represents fixed assets affected by the VAT reform, and L represents labor. For simplicity, from here on, fixed assets refer to only machines, equipment, and other non-structural assets affected by the VAT reform. Assume that innovation, denoted by R, increases the firm's output via 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, assume that $\tilde{A}(R)$ is a power function, so that the production function is Cobb–Douglas.

Firms with higher percentages of machines and equipment often have better technologies (see, for example, Wolff, 1991, and Midrigan and Xu, 2014). Therefore, we assume that a high-type firm has higher 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 machines than low-type production, but the per-unit cost also depends on how one unit is defined, for example. In any case, this does not affect our results and we simply allow the two types to have potentially different per-unit cost of fixed assets. A more important assumption is that to be a high-type firm, some additional operating cost must be incurred, such as the cost of training workers; purchasing more suitable but expensive software; and additional construction and managerial costs in high-type manufacturing

http://www.chinatax.gov.cn//n810341/n810765/n812176/n812783/c1194518/content.html (accessed May 11, 2019).

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

procedures, operation, organization, and quality control (see Teece, 1977, and Acemoglu and Finkelstein, 2008, among others).[17]

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

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

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

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

Result 1. *There exist two cutoffs $I^{**} < I^*$. Before and after the VAT reform, a firm with $I > I^*$ is high-type, a firm with $I < I^{**}$ is low-type, and none of these firms changes its optimal innovation. A firm with $I^{**} < I < I^*$ is low-type before the VAT reform and becomes high-type after, and its optimal innovation reduces after the VAT reform.*

After the VAT reform lowers the relative price of fixed assets, firms with the intermediate level of financial constraints switch from low-type to high-type. Since high-type firms have higher percentages of fixed assets, the VAT reform makes being high-type less costly. However, after they become

[17] The role of additional operating cost has been studied in Hopenhayn (1992), Melitz (2003), Buera, et al. (2011), and Midrigan and Xu (2014), among others. In our model, we do not think of the additional operating cost as some one-time expense incurred only at the time of upgrading. In a more realistic dynamic setting, the technology embedded in high-type fixed assets requires updating and maintenance constantly, and the high-type firms need to pay for the operating cost in every period.

[18] In our model, we assume I to be constant for each firm. In practice, I may change in the long run. If we allow I to change in the long run, the impacts of the reform on firm behaviors including innovation may be different in the long run. However, we do not include the long run effect discussion in our theoretical and empirical analyses, because it is difficult to identify clean long run effects.

high-type, part of their capital must cover the additional operating cost of being high-type, which crowds out innovation.

The heavily financially-constrained firms do not want to become high-type, because if they upgrade and pay for the additional operating cost, they will have little capital left to produce enough output. The financially less-constrained firms, on the other hand, are able to upgrade without the help of the VAT reform. Notice that firms' production functions are Cobb–Douglas. Therefore, firms that do not change types allocate a fixed fraction of capital to fixed assets, labor, and innovation, respectively. Therefore, changing the price of fixed assets has no impact on firms' optimal innovation.

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

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

From Result 1 we know that firms with $I > I^*$ or $I < I^{**}$ do not change their types and therefore do not change the expenditure of labor and fixed assets 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 cost of being high-type. Second, a high-type firm has a lower percentage of labor compared to a low-type firm. How the expenditure of fixed assets 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 cost of being high-type limits the firm's capital available to purchase fixed assets.

Several papers have studied the VAT reform's effects on labor and fixed assets. Result 2 is consistent with the empirical findings in Liu and Lu (2015), Zhang, et al. (2018), Cai and Harrison (forthcoming), and Liu and Mao (2019), although none of them discusses the non-monotonicity of the VAT reform's effects. 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 employment falls and the capital intensity of production increases for the affected firms. 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 those findings in details.

4. Data

4.1 Firm Sample

Our data are taken from the Annual Survey of Industrial Firms (ASIF). The survey is conducted by China's National Bureau of Statistics (NBS). It consists of all state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) with annual sales in excess of five million Renminbi (around 625,000 USD).[19] The data cover the information of firm characteristics and financial balance sheets collected at the end of each calendar year. By the end of 2007, the ASIF collected the information of more than 330,000 firms in manufacturing industries, accounting for around 95% of the nation's industrial output. Thus, it is the most comprehensive firm-level panel dataset of Chinese manufacturing firms and has been widely used in research, including Liu and Lu (2015), Liu and Qiu (2016), and Brandt, et al. (2017). Since the VAT pilot reform took place in 2004, we use a sample from 2001 to 2007, including years before and after the regulatory shock.[20]

To draw a final sample for regressions, we first drop firms where variables have error values, such as zero or negative values, in outputs or sales. Then we exclude firms changing locations or industries during the sample period to avoid the sample selection problem. Next we restrict the firms that are present at least once in each pre- and post-reform period.[21] Finally, similar to Zhang, et al. (2018), we exclude firms located in the 26 cities of central China as well as firms in mining and electricity sectors to eliminate the effect of the VAT reform in 2007. To reduce the effect of outliers, we winsorize all continuous variables at the top and bottom 1% by replacing values above the top 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 years, regions, and industries. In three northeastern provinces, on average, 83.13% of firms are affected by the VAT reform.

[Insert Table 1 Here]

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19 In the period of 2001–2007, the exchange rate between Chinese Renminbi and US dollar was approximately 8 Renminbi/USD.

20 The sample period refers to the period we collect our independent variables. Since we lag our independent variables by one year, we actually use the information of patents applied from 2002 to 2008 for our dependent variables. In a robustness check, we use patent information in year $t+2$ so the data of patents in this test range from 2003 to 2009.

21 The results are robust if we extend the sample to include all firms that appeared in the dataset at least once during the period.

4.2 Innovation Variables

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

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

We use patent data rather than innovation input data, such as R&D expenditures for two reasons. First, Chinese firms have incentives to manipulate accounting information on R&D expenditures to acquire subsidies from the government because some subsidy programs target qualifying high-tech enterprises with high R&D expenditures (e.g., Chen, et al., 2018). Second, R&D expenditures are available in the ASIF Database only for years 2005–2007, and hence are unsuitable in our paper because of the lack of data before the 2004 reform.[25]

Some previous studies have documented that China-granted patents are of lower value compared with the patents granted by international institutions (see, for example, Zhang and Chen, 2012; Dang and Motohashi, 2015; Hu, et al., 2017). In addition, government patent-friendly policies and the weak process of patent examination in China encourage and enable firms to counterfeit patents. Firms do have non-innovation motives for acquiring patents, including building reputation, advertising products, gaining government subsidies or tax benefits, and manipulating firms' market value. Indeed, Hu, et al. (2017) show that the correlation between patents and R&D is weak in China. To address this potential

[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 the given year for two reasons: First, the application year is the year when a firm produces the innovation output, and thus it better captures the actual 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 there are variations in approval time among different patent applications.
[25] Despite the shortcoming of R&D data for the manufacturing firms, we use R&D data during the period 2005–2007 to examine the effect of the 2007 VAT reform as a robustness check. The results are consistent with our main findings.

concern, for one robustness check, we use patents granted by a worldwide organization of the United Nations.

4.3 Summary Statistics

Table 2 presents summary statistics for the key variables used in the paper. Appendix 2 provides variable definitions. All monetary variables are deflated using the provincial Consumer Price Index with 1998 as the base year. Our sample firms apply for 0.049 total patents per year, on average, during the period 2001–2007 ($Pat_{i,t}$), 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 robustness checks. The firm-year patent stock is 0.340, on average, and the number of patents granted by the World Intellectual Property Organization (WIPO) is 0.007, on average. Then, we present the summary statistics of other outcome variables used in our study, such as total wages and fixed investment rate.

In addition, we present the summary statistics of the firm-year level control variables. On average, a firm in our sample has a book value of assets of 58.675 million in 1998 Renminbi, ROA of 0.065, firm age of 10.772, foreign share of 0.187, and state share of 0.056.[26]

[Insert Table 2 Here]

5. Empirical Strategy

The 2004 VAT pilot 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 changes of firms located in different industries; however, some industry level time-varying variables may be correlated with outcome variables and the regressors at the same time, leading to biases in our estimates. In light of this concern, we exploit the fact that the 2004 reform applies only 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:

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

The subscript i indicates firms, t indicates years, j indicates three-digit industries, and p

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26 The mean values of foreign and state ownership in our sample are in line with those in Zhang, et al. (2018) where the state-owned firms and foreign-invested firms account for, on average, 7.01% and 17.45%, respectively.

indicates provinces. The dependent variable $y_{ijp,t+1}$ represents firms' innovation, measured by the logarithm of one plus the number of total patents ($LnPat_{ijp,t+1}$) filed by firm i in year $t+1$ (and eventually granted). Because innovation activities take time—there is a time lag between firms' R&D investment and patent applications—we investigate the impact of the VAT reform on the number of firms' patents filed one year later that were eventually approved (e.g., Hsu, et al., 2014; Liu and Qiu, 2016; and Acharya and Xu, 2017). In the robustness checks, we also repeat our analysis based on the number of firms' patents filed two years later (and eventually granted).

In equation (1), NE_p is an indicator, which is 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, which is equal to one for the six industries targeted by the reform and zero otherwise. $Post2004_t$ is also an indicator, which is equal to one for years 2005–2007 and zero for years 2001–2004.[27] The coefficient of the triple interaction term ($NE_p * Eind_j * Post2004_t$), β, is of main interest. ε_{ijpt} is the error term with mean equal to zero. To address heteroscedasticity and serial correlation, we calculate standard errors by clustering over firms. We also cluster standard errors at the province-industry level as a robustness check and the results are consistent.

Using the DDD strategy allows us to include the full sets of firm fixed effects μ_i, province-year fixed effects γ_{pt}, and industry-year fixed effects τ_{jt}. By doing so, we control for time invariant and time varying provincial characteristics, industrial characteristics, and differences between industries across provinces. Therefore, we do not control for NE_p, $Eind_j$, and $Post2004_t$, separately and the double interactions between them since they are absorbed by the fixed effects mentioned above. Note that some time varying province-industry specific variables still remain, which could lead to bias in our estimates. We address this concern in Sections 6.1 and 7.1.

One pre-assumption for the validity of DDD needs to hold. That is, the difference in the pre-existing time trends of patents for firms in affected and unaffected industries should not be different between northeastern provinces and other parts of China. We address this concern in Section 7.2.

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

6. Empirical Results

6.1 Main Results

Table 3 provides the main results examining the effect of the 2004 VAT reform on firm-level innovation. The dependent variable is the logarithm value of one plus 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 from 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 to unaffected firms, the before-after change of the total number of patents for affected firms is 9.51% lower.[28]

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

The Chinese government did not randomly choose the six industries in the northeastern provinces as the pilot. Indeed, as stated in the official document,[29] the government chose the reform pilot firms, which are more likely to be owned by the state in traditional industrial base and less profitable, in order 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 had a higher probability of selection for the pilot of 2004 VAT reform. Their findings suggest that the goal of the 2004 VAT reform conform to the facts: some firm characteristics, such as firm size, firm profitability, firm age, state ownership, and foreign ownership, are not identical between affected and unaffected firms.

The non-random selection raises concerns that these characteristics could lead to different

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[28] Specifically, $\frac{d[ln(1+y)]}{dx} = \frac{1}{1+y}\frac{dy}{dx}$, and x represents the interaction among 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) from its mean value (0.0944) during 2002–2008 is then equal to $0.0082 \times (1 + 0.0944) = 0.0090$, which accounts for 9.51% of the mean value of the number of patents.

[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 details of the information, see the website: http://www.chinalawedu.com/falvfagui/fg22016/873.shtml (accessed by Sep 12, 2019).

over-time change of patents for affected firms, causing bias in our estimates. To address this issue, in columns (3) and (4), we control for the interactions between time dummies and the firm characteristics measured in the pre-reform period (averaged over 2001–2004). 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 on $NE_p * Eind_j * Post2004_t$ remain unchanged in both columns (3) and (4).

One caveat in the interpretation of the above results is that the crowding-out effect of the VAT reform on firms' innovation may continue to apply in the long run but cannot be identified empirically. In the long run, the treatment group and control group may stop being comparable due to confounding effects. Thus, identifying a clean long-run effect of the 2004 VAT reform on innovation is difficult.

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

6.2 Quality of Innovation

Our main result shows that the VAT has some negative spillover effects on innovation measured by the number of total patent applications by a firm (and eventually granted). However, different patents are associated with different qualities. Fewer patents may not simply mean that firms innovate less, since firms may concentrate more on high-quality innovation that normally requires more R&D inputs and longer time periods for development. To address this issue, in this section, we examine the impacts of the VAT on the number of patents with different innovative qualities.

Chinese Patent Law classifies patents into three types: invention patents, utility model patents, and design patents. Invention patents are required to show a significant technology improvement, need to 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 the new design of the shape, color, and graphic pattern of products, and hence they are the least innovative and under the shortest period of protection.[30]

[Insert Table 4 Here]

Table 4 reports the results of estimated impacts of the 2004 VAT reform on the number of different types of patents. The dependent variable in column (1) is the logarithm value of one plus the sum of the number of invention patents and utility model patents, which are recognized as the types of patents with higher innovativeness. In column (2), the dependent variable is the logarithm value of one plus the

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

number of design patents, which are considered to be of lower innovativeness. 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 appear with innovation quality improvement.

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

Our theory predicts that the crowding-out effect of the investment tax credits on innovation is significant only for firms with the intermediate level of financial constraints. Many studies have also found that firms with disparate financial constraints will be differently affected by fiscal policies (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 measuring firms' financial constraints, called the size-and-age (SA) index.[31] The SA index equals to $-0.737 * Size + 0.043 * Size^2 - 0.040 * Age$, where $Size$ is the logarithm value of inflation-adjusted book assets,[32] and Age is the firm's age, defined by subtracting firm's year of establishment 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 three reasons: First, the SA index doesn't count on endogenous variables such as cash flow or leverage. Second, 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 that vary slowly, reflecting the stickiness of firm-level financial constraints over time. Thus, the SA index appears more effective in capturing the cross-sectional variation in financial constraints than the time variation.

[Insert Table 5 Here]

We split the sample into deciles based on the average SA index over the pre-reform (2001–2004) period, and construct three subsamples based on the top three, the middle four, and the bottom three

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[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 WW Index (Whited and Wu, 2006).

[32] Following Hadlock and Pierce (2010), book assets statistics are in millions of inflation adjusted year 2004 Renminbi and are winsorized at 1% and 95% level.

[33] In the original SA index in Hadlock and Pierce (2010), Age is defined as the current year minus the first year that the firm has a non-missing stock price. Most of our sample firms are not publicly listed firms, thus we refine the definition of Age by subtracting firm's year of establishment from the observation year. As in prior studies (see Cabral and Mata, 2003; Angelini and Generale, 2008; Hall, 2008; and Howell, 2017, among others), young firms are more likely to face financial constraints because of higher information asymmetry and absence of collateral compared with old 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] Higher SA index corresponds to lower I in the model in Section 3.

deciles.[35] We then estimate equation (1) using these three subsamples separately. The results are reported in Table 5, with columns (1)–(3) representing firms with high, intermediate, and low SA index, respectively. We see that for firms with tight, intermediate, and loose levels of financial constraints, the coefficients of the triple interaction term $NE_p * Eind_j * Post2004_t$ are 0.0039, -0.0127, and -0.0123, respectively. Importantly, only the coefficient for firms in the middle group is statistically significant.

Finally, as complementary evidence, we construct two indicators, $Intermediate$ and $Loose$, based on the SA index to identify the groups of firms with the intermediate and loose financial constraints, respectively. Specifically, $Intermediate$ equals one for firms that belong to the middle four deciles and zero otherwise; $Loose$ equals one for firms that belong to the bottom three deciles and zero otherwise. We then include the interaction terms $NE * Eind * Post2004 * Intermediate$ and $NE * Eind * Post2004 * Loose$, as well as their triple and double interaction terms that are not absorbed by the fixed effects. The results are presented in column (4) of Table 5. The results are consistent with columns (1)–(3) in 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. It suggests that the negative impacts of the reform on firms with the intermediate level of financial constraints are stronger than other firms.

The above findings are consistent with our theory. Firms with the intermediate level of financial constraints upgrade from low type to high type, and the additional operating cost of being high-type causes the crowding out of innovation. However, financially more-constrained and less-constrained firms tend to remain their own previous types, respectively.

6.4 Ownership and the Effects of the VAT Reform

Poncet, et al. (2010) show that in China firms with different kinds of ownership face different financial constraints. Specifically, SOEs have the easiest access to bank loans due to political connections or other supports provided by the governments (e.g., Allen, et al., 2005; Cai and Liu 2009; and Jin, et al., 2019). Foreign-invested firms are also less likely to face tight financial constraints because foreign firms are more likely to obtain external financing (e.g., Ayyagari, et al., 2011). Besides, to attract foreign investors, Chinese government provides several financial benefits (e.g. lower corporate tax rates) to foreign-invested firms during our sample period. In contrast, domestic private firms do not

[35] In our sample, the SA index for the firm with the loose level of financial constraint is less than -2.203 while the SA index for the firm with the tight level of financial constraint is greater than -1.416.

enjoy 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 impacts of the VAT reform on innovation are different for firms with different ownership structures, as additional evidence for the predictions of our model.

[Insert Table 6 Here]

We split all 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 firms' ownership. A firm is considered as an SOE (domestic private-owned enterprises, foreign-invested firms) 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 having the same largest shares are dropped, since the 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). It is equal to -0.0086. The same estimated coefficients in column (1) (SOEs) and column (3) (foreign-invested firms) are insignificant. These findings show that the VAT reform has a negative effect on innovation of domestic private firms, but not SOEs or foreign-invested firms.

7. Robustness Checks

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

7.1 Alternative Explanations

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

[Insert Table 7 Here]

A. Confounding Policies

Around the same time two important policies may have induced similar effects on innovation as the 2004 VAT reform.

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 firms' export in textile clothing (see

Khandelwal, et al., 2013). If increasing exports induced firms to innovate less (because firms need to pay fixed costs to enter foreign markets (Melitz, 2003)), removing the MFA may have similar negative results since there were smaller proportions of textile and clothing industries in the three provinces in the northeastern region. To address this issue, we remove firms in the textile and clothing industries and estimate equation (1). The results presented in column (1) in Table 7 are robust to our main results.

Environmental Policies. Stricter environmental policies may add costs of production and reduce profits, leading to lower investment in R&D. We also check whether our main results are driven by the environmental policies enacted during the sample period. During the period of the eleventh Five-Year Plan (2006–2010), the Chinese government implemented a strict environment policy setting a pollution reduction target for each province, which may have reduced firms' innovation. Since 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 in the eleventh Five-Year Plan. To verify whether our results are driven by the environmental policy, following Shi and Xu (2018), we add 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 reduction in SO_2 emissions at province level;[36] $Post2005_t$ is a dummy variable equal to one for 2006–2007, and zero for 2001–2005; and $lnSO_{2_j}$ is the log of the industrial average SO_2 emissions (in 10 thousand tons) from 2003 to 2005. The results reported in column (2) of Table 7 show that our main findings are unchanged.

B. Life Cycle

Firms operating in the intermediate stage of their lifecycle 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 can observe similar effects even without VAT reform.

To address this issue, we check whether firms in the intermediate stage are concentrated in the six treatment industries in northeastern China. We use firm age to measure firms' lifecycle stage and split the sample into deciles based on the yearly average age over the pre-reform period. We construct a dummy variable, $Middle\text{-}stage\ Dummy$, to indicate the intermediate-stage firms. It is equal to one, if

[36] Pollution reduction targets at the province level are set through 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," issued by the China State Council in 2006. For more details of this document, see the website: http://www.gov.cn/gongbao/content/2006/content_394866.htm (accessed by Sep 12, 2019).

a firm belongs to the middle four deciles; 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 (3) of Table 7 show that the coefficient of $NE * Eind$ is insignificant, suggesting that firms with intermediate ages 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.

[Insert Table 8 Here]

Pre-existing Time Trends. For a valid DDD estimation, the difference in firms' innovation time trends between affected and unaffected industries should be the same across provinces without the VAT reform.

To test it, we replace the variable ($NE_p * Eind_j * Post2004_t$) in equation (1) with a series of interactions of NE, $Eind$, and pre-reform year dummies. The first year, 2001, in our sample is set as the base year. We re-estimate equation (1) using the sample excluding the post-reform observations. The results presented in column (1) in Table 8 show that none of the estimated coefficients of the triple interactions is significant, which justifies the presumption for the DDD estimation.

Expectation Effect. To check whether firms changed their innovation behaviors in anticipation of the coming VAT reform, we add to the regression an additional control ($NE_p * Eind_j * Year2004_t$), an interaction term between $NE * Eind$ and the dummy indicating one year before the reform. Such anticipation can render 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 insignificant, showing 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 affected industries in northeastern provinces significantly different from other firms? To answer this question, in addition to examining preexisting time trends, we use the propensity score-matched sample of affected and unaffected firms to re-estimate the results. We employ the nearest-neighbor matching implementation 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 sample shown in column (3) in Table 8 are robust.

Location Choice. Another concern might be that ineligible firms establish factories or production lines in the affected industries located in the northeastern region of China to enjoy the benefits of the

VAT reform, leading to bias in our estimates. Since firms located close to the affected provinces are more likely to establish factories there, we drop firms located in provinces within 500 miles from the affected provinces, including Anhui (around 470 miles), Beijing (around 200 miles), Hebei (0 mile), Henan (around 430 miles), Inner Mongolia (0 mile), Jiangsu (around 350 miles), Shaanxi (around 500 miles), Shandong (around 300 miles), Shanxi (around 500 miles), and Tianjin (around 150 miles), and re-estimate the main results. The results shown in column (4) in Table 8 are robust, ruling out the concern that our results were driven by the 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", $NE_{Random} * Eind * Post2004$, consisting of a randomly selected set of three affected provinces, true affected industries, and true post-reform dummy. We estimate equation (1) by replacing the true treatment dummy with this randomly generated interaction variable, $NE_{Random} * Eind * Post2004$. We repeat this exercise 500 times.[37] We conduct two similar tests. First, we randomly assign the value of $Eind$ among all industries, then we estimate equation (1) by replacing the true treatment dummy with this randomly generated value, $NE * Eind_{Random} * Post2004$. We repeat 500 times. Finally, we randomly assign the value of $Post2004$ and estimate equation (1) using this randomly generated variable, $NE * Eind * Post2004_{random}$, 500 times. Panels A, B, and C in Figure 1 show the probability distributions of the estimated coefficients of the triple interaction 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 estimated placebo effects regardless of how we randomly assign the treatment group. Taken together, the results in Figure 1 enhance our confidence that our findings are not driven by random factors.

[Insert Figure 1 Here]

7.3 Alternative Samples

We use three alternative samples to test the robustness of the prior results. First, since the VAT reform started in July 2004, year 2004 mixes pre- and post-reform information. We drop observations in 2004 and re-estimate equation (1). Second, in 2007, the VAT reform was expanded to another 26 cities in six other provinces located in central China. Although we dropped firms in these cities from our main sample, behaviors of firms in other cities also might be affected in 2007 because they might have expected the 2004 reform to expand to their cities. To address this concern, we drop observations in 2007 and re-estimate equation (1). Third, the 2004 VAT reform may induce firms to enter or exit the

[37] The same exercise has been conducted in Chetty, et al. (2009) and La Ferrara, et al. (2012).

market. For example, if the new entries had more incentives to upgrade and more firms entered northeastern regions, our results may be overestimated by capturing both the selection effect and true effect of the VAT reform on innovation. To eliminate the bias caused by firms' entry and exit, we employ a balanced sample, which includes firms operating throughout the whole sample period of 2001 to 2007 to estimate equation (1). The results of these tests shown 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 findings.

[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 one is $\ln\left[Pat_{ijpt} + \left(Pat_{ijpt}^2 + 1\right)^{1/2}\right]$, where Pat_{ijpt} is the total number of patents by firm i in industry j and province p in year t. This measure enables us to remove the potential bias caused by the usage of the log-like transformation in the main result. 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 defined as $Patent\_Stock_{ijpt} = (1-\theta)Patent\_Stock_{ijp,t-1} + r_{ijpt}$.[38]

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

Third, although the R&D expenditure information is not available in the ASIF database before 2004, the firms are required to report their R&D expenditure during 2005–2007. Since the VAT reform was expanded to 26 cities of six provinces in central China,[39] where the mining and electricity sectors

[38] Here, $Patent\_Stock_{ijpt}$ is the patent stock of firm i in industry j and province p in year t, θ is the depreciation rate of the patent stock (15% as set in prior work), and r_{ijpt} is the number of granted patents applied for by firm i in industry j and province p in year t. The patent stock measurement in year t is constructed using a declining balance formula and the past history of patents 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 for firm i in year t_0 and r_{ijp,t_0} is the number of granted patents applied for by firm i in year t_0. The patent data of r_{ijpt} from CNIPA go back to 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.

[39] The 26 affected cities in the 2007 VAT reform include 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.

would additionally be affected, we therefore use the R&D data during 2005–2007 and exploit the VAT reform in 2007 to investigate the impact of the 2007 VAT reform on R&D expenditures.[40] The specification is as follows:

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

where y_{ijct} is equal to R&D expenditures divided by the lagged total assets or by lagged total sales in year t for firm i. Mid_c is an indicator equal to one for the 26 selected cities; zero otherwise. $Eind_j$ is an indicator for eligible industries.[41] $Year2007_t$ is an indicator for post-2007 period because the 2007 VAT reform was implemented on July 1, 2007.[42] We control for firm, city-year, and three-digit industry-year fixed effects. Standard errors are clustered at the firm level.

The results of these tests shown in Columns (1)–(5) of Table 10 are all robust, providing additional support for our main findings.

Considering the Quality of the Patent Data in China. China-granted patents have been criticized for their low quality (e.g., Zhang and Chen, 2012; Hu, et al., 2017). The behaviors that some firms may counterfeit patents are egregious in China due to its ill-prepared legal system, especially in the early 2000s (e.g., Hu and Jefferson, 2009). Hu, et al. (2017) have shown that the correlation between patents and R&D expenditures in China is weak, implying that the patents granted by CNIPA could be manipulated or acquired through bribery. If the VAT reform induced affected firms to manipulate less, our results may be biased.

To address this issue, we use patents granted abroad as a proxy for innovation (e.g., Holmes, et al., 2015). We collect the information on patents applied by Chinese firms and granted by the World Intellectual Property Organization (WIPO).[43] We merge the WIPO dataset with our ASIF dataset and find that firms in ineligible industries have few global patents granted by the WIPO, making it difficult to conduct the DDD analysis. Due to the data limitation, we only use firms in the six affected industries[44] to compare the before-after change for firms in the northeastern provinces with firms in other parts of China. The following regression is estimated.

[40] To make the results comparable to the baseline estimation, we construct a sample of firms in manufacturing industries following the description in Section 4.1. The differences in data processing between the baseline analysis and this section is as follows: First, because the reform pilot is city-industry level for the 2007 VAT reform, we exclude firms changing located cities or (three-digit) industries during the sample period to avoid a sample selection problem. We include the firms located in the 26 cities affected by the 2007 VAT reform. We also delete 136 observations with missing R&D expenditures. Because the time period of our sample in this analysis covers only 2005–2007, we keep a balanced sample of firms that exist in the sample over the three years.

[41] 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).

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

[43] WIPO is a worldwide organization of the United Nations and provides intellectual property services.

[44] The eligible industries of 2004 VAT reform are described in Section 2.

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

where $y_{ip,t+1}$ is the logarithm of the number of patent applications filed (and eventually granted by the 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 which equals one for years 2005–2007, and zero for years 2001–2004. 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 could be due to the small sample size.

Alternative Financial Constraint Measures. We use the SA index as the main proxy for financial constraints. However, the SA index is constructed based on a sample of US listed firms (Hadlock and Pierce, 2010), which might not be suitable for Chinese firms. To address this concern, we follow Liu and Mao (2019) to use firm size and cash flow ratio as alternative proxies. Firm size and cash flow ratio are defined as the average value of firms' assets (in 1998 Renminbi) and the average ratio of firms' cash flow over total assets in the pre-reform period, respectively. Based on each measure, we split 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 all these subsamples, respectively.

[Insert Table 11 Here]

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

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

Our theory also suggests that other firm decisions may be affected by the VAT reform non-monotonically in the level of financial constraints. For example, the labor input of firms with the intermediate level of financial constraints should also be crowded out. The VAT reform's effect on fixed assets, on the other hand, may go both ways depending on the parameters of the production technology. That is, we should also observe the non-monotonic effect of the VAT reform on firms' labor inputs, but we may or may not observe that in 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 value 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 $t-1$ ($NFAS_{t-1}$),[45] as the proxy of 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 price index of fixed asset investment in year t relative to year 1998 from the Statistic Yearbook of China, used to adjust inflation.[46] 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 from the VAT deduction, where the tax rate of the VAT is equal to 17%.

[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 the intermediate level of financial constraints, consistent with our model (see Section 3 and Appendix 1). Firms with the intermediate level of financial constraints switch their type from low to high type after the reform. After becoming a high-type, the firm reduces the percentage of labor inputs and pays additional operating costs. Both effects lower labor inputs after the VAT reform.

For fixed asset investment, none of the three groups of firms with different levels of financial constraints responds significantly to the VAT reform. This is not contradictory to our model. In our model, the firms that upgrade their technologies after the VAT reform will increase the percentage of fixed assets, but in the meantime face additional operating cost that can crowd out fixed asset expenditures. Thus, the VAT reform may have two counteracting effects on fixed asset investment, and the net effect could go either way.

9. Conclusions

We examine the effect of investment tax credits on firms' innovation, focusing on the 2004 VAT reform pilot in six industries in the northeastern region of China. This reform switched from a production-type to a consumption-type VAT by allowing the cost of fixed assets to be deductible, reducing the relative price of machines and equipment.

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[45] In the ASIF dataset, net asset values are measured at different acquisition prices and we totaled them to get $NFAS_t$.

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

Our model indicates that this change in the relative price of machines and equipment leads to a decline in innovation for firms with the intermediate level of financial constraints. Using the DDD approach, consistent with the model, we show that the 2004 VAT reform has negative impacts on firm innovation. Firms confronted with different financial constraints are non-monotonically affected by the reform. The 2004 VAT reform has negative effects on innovation only for firms with the intermediate level of financial constraints. The results are robust to a battery of robustness checks.

To conclude, our research suggests that investment tax credits may have unintended negative effects on firms' innovation and deepens our understanding about the role of financial constraints in this problem. We acknowledge that our results may be more relevant in the short run after the reform, since firms' financial constraints can change in the long run. Over time, with performance enhancement and external financing improvement, more capital will be available for firms to produce. In this instance, the negative effects of the reform on innovation may be mitigated. Nevertheless, our findings on the crowding-out effects of investment tax credits on innovation are relevant to policy makers for designing optimal fiscal policies to improve innovation and boost economic growth. This is especially important for a country like China. Even with rapid economic growth, China has long been criticized for insufficient innovation. Promoting healthy economic growth motivated by innovation is crucial for long-term stable economic growth.

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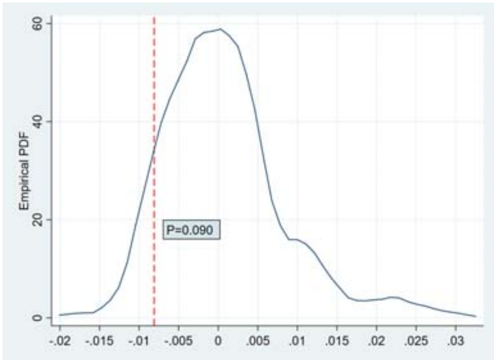
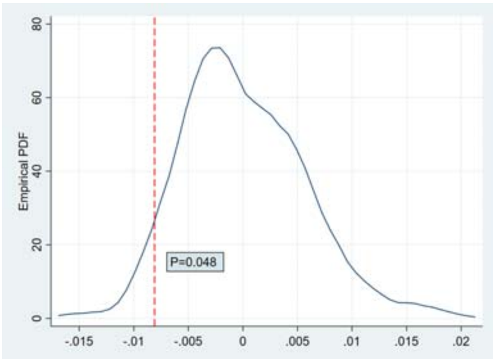
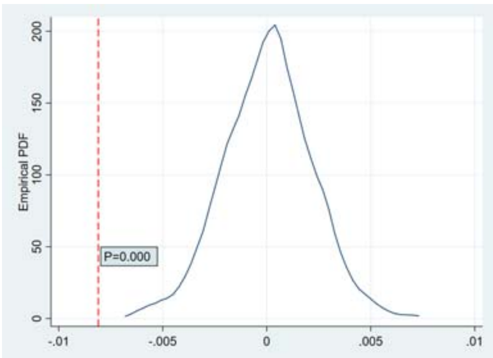
Figure 1. Empirical Probability Density Function of the Placebo Estimates.



Panel A. Using $NE_{Random} * Eind * Post2004$



Panel B. Using $NE * Eind_{Random} * Post2004$



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

Note: These figures plot three empirical distributions of 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 three affected provinces ($NE\_Random * Eind * Post2004$), randomly assigning the affected industries ($NE * Eind\_Random * Post2004$), and randomly assigning the affected years ($NE * Eind * Post2004\_Random$), respectively. The vertical lines show the treatment effect estimates reported in column (1) of Table 3.

Table 1. Yearly 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 yearly distribution of observations over the 2001–2007 period by regions and industry in our sample. 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 ship building. The sample excludes firms located in the 26 cities located in central China to eliminate the effect of the VAT reform in 2007. The sample also excludes firms changing locations or industries during the sample period to avoid a sample selection problem. The sample excludes firm-year observations with missing or error values. 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
			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 summary statistics of the main variables whose definitions can be found in Appendix 2. All continuous variables are winzorized at the 1st and 99th percentiles. Data period: 2001–2007.

Table 3. Effects 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 on 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 on the effect of the 2004 VAT reform on the total number of patents applied for by a firm and eventually granted by CNIPA. The dependent variable is the log value of one plus the number of total patents, which are applied for by a firm in year $t+1$ and eventually granted by the CNIPA. Column (1) estimates the basic impact 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 across 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 the pre-reform controls. Standard errors clustered at the firm level are in parentheses. The definitions of these control variables can be found in Appendix 2.

Table 4. Effects 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 on level variable	-0.0070	-0.0021
% effect relative to level mean	-13.04%	-11.69%

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

Table 5. Heterogeneity: Financial Constraint.

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 on 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 by the financial constraint index (SA index). The dependent variable is the logged value of one plus the number of total patents, which are applied for by a firm in year $t+1$ and eventually granted by the CNIPA. The average SA financial constraint index (Hadlock and Pierce, 2010) measured in the pre-reform years are used to divide the sample into deciles and define the top three deciles as tight, the middle four deciles as intermediate, and the bottom three deciles as loose financial constraints. $Intermediate$ and $Loose$ are two dummy variables based on SA index to identify the groups of firms with the intermediate level and the loose level of financial constraints, respectively. $Intermediate$ equals 1 for the firms in the middle four deciles when the sample firms are divided based on SA index, and 0 otherwise; and $Loose$ equals 1 for firms which belong to the bottom three deciles when the sample firms are divided based on SA index, and 0 otherwise. The definitions of all variables can be found in Appendix 2. Robust standard errors clustered at the firm level are reported in parentheses.

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 Fixed Effects	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 on 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 by ownership. The dependent variable is the logged value of one plus the number of total patents, which are applied for by a firm in year $t+1$ and eventually granted by the CNIPA. Columns (1)–(3) report the results using the samples of state-owned enterprises, domestic private-owned enterprises, and foreign invested firms, respectively. The ownership nature is defined based on the information in 2004. A firm is considered a SOE (domestic private-owned enterprises), 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 the foreign investors own the largest share of its total paid-in capital. In this analysis, firms with two or three shareholders having the same largest shares are dropped since the ownership cannot be clearly defined. The definitions of all variables can be found in Appendix 2. Robust standard errors clustered at the firm level are reported in parentheses.

Table 7. Robustness Checks: Other Explanations.

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

Note: This table reports three robustness checks to exclude some potential explanations for our empirical findings. Columns (1) and (2) rule out the confounding effects of the removal of MFA policy and the environmental regulation on the emission of SO_2. The dependent variable in columns (1)–(2) is the logged value of one plus the number of total patents, which are applied for by a firm in year $t+1$ and eventually granted by the CNIPA. Column (1) drops the observations in the textile and clothing industries, which are MFA-affected industries. Column (2) controls for the influence of the environmental regulation, which sets 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 1 for 2006–2007 and 0 for 2001–2005; and $lnSO_2$ is the log of the industrial average SO_2 emissions (in 10 thousand tons) from 2003 through 2005. Column (3) uses the pre-reform average to construct a cross-sectional sample to check if the proportion of middle-stage firms in the affected group is disproportionally greater than other firms. The dependent variable in column (3) is $Middle\text{-}stage\ Dummy$, a binary variable which equals 1 for firms in the intermediate stage of the lifecycle and 0 for other firms. All firms in our sample are split into deciles based on their yearly average age before the 2004 VAT reform and the firms in the middle four deciles are defined as those in the intermediate stage of lifecycle. The definitions of all variables can be found in Appendix 2. Robust standard errors clustered at the firm level are reported in parentheses.

Table 8. Robustness Checks: Justification of 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*Year2002	0.0049			
	(0.0080)			
NE*Eind*Year2003	0.0041			
	(0.0085)			
NE*Eind*Year2004	-0.0027	-0.0073		
	(0.0082)	(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 on 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)–(4) is the logged value of one plus the number of total patents, which are applied for by a firm in year $t + 1$ and eventually granted by the CNIPA. Column (1) drops the post-reform observations and uses the interactions of NE, $Eind$, and pre-reform year dummies ($Year2002$, $Year2003$, 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) keeps the propensity matching sample, where the control group is constructed using a one-to-three nearest-neighbor matching implementation (with replacement) of the propensity score matching approach. Column (4) keeps the firms affected by the 2004 VAT reform and the control firms located in the provinces that are distant from the northeast region of China. The distant provinces are defined as the provinces whose minimum distance from northeastern provinces is more than 500 miles. The definitions of all variables can be found in Appendix 2. Robust standard errors clustered at the firm level are reported in parentheses.

Table 9. Robustness Checks: 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 on 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 checks using alternative samples to examine the effect of the 2004 VAT reform on firm innovation. The dependent variable in columns (1)–(3) is the logged value of one plus the number of total patents, which are applied for by a firm in year $t + 1$ and eventually granted by the CNIPA. Columns (1) and (2) remove the observations in year 2004 and year 2007, respectively. Column (3) uses a balanced panel of firms that continuously operated for all 7 years. The definitions of all variables can be found in Appendix 2. Robust standard errors clustered at the firm level are reported in parentheses.

Table 10. Robustness Checks: Alternative Measurements 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)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
NE*Eind*Post2004	-0.0104	-0.0128	-0.0096				
	(0.0050)	(0.0055)	(0.0044)				
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
Year-Province FE	Yes	Yes	Yes	No	No	Yes	Yes
Year-Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-City FE	No	No	No	Yes	Yes	No	No
Observations	722,855	722,855	722,855	445,161	445,161	583,311	1,091
R-squared	0.532	0.845	0.534	0.506	0.535	0.583	0.583
N (affected group)	7,044	7,044	7,044	5,894	5,894	7,044	11
N (control group)	144,006	144,006	144,006	142,493	142,493	115,406	199
Mean of dep. var.	0.0507	0.1027	0.0473	0.0093	0.0086	0.0006	0.3145
Std. dev. of dep. var.	0.3008	0.4153	0.2649	0.0391	0.0351	0.0345	0.7325
Change on level variable	-0.0114	-0.0172	-0.0108	-0.0020	-0.0023	-0.0003	-0.5768
% effect relative to level mean	-12.06%	-5.04%	-8.88%	-21.51%	-26.74%	-3.56%	-12.63%

Note: This table reports the results of robustness checks 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, Lerner, and Wu (2017). Column (3) uses the dependent variable $LnPat_{t+2}$, the logged value of one plus the number of total patents applied for by a firm in year $t+2$ and eventually granted by the CNIPA. Columns (4) and (5) investigate the impact of the 2007 VAT reform on R&D expenditures. Mid_c is an indicator, equal to one for the 26 cities affected by the 2007 VAT reform, and equal to zero otherwise. The sample in columns (4) and (5) include firms located in the 26 cities affected by the 2007 VAT reform and are a balanced sample during the period 2005–2007. As the reform pilot is city-industry level for the 2007 VAT reform, firms changing located cities or (three-digit) industries during the sample period are excluded. Columns (6) and (7) examine the effect of the VAT reform on patent quality, proxied by the number of patents which are applied for by Chinese firms in year $t+1$ and successfully granted by WIPO. The definitions of all variables can be found in Appendix 2. Robust standard errors clustered at the firm level are reported in parentheses.

Table 11. Robustness Checks: Alternative Measurements 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 on 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 on the heterogeneous effects of VAT reform on firm-level innovation using subsamples based on alternative measures of financial constraints: cash flow ratio (columns (1)–(3)) and total assets (columns (4)–(6)). The dependent variable in columns (1)–(6) is the logged value of one plus the number of total patents, which are applied for by a firm in year $t+1$ and eventually granted by the CNIPA. The financial constraint measures are constructed using the average values of cash flow ratio and total assets in the pre-reform years for each firm. All firms in our sample are split into deciles based on the two measures respectively. The bottom three, the middle four, and the top three deciles are defined as the firms with tight, intermediate, and loose financial constraints, respectively. Columns (1)–(3) are the results of the heterogeneous effects of VAT reform on firm innovation by financial constraints proxied by the ratio of cash flow over the total assets. Columns (4)–(5) are the results of the heterogeneous effects of VAT reform on firm innovation by financial constraints proxied by total assets. The definitions of all variables can be found in Appendix 2. Robust standard errors clustered at the firm level are reported in parentheses.

Table 12. Labor and Capital Response 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 on level variable	63.1716	-107.8597	-211.9406
% effect relative to level mean	5.70%	-5.65%	-2.88%
Dependent variable	Fixed Investment Ratio		
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 on level variable	0.0798	-0.0569	0.0692
% effect relative to level mean	12.74%	-12.67%	22.91%

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

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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 from some previous studies on the VAT reform can also be rationalized in this simple framework.

We consider an economy with a final good as firms' outputs 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 needs to pay some additional operating costs as described in Section 3.

Specifically, a high-type firm's production function is $\tilde{A}_h(R)K_h^{\alpha_h}L^{\beta_h}$, and a low-type firm's production function 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 cost of being high-type may differ across firms. We assume that the additional operating cost of being high-type is 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 cost $\theta(I)$ to the total amount of capital I is decreasing, and the rate of change in $\theta(I)$ eventually approaches zero. Note that $\theta(I)$ is allowed to be increasing or decreasing, or to change nonmonotonically with I. Under our assumptions, however, even if $\theta(I)$ is increasing, a firm with a higher I will be more comfortable covering the additional operating cost of being high-type, compared to a firm with a lower I. Our assumptions also allow $\theta(I)$ to be

[1] Recall that we have omitted real estate assets, such as factories and buildings that are unaffected by the VAT reform, from production functions. Our findings below will be unaffected if we bring those assets back to production functions, or we leave those assets out but assume that production functions have decreasing returns to scale (because some factor of production has been left out).

constant—firms may face identical additional operating costs of being high-type. Below is a consequence of the assumptions on $\theta(I)$ that will be used later.

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

Proof. Fix 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 above, we must have $\lim_{I \to +\infty} \frac{\theta(I)}{I} = 0$. Otherwise, as I goes to infinity, $\theta(I)$ goes to infinity as well. In that 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 $\lim_{I \to +\infty} \theta'(I) = 0$. We have proved 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, due to 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 higher than c_{K_l}, but this is not important to 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 profits of a low-type firm are

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

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 that case, the optimal profits of a high-type firm are

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

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

So far, we have not made any assumption about the relation between the firm's type and its financial constraint I. Our next two assumptions will imply that the low-type firms must also be the more financially constrained ones.

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

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 high-type and the

[2] Some studies have found that the prices of fixed assets will change after some tax reforms (see, for example, Goolsbee, 1997). Such change will not affect our results qualitatively.

profits of being low-type, and decide which type it wants to be. Since $\alpha_h + \beta_h + \gamma = \alpha_l + \beta_l + \gamma$, 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) is the firm's profits of being low-type, while the right-hand side of (A5) is the firm's profits of being high-type if the additional operating cost were zero ($\theta(I) = 0$). Thus, the second assumption means that without the additional operating cost, a firm prefers to be high-type.

The two terms in Assumption 2 will become useful soon. Let us define $\phi_l := A_l \left(\frac{\alpha_l}{c_{K_l}}\right)^{\alpha_l} \left(\frac{\beta_l}{c_L}\right)^{\beta_l}$ 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 $I^* = \frac{\phi_h}{\phi_h - \phi_l}\theta(I)$. Then, (a) if $I < I^*$, the firm must be low-type, (b) if $I > I^*$, the firm must be high-type, and (c) if $I = I^*$, the firm is indifferent to being either type.*

Proof. According to Assumption 1, every firm compares π_l and π_h, and then becomes the type with the larger profit. Because 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, $\phi_h > \phi_l$, and 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 as I^*. Moreover, because $\left(\frac{\phi_h}{\phi_l} - \frac{\phi_h}{\phi_l}\frac{\theta(I)}{I}\right)' > 0$, if $I \le I^*$, $\pi_h \le \pi_l$ and the firm chooses to be low-type, 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, and hence the firm prefers to be low-type. For example, recall that our assumptions allow the additional operating cost $\theta(I)$ to be constant. In this case, firms with 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 high-type.

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 of firms with different financial constraints non-monotonically.

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

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

Proposition 1 implies that after the VAT reform, the profit-maximizing R weakly decreases for every firm. Part (b) of Proposition 1 suggests that firms with the 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 types. The intuition is explained in Section 3.

The next proposition shows how firms facing various financial constraints are affected differently by the VAT reform in terms of the 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* $I < I^{**}$, *the profit-maximizing* L *and the expenditure of fixed assets do not change, and (b) for any firm with* $I^{**} < I < I^*$, *the profit-maximizing* L *decreases and if* $\frac{\alpha_l}{\alpha_h} \leq \frac{\phi_l}{\phi_h} \tau^{\alpha_h - \alpha_l}$, *the expenditure of fixed assets 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 that case,

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

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,

[3] According to the details of the VAT reform, it may lower the cost of high-type fixed assets more significantly; however, this will only strengthen our findings.

when $I = I^{**}$, $\pi_h = \pi_l$. Because 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 proved that before the VAT reform, the firm produces as a high-type if $I > I^*$. Since $\left.\frac{\pi_h}{\pi_l}\right|_{I=I^*} = \frac{\phi_h(I^* - \theta(I^*))}{\tau^{\alpha_h - \alpha_l}\phi_l I^*} = \frac{\phi_h}{\tau^{\alpha_h - \alpha_l}\phi_l}\left(1 - \frac{\theta(I^*)}{I^*}\right) > \frac{\phi_h}{\phi_l}\left(1 - \frac{\theta(I^*)}{I^*}\right) = 1$, every firm with $I > I^*$ remains high-type after the VAT reform. Therefore, before and after the VAT reform, the profit-maximizing L, R, and the expenditure of fixed assets do not change.

Similarly, every firm with $I < I^*$, produces as a low-type before the VAT reform. If $I < I^{**}$, the firm will still be low-type after the VAT reform. The profit-maximizing L, R, and the expenditure of fixed assets do not change before and after the VAT reform.

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

Next, we discuss our model's implication on firms' total factor productivity and innovation expenditure per employee. Regarding the total factor productivity, according to how it is measured in the previous empirical studies, we should investigate $A_h R^\gamma$ 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 conditions under which firms' total factor productivity increases and innovation expenditures per employee increase.

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

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

For any firm with $I^{**} < I < I^*$, it will change from a low-type to a high-type after the VAT reform. When the firm produces as a low-type, $c_R R/L$ is equal to $c_L \gamma/\beta_l$. After VAT reform, it produces as a high-type, and 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 equals 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 the total factor productivity for firms with $I^{**} < I < I^*$ after VAT reform is $\frac{A_h(I^{**}-\theta(I^{**}))^\gamma}{A_l I^{**\gamma}} > 1$. That is, $\left(\frac{A_l}{A_h}\right)^{1/\gamma} \leq \frac{\phi_l}{\phi_h}\tau^{\alpha_h-\alpha_l}$. ■

Proposition 3 rationalizes the empirical results in Liu and Mao (2019) and Cai and Harrison (forthcoming). Liu and Mao (2019) find that the VAT reform raises total factor productivity by improving the R&D expenditures per employee, while Cai and Harrison (forthcoming) show no significant increase in productivity. The sample firms in those two studies come from different datasets through different periods, and thus show different responses to the VAT reform. Their findings, however, can be simultaneously rationalized in our framework.

Appendix 2: Variable Definitions.

Variable	Definition
Measurements 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	The number of patent stock is the total number of patent applications filed (and eventually granted by the CNIPA) by a firm in a given year plus the past history of patents with a 15% depreciation.
WIPO patents	Total number of patent applications filed (and eventually granted by the WIPO) by a firm in a given year.
LnR&D	The logarithm of one plus the R&D expenditures adjusted by the price index relative to year 1998.
R&D/Assets	R&D expenditures in a given year divided by lagged total assets (adjusted by the consumer price index).
R&D/Sales	R&D expenditures in a given year divided by lagged total sales (adjusted by the consumer price index).
Other Variables	
Post2004	A dummy variable which equals 1 for 2005 – 2007 period and 0 for 2001–2004 period.
NE	A dummy variable which equals 1 for a firm located in three northeastern provinces (Heilongjiang, Jilin, and Liaoning) and 0 otherwise.
Eind	A dummy variable which equals 1 if a firm belongs to one of the six broadly defined eligible industries and 0 otherwise.
ln(Total Wage)	The logarithm of the total wage (in thousands of Renminbi), adjusted by the consumer price index relative to year 1998, 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 price index relative to year 1998 (in millions of Renminbi).
Firm Age (years)	Firm's age, defined by subtracting firm establishment year from the year of survey.
ROA	Return on assets ratio defined as operating income divided by book value of total assets.
Foreign Share	The proportion of capital owned by the foreign sector 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 equals to $-0.737 * Size + 0.043 * Size^2 - 0.040 * Age$, where $Size$ is the logarithm value of inflation-adjusted book assets, and Age is the firm's age, defined by subtracting firm's year of establishment 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 indeed valid determinants of the VAT reform pilot using the pre-reform (2001–2004) mean 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 is located in the eligible industries in the three northeastern provinces.

According to the official document of the policy,[4] the 2004 VAT reform was designed to facilitate upgrading for firms that were lagging behind in the nationwide development and thus lacked 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 matching covariates including two-digit industry fixed effects, firm size ($LnAssets$), profitability (ROA), firm age ($Firm\ Age$), state ownership ($State\ Share$), and foreign ownership ($Foreign\ Share$). The detailed definitions of covariates are listed in Appendix 2. The logit model is estimated across 124,611 firms containing non-missing data for all the covariates before 2004 to ensure that the covariates capture the determinants of the VAT policy treatment. The result of the logit model is presented in Table A3 below, showing that the model captures a significant amount of variation in the selection variable, as implied by a below 1% p-value from the Chi-test of the overall model fitness. Specifically, we find that the firms with larger size and lower profitability have a higher probability of becoming the eligible firms. In addition, if the firms are younger, they are more likely to receive the policy treatment. In terms of ownership, the firms with higher proportions of state ownership and lower proportions of foreign ownership tend to be selected as the reform pilot.

Then, we use the propensity score estimated from 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 reports the difference between treatment and control groups on various firm characteristics after matching to gauge the quality of the matching procedure. The results suggest that for most firm characteristics there appears to be no significant difference between the two groups of firms. The matching process eliminates major differences between these two groups of firms.

[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 details of the information, see the website: http://www.chinalawedu.com/falvfagui/fg22016/873.shtml (accessed by Sep 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 region of the three northeastern provinces of China and in 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 firm characteristics as reported in the pre-reform period (2001–2004). The model is used to generate the propensity scores for matching. The detailed definitions of control variables are listed in Appendix 2. Robust standard errors clustered at the firm level are reported in parentheses.

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 tests the comparisons of the matched firm characteristics on which the matching is performed between treatment and control groups both pre-match and post-match. The standard errors for comparison of means tests are reported in parenthesis.

Appendix 5: Heterogeneity by 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 on the heterogeneous effects of the 2004 VAT reform on firm-level innovation by financial constraints based on two measures of financial constraints: cash flow ratio and total assets. The average financial constraints measured in the pre-reform years are used to divide our firm sample into decile groups 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 constraint to identify the groups of firms with the intermediate level and the loose level of financial constraints, respectively. Taking firm size as an example, *Intermediate* equals 1 for the firms in the middle four deciles when the sample firms are divided based on total assets, and 0 otherwise; and *Loose* equals 1 for firms which belong to the top three deciles when the sample firms are divided based on total assets, and 0 otherwise. Standard errors (in parentheses) are clustered by firm in all regressions.