Does Outsourced R&D Crowd Out In-house R&D? Firm-Level Evidence from China's Tax Reform*

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Abstract

Using firm-level panel data from the National Tax Survey, this paper examines the relationship between firms' outsourced R&D and in-house R&D. The identification relies on a natural experiment created by the "business tax to value-added tax reform" (BT-to-VAT) in China, which reduced the costs of outsourced R&D for manufacturing firms. Our difference-in-differences estimates indicate that the BT-to-VAT reform increases both outsourced R&D and in-house R&D for manufacturing firms. To separate the substitution effect from the scale effect, we estimate the elasticity of substitution between the outsourced R&D and in-house R&D with a structural model. We find that they are complementary inputs in large-size firms or high-technology firms. But the relationship turns out to be substitutes among small-size firms or low-technology firms. We conclude that the relationship between outsourced and in-house R&D depends on the firms' size and technology level.

Keywords: outsourced R&D, in-house R&D, tax reform, innovation, China
JEL Classifications: O3, H25

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1 Introduction

R&D plays an important role in innovation and economic growth. According to the source of R&D, it can be divided into two types, one is in-house R&D and the other is outsourced R&D. Firms could adopt different combinations of in-house and outsourced R&D according to their own circumstances. Since both types require financial support and human resources, it is important to understand whether they are complements or substitutes. If these two kinds of R&D are substitutes, maintaining both in combination leads to redundancy. But if they are complements, it would be efficient and beneficial for firms to invest in both. For the government, having a good understanding of the nexus of in-house and outsourced R&D is critical for policymakers to formulate efficient R&D policies. Thus, the relationship between in-house R&D and outsourced R&D has been studied by previous scholars. But the results are inconclusive. Based on the National Tax Survey Database (NTSD) and input-output table, our paper studies the relationship between outsourced R&D and in-house R&D for the manufacturing firms in China.

In this paper, we address two main questions. First, how does the R&D outsourcing bonus (R&D bonus), induced by business tax to value-added tax reform (BT-to-VAT, "营改增"), impact outsourced and in-house R&D? Second, whether outsourced and in-house R&D are complements or substitutes in the Chinese context?

China is an interesting case to study. According to the OECD, China's R&D spending accounted for just 0.72 percent of its GDP in 1991. In 2020, China's R&D expenditure had surged to 2.4 percent of its GDP. The manufacturing sector has seen tremendous growth and progress thanks to the industrial revolution and innovation brought about by R&D. Figure 1 shows the comparison of R&D expenditure as share of GDP between 1996 and 2016 for four countries: Canada, China, India and United States. China has been catching up quickly during the two decades.

For the first question, combining the NTSD data and input-output table, we utilize the difference in difference (DID) framework to estimate the effect of R&D bonus caused by the BT-to-VAT reform on outsourced and in-house R&D in the manufacturing sector. BT-to-VAT reform is an important tax reform with a goal to convert the business tax in the service sector to the value-added tax. This muti-step reform started in Shanghai in 2012. The transportation industry and some selected modern service industries were covered in the first stage. In the second stage, it rapidly expanded to other eight provinces during the second half of 2012. The reform was implemented nationwide in 2013 at the third stage. The remaining service sectors were included in the reform step-step and were fully covered in May 2016. Even though this reform was not directly applied to the manufacturing sector, it influences manufacturing firms through input-output linkages. With the promotion of this policy, services purchased by manufacturing firms could be deducted from the calculation of the value added tax, which greatly stimulated outsourced service in the manufacturing sector. In the Figure 2, we could see that there is a great increase in the share of outsourced R&D in total inputs after 2012. From 2012 to 2015, the outsourced R&D share nearly doubles.

How does the R&D bonus induced by BT-to-VAT reform affect the outsourced R&D and in-house R&D of the manufacturing firms? Specific to the "R&D service sector", it was included as one of the first stage industries in 2012. After that, the allowed deduction benefits the manufacturing firms since most manufacturing industries need R&D service inputs. BT-to-VAT reform lowers the cost of R&D outsourcing for the manufacturing firms by allowing deduction while purchasing R&D services. Therefore, with the implementation of BT-to-VAT reform, there comes an R&D bonus. We use the ratio of R&D service input to total inputs (R&D ratio) to measure the degree to which firms are affected by R&D bonus. Manufacturing industries with higher R&D ratios benefit more from R&D bonus in terms of R&D outsourcing. In our paper, we take the regional variation into consideration and hold the assumption that firms are likely to purchase R&D services near them. In sum, we only use the R&D ratio to differentiate treatment and control groups after 2013 since BT-to-VAT was expanded nationwide in this year. But in 2012, the treatment group includes firms in industries with high R&D ratios in nine first stage provinces and all the remaining firms consist of the control group. By comparing firms that benefit more from the R&D bonus to those that benefit less, we isolate R&D outsourcing effect that is independent of other idiosyncratic shocks faced by a certain firm. Figure 3 shows that the increasing trend for the high dependence group is more evident than that for the low dependence group during the research time period. Since we follow the firms from 2010 to 2015, firms' in-house R&D was allowed to fully adjust along multiple margins under the impact of R&D outsourcing.

The identification assumption underlying the DID estimation is that there were no obvious differential trends between the more affected and less affected firms before the R&D bonus was implemented. Our DID empirical results reveal that manufacturing firms respond to the R&D bonus by increasing both outsourced R&D and in-house R&D. In particular, we estimate that the treated firms increase outsourced R&D by 4.71% and in-house R&D by 5.49% relative to non-treated firms after the reform was implemented. Moreover, this bonus also stimulates capital stock and employment, leading to an increase in output and patents. The above results are robust to allowing for trends that differ by province or pre-reform measures of firm size and productivity.

The second research question deals with the elasticity of substitution between the outsourced and in-house R&D. The finding that a reduction of outsourced R&D cost is associated with an increase in both types of R&D does not imply that they are complements. This is due to the scale effect. A reduction of outsourced R&D cost will free up some firm resources to invest in in-house R&D, even when the outsourced and in-house R&D are substitutes. To separate the substitution effect from the scale effect, we follow Curtis et al. (2022) and estimate a structural model. Curtis et al. (2022) use a standard economic measure, partial substitution elasticity among inputs, to theoretically measure the relative change in the ratio of inputs when their relative prices change. We adopt a similar framework and estimate the elasticity of substitution between the outsourced R&D and in-house R&D.

We further investigate how the relationship between internal and external R&D depends on size or technology by splitting the sample by pre-reform average employment and technology level. We show that the increased in-house R&D is larger than the amount induced by the scale effect for large or high-technology firms. Through the structural models, we further show that outsourced R&D and in-house R&D are complements in large-size firms or high-technology firms. But the relationship turns out to be substitutes among small firms or low-technology firms.

Why would the relationship between in-house and outsourced R&D depend on firm size? First, there exists a difference between in-house and outsourced R&D in terms of the risk or uncertainty related to return on these two types of investment. The return of investing in in-house R&D is more uncertain than that of purchasing R&D from outside. Thanks to the experience and comparative advantage of professional R&D service providers, uncertainty could be lowered, and corresponding returns could be verified. Second, in-house R&D investment required a large amount of time and money to start off. It is impossible to recover once the investment decision is made. Therefore, in-house R&D has more suck cost compared to outsourcing R&D. In conclusion, small firms cannot bear the uncertainty of returns on in-house R&D or the risk of sunk costs, more outsourced R&D will crowd out in-house R&D. Although the uncertainty and sunk cost also exist in large firms, they are able to diversify risk by restructuring resources across various projects. Besides, they face relatively fewer financial constraints and have the stronger economic strength to bear the sunk cost of in-house R&D investment, so in-house and outsourced R&D are more likely to be complements in large firms.

Absorptive capacity can explain why the relationship between in-house and outsourced R&D depends on the technology level. Absorptive capacity measures firms' ability to explore and utilize external knowledge can explain why this relationship depends on technology. For the firms who choose to purchase R&D service, how to absorb and exploit external technical knowledge and subsequently integrate it into its own knowledge base is all that matters. A minimum level of absorptive capacity, derived from in-house R&D, is required for effectively acquiring and assimilating external R&D. Thus, absorptive capacity is regarded as the key driver of complementarity between two R&D activities. High-technology firms tend to hire more skilled human resources, which is beneficial for in-house R&D. The activity of internal R&D promotes the absorptive capacity, and therefore the expected gain from outsourced R&D is greater. Thus, in-house R&D tends to be complementary to outsourced R&D in high-technology firms.

Our research contributes to the literature that examines the relationship between internal and external R&D. Firstly, Lee and Kim (2022) found that the relationship between internal and outsourced R&D depended on size and technology, consistent with our findings. But they regressed in-house R&D on outsourced R&D directly which caused an endogeneity problem. We exploit the R&D bonus induced by a natural experiment, BT-to-VAT policy, which lowers the price of purchasing R&D to solve the endogeneity problem. Secondly, many studies demonstrated that internal R&D and external technology sourcing were complementary in the innovation-specific context (Caloghirou et al., 2004; Cassiman and Veugelers, 2006; Tsai and Wang, 2008). However, a host of empirical works had found substitutability instead (Blonigen and Taylor, 2000; Higgins and Rodriguez, 2006; Laursen and Salter, 2006; Watkins and Paff, 2009). Lokshin et al. (2008) discussed this relationship in the TFP context. We examine the relationship between internal and external R&D under the profit maximization context, which is closer to reality compared to the context in previous literature. Finally, existing literature studies the relationship for some specific industries where data are more readily available. For example, Blonigen and Taylor (2000) focused on electronic and electrical equipment industries, Watkins and Paff (2009) paid attention to bio-pharmaceutical and software industries, and Xu, Wu, and Cavusgil (2013) explored the pharmaceutical industry. We solve the sample limitation by using NTSD to examine the relationship between in-house and outsourced R&D in the whole manufacturing sector. Previous research was unable to provide a general conclusion partly because of its focus on only selected industries.

This paper is also related to the literature on China's tax reform. Liu and Lu (2015), Liu and Mao (2019), and Yang and Zhang (2020) have explored the effect of VAT reform on the manufacturing sector. But for the BT-to-VAT reform, relevant research is limited, and less attention has been paid to the effects on R&D outsourcing. We focus on the R&D service among many reform-affected service industries and separate the R&D bonus from BT-to-VAT reform. We study the effect of R&D bonus on the manufacturing sector in different dimensions, including outsourced R&D, in-house R&D, capital, labor, output and patents.

The rest of the paper is organized as follows. Section 2 introduces the BT-to-VAT reform in detail. Section 3 describes the data. Sections 4 and 5 present the empirical method and results. Section 6 shows the model setup and elasticity calculation. Section 7 concludes.

2 Reform Background

2.1 BT-to-VAT reform

The business tax in China was formally established in 1950 when the national tax system was unified. The business tax is simple and easy to implement as soon as you open a business, you pay a pro-rata tax. However, with the development of the market and the increase of circulation links, the drawback of "simple and crude" business tax has become increasingly apparent. Goods are not only taxed upstream but also are taxed again downstream, resulting in double taxation. Thus, a more sensible alternative to the business tax is needed.

VAT entered China in 1979. At that time, it was only piloted in two industries: machinery and agricultural machinery. Chinese modern tax system formulated in 1994 brought about the concurrence of BT and VAT. The "Interim Regulations on Value-Added Tax" implemented in 1994 stipulated that value-added tax should be levied uniformly on all goods and processing, repair, and repair services, but business tax should be levied on other services, real estate, and intangible assets. The two coexisting indirect taxes led to an imbalance of industrial development and the problem of tax inequality. The double taxation of business tax was particularly prominent since it disallowed any input tax credit, which may create distortions in the economy.

In response, the "BT-to-VAT" policy was implemented in Shanghai on January 1st, 2012, which targeted some selected transportation and modern service industries. Why BT-to-VAT reform chose Shanghai as a starting point? National Tax Bureau and the Local Tax Bureau were one group and one organization in Shanghai. The Shanghai Local Taxation Bureau worked jointly with the Shanghai Municipal Taxation Bureau and Shanghai Tax Bureau managed both value-added tax and business tax. So, it was relatively easy to manage and coordinate while implementing the BT-to-VAT reform in Shanghai, which was different from the implementation in other cities. Another reason was that Shanghai had a wide range of service sectors, which had a significant impact on the overall economy. Choosing Shanghai as the first pilot city would help the government accumulate more experience for the comprehensive implementation of reform. The BT-to-VAT reform chose these industries for the following two main reasons. One was that the transportation service industry was closely linked with production and circulation. The other was that transportation expenses were within the scope of the current VAT input deduction, and freight invoices had been included in the VAT management system, which provided a good foundation for the reform. Selecting part of the modern service industries as the pilot industries mainly considered the following two reasons. One was that the modern service industry was an important indicator to measure the degree of economic and social development of a country and supporting its development through reform was conducive to enhancing the overall strength of the country. Another reason was that choosing the modern service industry as the pilot industry could reduce the double taxation in the industrial division of labor, which could not only benefit the development of the modern service industry but also benefit the manufacturing industry upgrading and technological progress since modern service industry was closely related with the manufacturing.

At the second stage of this reform, the geographical coverage of this policy expanded to Beijing, Tianjin, Jiangsu, Anhui, Zhejiang, Fujian, Hubei, and Guangdong from September 1st to December 1st of the year 2012. But the industry coverage remained the same. This pilot reform was then expanded to the whole country in 2013. Meantime, radio, film, and television services were included in the selected modern service in the same year at the third stage. The postal service industry and telecommunications industry were separately included in this pilot reform in the year 2014 as the fourth and fifth stages. In 2016, the policy was applied to all the industries which were covered by business tax before the BT-to-VAT reform, which was also the last stage of BT-to-VAT reform. The detailed expansion stages are shown in Table 1.

After 2016, units and individuals who sell services, intangible assets, or real estate within the territory of the People's Republic of China should be VAT taxpayers instead of paying business tax. VAT taxpayers are divided into general VAT taxpayers, for whom total sales must exceed a certain amount, and small-scale VAT taxpayers, for whom total sales are generally small in scale. For the general VAT taxpayers, the tax base is the usual value-added (the difference between the total value of sales and the cost of purchased material or service inputs). But the tax base of the small-scale VAT taxpayers is simply the total value of sales without deducting any cost of material or service inputs. That is, the tax regime does not allow for any deductions of the cost of material or service inputs while calculating a small-scale VAT taxpayer's VAT liability.

The VAT rate for most of the value-added taxpayers covered by BT-to-VAT reform is 6% except for the following three categories. Firstly, the value-added tax rate for units or individuals who provide transportation service, postal service, basic telecommunications service, construction service, real estate leasing service, real estate selling service, and transfer of land use right service is 11%. Secondly, for units or individuals who provide tangible chattel leasing service, value added tax rate is 17%. Lastly, the tax rate should be zero for cross-border taxable activities of domestic units and individuals. Moreover, the VAT levy rate is 3%. The calculation method of value-added tax includes the general method of tax calculation and the simplified method of tax calculation. The general method of tax calculation applies to the general VAT taxpayers and the simplified method of tax calculation applies to the small-scale VAT taxpayers. Furthermore, the simplified method of tax calculation is not allowed to deduct the input tax and is based on the VAT levy rate (3%) instead of the VAT rate (6%, 11%, or 17%).

2.2 R&D Bonus

Our focus is R&D service in the 2012 pilot, which was covered in the first stage of the reform. R&D service, as one of the so-called "modern service" industries, refers to the business activities of conducting research, testing, and development of new technologies, new products, new processes, or new materials and their systems. After 2012, the R&D service industry was no longer a BT (business tax) taxpayer, but a VAT (value added tax) taxpayer. Consequently, the cost of purchasing material or service inputs was allowed to deduct for the taxpayers in the R&D service, which stimulated both the material and service outsourcing for firms who provided R&D service. Through the linkage between the service sector and the manufacturing sector, this service-oriented policy would have an influence on the firms in the manufacturing sector. As the first group of industries affected by the BT-to-VAT reform in 2012, the allowed deduction in the R&D service sector caused by the reform also influences the manufacturing firms. Most manufacturing industries need R&D service inputs in their production process which could be shown in the input-output table from the National Bureau of Statistics. The BT-to-VAT reform lowers the cost of R&D outsourcing, which we name it R&D bonus, by allowing manufacturing firms to deduct the expense of purchasing R&D service during their production procedure.

Unlike the BT-to-VAT policy study of the service sector, we cannot directly determine eligible and ineligible industries in the manufacturing sector. Therefore, we turn to the input-output linkage to establish an indirect policy transmission effect. Each manufacturing sector has its own input from various service industries, which could be shown in the input-output table. Although each manufacturing industry has lots of different service outsourcing and BT-to-VAT reform covers many service industries, we only care about the R&D service industry. We know that BT-to-VAT reform affected manufacturing firms will increase R&D outsourcing since their cost of purchasing R&D service is allowed to deduct with the promotion of this policy. However, firms from different manufacturing industries will respond to this R&D outsourcing bonus differently. The ratio of R&D service input to total inputs we constructed using the input-output table helps us to measure the magnitude of the R&D bonus impact. R&D outsourcing in the firms with higher the above-defined ratio (ratio of R&D service input to total inputs) will be more likely to be influenced by the reform and therefore these firms benefit more from the R&D bonus. But for those with lower ratios, their R&D outsourcing is less likely to be affected by BT-to-VAT reform and thus benefit less from the R&D bonus. We could think of an extreme example, the firms in the Auto parts and accessories industry, they do not have R&D service as their production inputs from the 2012 input-output table. So, their R&D outsourcing decision will not be affected by the BT-to-VAT reform. Although the BT-to-VAT reform brings about the R&D bonus which lowers R&D purchasing costs, Auto parts and accessories cannot benefit from this bonus. But they may benefit from the BT-to-VAT reform in terms of other service purchases since R&D service is only one affected industry, there still exist many other service industries covered in the BT-to-VAT reform.

Considering the multiple stages of the BT-to-VAT reform, it consists of region, industry, and time dimensions, i.e., three-dimension variation for the service sector. But the manufacturing sector only has two-dimension variation, that is region and time for specific firms since the indirectness property of the reform. However, whether the region variation works is a controversial and mixed problem, and it depends on the detailed service that they purchase. If the outsourced service has high transportation costs, then the regional variation will have its influence. For example, the automobile manufacturing industry that purchases one kind of service M (covered in the first stage) during its production and this service demands very high transportation costs once inter-provincial transport is required. Extremely high transportation costs will make firms more likely to purchase local service M instead of purchasing it from other cities. The region covered by the BT-to-VAT had only nine provinces including Shanghai, Beijing, etc. in 2012 and was expanded nationwide in 2013. In this situation, suppose there are two automobile manufacturing firms, A located in Beijing and B located in Xinjiang, these two firms would be different in purchasing service M under the BT-to-VAT reform. Service M outsourcing of firm A will have a larger increase compared to that of firm B after the 2012 pilot year since Beijing belongs to one of the 2012 pilot cities, but Xinjiang does not. They are both automobile manufacturing firms, so the M service input ratio in total inputs remains the same considering that the input-output table can only be specific to the sector dimension. Therefore, for the firms in the same industry, both time and region variation work if the above local purchase assumption holds. But in reality, this assumption is very strong, and we cannot make sure that only local service purchase exists. In the real world, cross-city service purchases may be more common compared to local purchases and meanwhile, we cannot reject that for some services, the region variation indeed would make some difference considering the high transportation cost. In our empirical analysis, we consider city variation even if the function of city dimension is neglected to some extent.

In sum, we use this R&D ratio to differentiate the treatment and control group in our empirical analysis after 2013 since the BT-to-VAT reform was expanded nationwide this year. But the year 2012, the beginning year of BT-to-VAT, is special since the region coverage of reform only includes 9 provinces this year. Considering the region variation, the treatment group includes only industries with high R&D ratios in these 9 provinces in 2012.

3 Data

We use firm-level data from National Tax Survey Database (NTSD), jointly collected by the State Administration of Taxation of China and the Ministry of Finance of China (SAT-MOF) annually based on the stratified random sampling method. Stratification occurs by total sales, industry, and types of taxpayers. The objective of this dataset is to better control the tax base information and evaluate the tax policy effect. This dataset was initiated in 1985 for tax enforcement purposes. The main content of this tax survey has been expanded to cover all 16 tax categories associated with enterprise operations. In addition to more than 30 indicators for specific products and services, more than 400 indicators for enterprises are also surveyed. Tax return indicators of major tax categories, data from major financial statements, and various indicators needed for fiscal and tax system reform have been uniformly included in the scope of the survey. The survey respondents are all independent and actual taxpayers (excluding self-employed entrepreneurs). The Tax Administration Department of the Ministry of Finance, 71 provincial tax authorities and their subordinate tax authorities, and more than 700,000 enterprises are under investigation. Those surveyed firms are asked to log in to a specially designed electronic system within a period to complete the survey online and local tax agencies take efforts to ensure the completion and quality of the survey. Then the tax authorities regularly audit the survey forms submitted by the investigated enterprises every year and then summarize and report them step by step to form the national tax survey data, adhering to the truth, accuracy, and completeness as the highest principle.

Combining the implementation date of the BT-to-VAT reform and data availability, the time we focus on is 2010-2015 which could not only avoid the effect of VAT reform but also consider the multiple steps of BT-to-VAT reform. Besides, we use the 2012 input-output table from the National Bureau of Statistics to connect the BT-to-VAT reform with the manufacturing sector. We choose the 2012 input-output table since it is relatively disaggregated by sector. The 2012 input-output table contains 139 sectors in detail. We also match the patent information from the State Intellectual Property Office of P.R. China with NTSD, which is treated as a measure of innovation performance.

Our sample is further cleaned and derived by imposing the following restrictions. Firstly, to make the industry codes comparable across the entire period, we harmonize the industry classification codes before and after 2011, the year in which the modified classification system was introduced. Secondly, we drop firms with zero employees, negative fixed assets, and negative outputs. Thirdly, we winsorize the upper and lower 1 percentile of the distribution of variables included in the regressions. This is to deal with the outliers that result from the reporting errors. Fourthly, for the benchmark analysis of our paper, we only focus on manufacturing firms with observations in other sectors dropped in our data processing. Fifthly, small-scale VAT taxpayers in the manufacturing sector cannot deduct any intermediate input and do not adjust their tax rates during the BT-to-VAT reform. But, this part of firms is only a very small portion of our sample, which is about 0.98% in the total sample. So, we drop these firms in our analysis. Finally, to avoid likely heterogeneity in R&D choices unrelated to price effects among firms that are failing, acquired, or newly started, we excluded those firms not in operation for the entire study period, 2010-2015. By focusing on a balanced panel, our baseline results speak to how existing firms respond to the R&D bonus induced by the BT-to-VAT reform. In sum, imposing these restrictions gives us a sample of about 147,330 observations for empirical analysis. Summary statistics for the manufacturing sample are given in Table 2.

4 Empirical Method

We estimate the effects of R&D outsourcing bonus on manufacturing outcomes using the following regression:

$$Y_{it} = \beta(R\&D\_Bonus)_{it} + X'_{it}\eta + \lambda_i + \lambda_t + \nu_{it}, \quad (1)$$

where Y_{it} is an outcome of interest for firm i in year t, including employment, capital stock, in-house R&D, and purchased R&D, which are four inputs used in the model below. Furthermore, output level, number of patents application, and total factor productivity are also treated as outcome variables in our analysis. β^L , β^K, β^{IN} and β^{EX} represent the effect of this bonus on plants' employment, capital stock, in-house R&D and purchased R&D respectively. β^Y, $\beta^{patents}$, β^{TFP} represent the effect of this bonus on plants' output, the number of patents applications, and total factor productivity.

R&D outsourcing bonus of the manufacturing firm i in year t is constructed as follows:

$$R\&D\_Bonus_{it} = high\_dependence_i * BTVAT_{it},$$

where $BTVAT_{it}$ represents different stages of BT-to-VAT (two stages 2012, 2013 reform) considering only the regional and time variations without industry variation. Here, $BTVAT_{it} = 1$ if $year2012_{it} = 1$ and $pilot\,cities_i = 1$; $BTVAT_{it} = 1$ if $year2013_{it} = 1$ and $pilot\,cities_i = 0$; $BTVAT_{it} = 0$ otherwise. $pilot\,cities_i$ equals 1 if a firm belongs to the pilot cities of BT-to-VAT reform in 2012 and 0 otherwise. The pilot cities include Shanghai, Beijing, Tianjin, Jiangsu, Anhui, Zhejiang, Fujian, Hubei, and Guangdong in detail. $year2012_{it}$ equals 0 for the 2008-2011 period and 1 for the 2012-2015 period; $year2013_{it}$ equals 0 for the 2008-2012 period and 1 for the 2013-2015 period. $high\_dependence_i$ is a dummy variable to differentiate whether the manufacturing firms belong to the more affected industries and less affected industries by the R&D bonus caused by the BT-to-VAT reform. Here we use inputs from R&D service industries to total intermediate inputs to determine the dummy variable, i.e., $high\_dependence_i$. That is, manufacturing firms with high ratios of R&D service input to total inputs are categorized as the more affected firms with $high\_dependence_i = 1$, and others with low ratios are the less affected firms with $high\_dependence_i = 0$. Table A1 in the appendix shows the detailed value of $high\_dependence$ for each sector of the input-output table. X'_{it} is a vector of fixed effects that varies across specifications; λ_i is the firm-level fixed effect that captures all time-invariant components of manufacturing activity; λ_t is year-fixed effects to control for macroeconomic shocks such as global financial crises and fiscal stimulus to all firms.

We rely on the key assumption that in the absence of the R&D bonus, the more affected and less affected firms would have similar trends. Although we cannot directly check this assumption, we can examine whether the more and less affected firms shared the same trend in the pre-reform period. If it is the case, the more affected firms would still potentially have the same trend as less affected firms in the post-reform period if the BT-to-VAT reform were not carried out. For this purpose, we use the imputation approach of Borusyak, Jaravel, and Spiess (2021), which includes pre-trend testing in event studies. The corresponding figures for the pre-tend testing in event studies are listed in Figures 4-8. The results are shown in Table A2 in the appendix.

Furthermore, we show that our results are robust if we include province-by-year fixed effects and flexible controls for trends that are correlated with firms' characteristics. In detail, we include firms' asset size bins interacted with year-fixed effects, firms' TFP bins interacted with year-fixed effects, and firms' employment size bins interacted with year-fixed effects. Assets size is determined by the average value of firms' assets in the pre-reform period and employment size is determined by the average value of firms' employment in the pre-reform period. TFP is calculated by using the LP method with ACF correction and we measure it using the pre-reform average value of the calculated values. We define two bins for each of the above variables, i.e., assets size, TFP, and employment size. The controls make sure that the effects of R&D bonus are not confounded by trends that affect firms of different assets size, employment size, or productivity.

5 Effects of R&D Outsourcing Bonus

This section presents the estimates of the effect of R&D bonus on manufacturing outcomes. We first estimate the effect of the R&D outsourcing bonus on outsourced R&D and in-house R&D. We also introduce patent applications as a measure of innovation performance. Then we estimate the effects of the bonus on other inputs, i.e., capital and labor. Finally, we characterize how this R&D outsourcing bonus influences output and total factor productivity.

5.1 Outsourced R&D Response

We begin by investigating the effects of R&D bonus on outsourced R&D. Panel A of Table 3 shows the estimates of the effects of R&D bonus on log outsourced R&D. Column (1), which reports difference-in-difference (DD) estimates with only firm and year fixed effects, shows an approximately relative outsourced R&D increase of 4.71% ($p<0.01$). In column (2), we add province-by-year fixed effects which assuage concerns that differences across provinces may impact our results. We obtain an increase in outsourced R&D of about 5.36% ($p<0.01$) once the province-by-year fixed effects are considered. Column (3) introduces firms' asset trends based on column (2), yielding about a 4.57% increase in outsourced R&D under the effect of the R&D bonus. The firm's asset size is measured by pre-reform average total assets, and we divided it into two bins in the following analysis. Corresponding trends are constructed by an interaction of asset size bins and year-fixed effects. This trend ensures that the effects of R&D bonus are not confounded by trends that will influence firms of different assets.

Besides the asset trends, trends that affect firms of different employment levels and TFP could also confound our results. Thus, we add relevant trends in columns (4) and (5). TFP here is determined by the pre-reform average level and employment size is measured by pre-reform average employment. Both are divided into two bins in the trend's construction. In column (4), an interaction term of TFP bins and year-fixed effects is added. We find that outsourced R&D has an approximately 4.57% increase. In column (5), we consider all the above-mentioned trends and achieve about a 4.73% increase in outsourced R&D. In detail, Column (5) supplements column (4) by including employment size bins that interact with year fixed effect.

From the Tax Survey data, we could notice that many firms have no R&D service outsourcing. Outsourced R&D service has many zero values, prompting us to consider another outcome variable to capture extensive margin responses. We use the inverse hyperbolic sine (IHS, i.e., $\sqrt{x^2+1}$) of outsourced R&D to capture both intensive and extensive margins of response. Corresponding results are shown in Panel B of Table 3. Results in Panel (A) are nearly identical to results in Panel(B) since IHS of outsourced R&D takes similar values as the simple ln(outcome variable) for large values of outsourced R&D. Column (1) in panel B considers only firm and year fixed effect, column (2) adds province-by-year fixed effect to column (1). Assets bins-by-year fixed effects, TFP bins-by-year fixed effects, and employment bins-by-year fixed effects are progressively included in the estimations. All the columns produce estimates for the increase in IHS of outsourced R&D that vary from 5.44% to 6.40%. In sum, the effect of the R&D bonus stimulated by BT-to-VAT reform on outsourced R&D is positive and statistically significant. In Section 6, we will show that R&D bonus may influence outsourced R&D through both scale effect and substitution effect. We also show that our results are robust to extending our sample to an unbalanced one, which is reported in the Table A3 in the online appendix.

From the Figure 4, we can see that differences in ln(outsourced R&D) shown in

Panel A and IHS of outsourced R&D shown in Panel B are both statistically insignificant in the pre-reform period, supporting the validity of our empirical method. During the post-reform period, firms that benefit more from the R&D bonus have a large increase in ln(outsourced R&D) and IHS of outsourced R&D compared to the ones that benefit less from the R&D bonus. The difference in ln(outsourced R&D) and IHS of outsourced R&D between treatment and control groups are statistically significant in all years after 2012 when the BT-to-VAT reform was carried out. From the figure, we could see that the trend in Panel A is very similar to that in Panel B. The difference is in the detailed coefficient values of different terms about outsourced R&D.

5.2 In-house R&D Response

The above results demonstrate that the R&D bonus caused by the BT-to-VAT reform has a positive and significant impact on outsourced R&D. We now turn to the in-house R&D and explore whether the increase in outsourced R&D will crowd out the in-house R&D. Opposite to the crowding out effect, firms may promote their in-house R&D to interact with more outsourced R&D. Corresponding result of the event study about the effect of R&D bonus on in-house R&D is shown in Figure 5. From the figure, we could see that the treated and control firms almost have similar trends in ln(in-house R&D) and IHS of in-house R&D before the occurrence of the R&D bonus. But both the ln(in-house R&D) and IHS of in-house R&D of the treated firms have a large and significant increase compared to the control ones after they are affected by the R&D bonus. Although this effect continues during the sample period, the relative increase has a slowdown trend in later years. Trends in Panel A and Panel B are almost the same, the only difference is the detailed values of estimated coefficients of different outcome variables.

The effects of the R&D bonus on in-house R&D from both intensive and extensive margins are reported in Table 4. Column (1) in panel A shows an approximately 5.49% increase in in-house R&D among treated firms when only firm and year fixed effects are considered in the regression. Once the province-by-year fixed effect is added, in-house R&D increases by 5.54% under the effect of the R&D bonus. Like the empirical analysis of outsourced R&D, we introduce flexible controls for trends related to firms' characteristics like assets, TFP, and employment. Column (3) reports an about 4.97% increase with asset trends considered. Column (4) supplements column (3) by TFP trends, yielding also an about 4.97% increase in in-house R&D. Column (5) appends column (4) by employment trends, resulting in about a 5.05% increase in in-house R&D. Panel B provides us with the results about the effects of the R&D bonus on in-house R&D considering extensive margin. In sum, the increase in IHS of in-house R&D ranges from 5.94% to 6.61% in different specifications of regressions. Combining the above results from Tables 3 and 4, we find that not only the outsourced R&D but also the in-house R&D is positively and significantly influenced by the R&D bonus induced by the BT-to-VAT reform. When we extend the sample to an unbalanced one in Table A4 in the appendix, the results of in-house R&D are robust.

5.3 Patent Response

We utilize patent applications as a measure of innovation performance. The correlated results are displayed in Table 5. Different from the innovation inputs (in-house R&D and outsourced R&D), it often takes some time for firms to own patent applications. So, we use the one-period forward of ln (number of patent applications) as our outcome variable. In detail, we examine the effect of an R&D bonus not only on the total patent applications in Panel A but also on the invention patent applications in Panel B. Patent has three types including invention patent, utility model patent, and design patent. Among them, the invention patent is the most important type of innovation. Therefore, we include it as a separate outcome variable in our analysis.

We start off the estimation by controlling for firm fixed effects and year fixed effects in column (1) of panel A. It turns out that the R&D bonus is positively and statistically significantly associated with the number of total patent applications, which is consistent with previous findings about the in-house R&D. Column (2) takes a further step by including province-by-year fixed effects. The coefficient of the R&D bonus is still positive and statistically significant at the 1 percent level. Column (3) adds asset bins-by-year fixed effect, implying that relative to the control firms, the R&D bonus led to a 1.69 log points increase in the number of total patent applications of the treated firms. Column (4) appends the predicting column by considering TFP bins-by-year fixed effect and yields a similar result to column (3). Column (5) incorporates all the above-mentioned fixed effects and shows a 1.65 log points increase.

The results of the invention patent applications are reported in panel B. In all five specifications, firms exhibit positive and significant responses in the number of invention patent applications to the R&D bonus. The estimated coefficient of the R&D bonus in column 5 is 0.0096, which indicates that the number of invention patent applications of the treated firms' increases on average by 0.96% more than that of the control firms under the effect of the R&D bonus. As shown, our results about the effects of the R&D bonus on total patent applications and invention patent applications are quite robust across these alternative specifications. Furthermore, the patents' responses to the R&D bonus are robust if we change to the unbalanced sample and relevant results are reported in Table A5 in the appendix.

5.4 Other Inputs Responses

We now turn our attention to other basic inputs, i.e., capital and labor, in the manufacturing firms' production. The event study coefficients reflecting the effects of bonus on real capital stock and employment are depicted in Figures 6 and 7 respectively. The treated and control firms have similar trends for both capital and employment in the pre-reform periods. In 2012, we observe that relative to control firms, treated firms saw a large and statistical increase in real capital stock and employment. This effect continues during the sample period and increases further in the later years.

In addition, we find real capital stock and employment are both positively and significantly influenced by the R&D bonus and relevant results are shown in Table 6. From Panel A of Table 6, there is an increase ranging from 4.31% to 4.85% in real capital stock under the influence of the R&D bonus. The different fixed effects included in each column are the same as the previous analysis of outsourced R&D and in-house R&D. In Panel B, a range from 4.72% to 5.78% increase in employment occurred among the R&D bonus-treated firms in various specifications considering different fixed effects as before. The results are robust even if we rely on an unbalanced sample, which is represented in Table A6 of the appendix.

5.5 Outputs

Besides the inputs used in production, we also examine how the total output is affected. In Figure 8, we could see that there is no difference in output levels between the more and less affected firms before the implementation of the BT-to-VAT reform. But the more affected firm have a large increase in their output level compared to the less affected ones after 2012. The coefficients estimate in Panel A of Table 7 shows us a large and statistically significant increase in output (from 2.78% to 4.03%) when firms are faced with the R&D bonus under the BT-to-VAT reform. The results shown in each column are consistent with the previous analysis of various inputs used in the production. When all the inputs are positively and significantly stimulated by the R&D bonus, the total output will also be promoted. These findings suggest that R&D bonus help treated firms increase their overall scale.

6 Estimating the Elasticity of Substitution

The above empirical analysis shows the effect of the R&D bonus induced by the BT-to-VAT reform. But to have a better and more comprehensive understanding of the economic mechanism through which the reform influences the outsourced and in-house R&D, we turn to a structural model. Marshall (1890) and Hicks (1932) found that policies that changed the price of inputs impacted both plants' choice of input to minimize the cost (substitution effect) and the output level to maximize profits (scale effect). Based on their research, we follow Curtis et al. (2022) to set up a model to estimate factor demand using the variation caused by the R&D bonus. With the help of the model, we could not only estimate which effect dominates and meanwhile calculate the elasticity of substitution between outsourced and in-house R&D.

6.1 Model Setup

The model studies the production and pricing decisions of plants in the manufacturing sector. Suppose firms have a production function with constant returns to scale, which uses four inputs in their production process: capital K, labor L, in-house R&D, and purchased R&D. Firms first optimally choose inputs to minimize costs and then maximize profits by choosing output. Demand here has a constant price elasticity since the output market is characterized by monopolistic competition. BT-to-VAT reform lowers the cost of purchasing R&D service, denoted by $\phi \equiv \frac{\partial ln(Cost\ of\ R\&D\ outsourcing)}{\partial R\&D\_bonus} < 0$, that is $\phi \equiv \frac{\partial ln(P_{EX})}{\partial R\&D\_bonus} < 0$.

Firms minimize production costs subject to constant returns to scale technology; let $c(w, R, P_{IN}, P_{EX})$ denote the firm's unit cost function, which depends on the wage (w), the rental rate of capital (R) and the price of in-house R&D (P_{IN}) and the price of purchasing R&D from outside (P_{EX}). With constant returns to scale production technology, profit maximization for a firm producing variety i is determined by the following expression:

$$\max_{q(i)} p(q(i))q(i) - c(w, R, P_{IN}, P_{EX})q(i)$$

Solving and rearranging yields the following first-order condition:

$$\left(\frac{\partial p(i)q(i)}{\partial q(i)p(i)} + 1\right) p(i) = c(w, R, P_{IN}, P_{EX})$$

The optimal price for i as a function of fixed mark-up μ and input prices:

$$p(i) = \underbrace{\frac{k}{k-1}}_{\equiv\mu} c(w, R, P_{IN}, P_{EX})$$

Taking natural logarithms and differentiating with respect to P_{EX} gives

$$\frac{\partial lnp(i)}{\partial P_{EX}} = \frac{\partial lnc(w, R, P_{IN}, P_{EX})}{\partial P_{EX}} + \frac{\partial ln\mu}{\partial P_{EX}}$$

Given that the mark-up μ is constant, $\frac{\partial ln\mu}{\partial P_{EX}} = 0$. Shephard's lemma ($\frac{\partial c(w,R,P_{IN},P_{EX})}{\partial P_{EX}} = c_{P_{EX}} = \frac{EX}{q}$) then implies that the elasticity of output prices with respect to the price of purchasing R&D from outside is equal to the share of R&D outsourcing cost in total cost, S_{EX}:

$$\frac{\partial lnp(i)}{\partial lnP_{EX}} = \frac{P_{EX} \times c_{P_{EX}}}{c} = \frac{P_{EX} \times EX}{cq(i)} \equiv S_{EX}$$

Letting $-\eta \equiv \frac{\partial lnq(i)}{\partial lnp(i)}$

$$\frac{\partial lnq(i)}{\partial lnP_{EX}} = \frac{\partial lnq(i)}{\partial lnp(i)} \frac{\partial lnp(i)}{\partial lnP_{EX}} = -\eta S_{EX}$$

For the optimal choice of R&D outsourcing, Shephard's lemma gives $EX = c_{P_{EX}} q$. Therefore,

$$\frac{\partial \ln EX(i)}{\partial P_{EX}} = \frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}} + \frac{\partial \ln q(i)}{\partial P_{EX}}, c_{P_{EX}P_{EX}} = \frac{\partial c_{P_{EX}}}{\partial P_{EX}}$$

Multiplying both sides of the above expression by $\frac{\partial P_{EX}}{\partial lnP_{EX}} = P_{EX}$ and substituting for the previously derived expression for $\frac{\partial lnq(i)}{\partial lnP_{EX}} = -\eta S_{EX}$ yields

$$\frac{\partial \ln EX(i)}{\partial \ln P_{EX}} = P_{EX} \frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}} - \eta S_{EX}$$

To write $\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}}$ in terms of elasticities of substitution, note that constant returns to scale and Shephard's lemma imply that:

$$qc(w, R, P_{IN}P_{EX}) = wL + RK + P_{IN}IN + P_{EX}EX$$

$$qc(w, R, P_{IN}, P_{EX}) = wc_w q + Rc_R q + P_{IN}c_{P_{IN}} q + P_{EX}c_{P_{EX}} q$$

$$c(w, R, P_{IN}, P_{EX}) = wc_w + Rc_R + P_{IN}c_{P_{IN}} + P_{EX}c_{P_{EX}}$$

Differentiating with respect to the cost of R&D outsourcing (P_{EX}) implies

$$c_{P_{EX}} = wc_{wP_{EX}} + Rc_{RP_{EX}} + P_{IN}c_{P_{IN}P_{EX}} + c_{P_{EX}} + P_{EX}c_{P_{EX}P_{EX}}$$

$$1 = w\frac{c_{WP_{EX}}}{c_{P_{EX}}} + R\frac{c_{RP_{EX}}}{c_{P_{EX}}} + P_{IN}\frac{c_{P_{IN}P_{EX}}}{c_{P_{EX}}} + 1 + P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}}$$

$$P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}} = -w\frac{c_{wP_{EX}}}{c_{P_{EX}}} - R\frac{c_{RP_{EX}}}{c_{P_{EX}}} - P_{IN}\frac{c_{P_{IN}P_{EX}}}{c_{P_{EX}}}$$

$$P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}} = -\frac{wL}{qc} \times \frac{cc_{wP_{EX}}}{c_w c_{P_{EX}}} - \frac{RK}{qc} \times \frac{cc_{RP_{EX}}}{c_R c_{P_{EX}}} - \frac{P_{IN}IN}{qc} \times \frac{cc_{P_{IN}P_{EX}}}{c_{P_{IN}}c_{P_{EX}}}$$

$$P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{EX}} = -S_L\sigma_{LEX} - S_K\sigma_{KEX} - S_{IN}\sigma_{INEX}$$

Here S_L represents the cost share of labor, S_K represents the cost share of capital, S_{IN} represents the cost share of in-house R&D. Based on the previous expression for $\frac{\partial lnEX(i)}{\partial lnP_{EX}}$, we can get

$$\frac{\partial \ln EX(i)}{\partial \ln P_{EX}} = -S_L\sigma_{LEX} - S_K\sigma_{KEX} - S_{IN}\sigma_{INEX} - \eta S_{EX}$$

Again letting $\phi \equiv \frac{\partial ln(P_{EX})}{\partial R\&D\_bonus} < 0$ and combining the above expression, we could have

$$\frac{\partial \ln EX(i)}{\partial R\&D\_\text{bonus}} = (-S_L\sigma_{LEX} - S_K\sigma_{KEX} - S_{IN}\sigma_{INEX} - \eta S_{EX}) \times \phi$$

A more detailed derivation of the model is provided in the Appendix. These simple assumptions allow us to capture the effects of R&D bonus caused by the BT-to-VAT reform on firms' demands for inputs of production. The reduction in the cost of purchasing R&D service ϕ influences both the choice of cost-minimizing inputs (substitution effect) and the profit-maximizing output level (scale effect). To see this, note that the effect of the R&D bonus on the demand for R&D outsourcing is

$$\begin{aligned}\beta^{EX} &= \frac{\partial lnEX(i)}{\partial R\&D\_bonus} \\ &= (\underbrace{-S_L\sigma_{LEX} - S_K\sigma_{KEX} - S_{IN}\sigma_{INEX}}_{Subsitution\ Effect} - \underbrace{S_{EX}\eta}_{Scale\ Effect}) \\ &\times \underbrace{\phi}_{BT-to-VAT\ reform\ lowers\ cost\ of\ R\&D\ outsourcing}\end{aligned} \tag{2}$$

This equation was interpreted by Jaffe, Minton, Mulligan, and Murphy (2019) as the production analogue of the Slutsky equation since it realizes the separation of substitution effects conditional on output from firms' scale change. Firms (purchasing R&D services from outside) increase their R&D outsourcing to the extent that lower production costs help each plant increase its sales. The strength of this scale effect depends on the cost share of R&D outsourcing S_{EX} and the elasticity of product demand η. Plants also increase their R&D outsourcing by substituting away from other inputs L, K, and in-house R&D. The strength of this substitution effect depends on the input shares (S_L, S_K and S_{IN}) and on the Allen partial elasticities of substitution (σ_{LEX}, σ_{KEX} and σ_{INEX}). σ_{LEX} is the elasticity of substitution between labor and outsourced R&D. σ_{KEX} is the elasticity of substitution between capital and outsourced R&D. σ_{INEX} is the elasticity of substitution between in-house and outsourced R&D. Allen (1938) defines inputs m and n as complements in production whenever $\sigma_{mn} < 0$, while $\sigma_{mn} > 0$ implies that these inputs are substitutes. Both the scale and substitution effects depend on the degree to which an R&D bonus lowers the overall cost of R&D outsourcing, including financing and other frictions. ϕ is treated as the experienced reduction in the cost of R&D outsourcing inclusive of these frictions.

Then, we consider the model's prediction of the effect of R&D bonus on the demands for in-house R&D

$$\beta^{IN} = \frac{\partial IN(i)}{\partial R\&D\_bonus} = (S_{EX}\sigma_{INEX} - \eta S_{EX}) \times \phi \tag{3}$$

Above equation shows that R&D bonus increases in-house R&D when in-house R&D and outsourced R&D are complements, i.e.,$\sigma_{INEX} < 0$, or when the scale effect dominates the substitution effect, i.e., $\eta > \sigma_{INEX} > 0$. Finally, consider the model's prediction of the effect of an R&D bonus on sales

$$\beta^{Revenue} = \frac{lnRevenue}{\partial R\&D\_bonus} = (S_{EX} - \eta S_{EX}) \times \phi \tag{4}$$

Equation (4) shows that the effect of R&D bonus on revenue combines a price decrease of $S_{EX} \times \phi$ with an increase in the quantity sold of $-\eta S_{EX} \times \phi$. There are different methods to define substitution elasticities if more than two inputs are used in the production. Elasticities of substitution in equations (2) and (3) are Allen partial elasticities, which capture substitution between outsourced R&D and other inputs. Allen elasticities could not only help separate the scale and substitution effects of the R&D bonus stimulated by the BT-to-VAT but also construct a transparent link between reduced-reform estimation and model parameters.

6.2 Separating Scale and Substitution Effects

Firstly, we use the model to decompose the effects of R&D bonus on in-house R&D into scale and substitution effects. We can quantify the scale effect using our reduced-reform estimates. The symmetry of Allen elasticities (i.e., $\sigma_{INEX} = \sigma_{EXIN}$) implies that:

$$\bar{\beta} \equiv S_{EX}\beta^{EX} + S_{IN}\beta^{IN} + S_K\beta^K + S_L\beta^L = \eta S_{EX} \times \phi > 0 \tag{5}$$

This equation shows that the cost-weighted average of the effects of R&D bonus on all the plants' inputs of production, $\bar{\beta}$, identifies the common scale effect, $\eta S_{EX} \times \phi$. The scale effect measures the common increase in the use of each input absent the substitution effect. By using equation (5), we could easily calculate the common scale effect of the R&D bonus on the demand for firms' inputs. Panel A in Table 8 displays the estimates of the scale effect using empirical results. According to the calculation of cost shares of all the inputs, column (1) reports that the scale effect is about 5.48%. So, we can say that there is an increase of about 5.48% in the demands for all used inputs once the firms with the goal of maximizing their output level are affected by the R&D bonus caused by the BT-to-VAT reform. Then, we could calculate the elasticity of substitution between in-house & outsourced R&D based on reduced form results and demand elasticity, η. Taking the ratio of equations (3) and (5), we can get

$$\sigma_{INEX} = \eta(1 - \frac{\beta^{IN}}{\bar{\beta}}) \tag{6}$$

When the effect of the R&D bonus on in-house R&D demand β^{IN} is smaller than the scale effect $\bar{\beta}$, in-house R&D (IN) is a substitute for external R&D (EX), i.e., $\sigma_{INEX} > 0$. Conversely, IN complements EX ($\sigma_{INEX} < 0$) when $\beta^{IN} > \bar{\beta}$.

Based on different regression specifications and demand elasticities, the elasticities of substitution between in-house and outsourced R&D are reported in Panel B of Table 8. From column (1), we obtain σ_{INEX} = -0.0089 with the demand elasticity equal to 3.5. Columns (3) and (5) utilize different assumed values of demand elasticity. All the elasticities of substitution in columns (1), (3), and (5) are all calculated based on the regression considering only firm and year fixed effect. Elasticities of substitution in columns (2), (4), and (6) come from the regression specification with province-year fixed added and are based on different demand elasticities. Although there exists a difference in the detailed results, all the calculations show that σ_{INEX} is negative, which means that in-house R&D and outsourced R&D are complements. Since there is an approximately

5.49% increase in in-house R&D once the R&D bonus takes place, which is greater than the common scale effect, 5.48%. In sum, we draw the conclusion that in-house R&D complements outsourced R&D under the influence of the R&D bonus stimulated by the BT-to-VAT reform.

6.3 Heterogeneous Effect

In this section, we explore how the heterogeneity in a firm's size and technology may affect the relationship between internal and external R&D. We proceed by dividing our sample across two indicators. The first indicator measures firm's size by pre-reform average employment. The second one measures the firm's technology according to OECD Directorate for Science, Technology, and Industry Economic Analysis and Statistics Division (2011). We perform separate estimations for each subsample of firms and then use the empirical results to calculate the detailed elasticities of substitution for different groups divided by the above indicators.

First, we show how the firm's size influences the relationship between outsourced R&D and in-house R&D. We use the mean value of employment in the pre-reform for each firm to split the sample into two groups: large-size firms and small-size firms. From Columns (1) and (2) in Table 9, we find that complementarity exists in firms with large sizes, but substitution exists in firms with small sizes. To explain how the size leads to the existence of heterogeneity in the relationship between internal and external R&D. We need to recall the characteristics of R&D investment. From the introduction section, we know that in-house R&D is riskier, more uncertain, and more time and money-consuming compared to outsourced R&D. In the meantime, it has more suck cost. Based on these characteristics, large-size firms are more likely to diversify the risk and bear the sunk cost, so complementarity occurs in this group but not the small-size firms.

Second, we investigate how the technology level affects the relationship. We use the OECD division to differentiate all the industries into a high-tech group and a low-tech group. Firms that belong to the high-technology industries and medium-high-technology industries are deemed to be high-technology firms and the others are treated as firms with low technology. The detailed division from OECD is shown in Table A7 of the Appendix. Column (3) shows that the effect of R&D bonus on in-house R&D is larger than the scale effect of the bonus for high-tech firms, so the in-house R&D complements outsourced R&D. But Column (4) shows opposite results for low-tech firms. Absorptive capacity is a critical element to explain how the technology level results in the heterogenous relationship. Based on the previous analysis, absorptive capacity is strictly positively related to firms' technology level. Firms in high-technology industries can hire more skilled labor, which will positively influence in-house R&D. This updated and promoted in-house R&D will enhance the absorptive capacity. So, high-tech firms with stronger absorptive capacity can better exploit and utilize the outsourced R&D. They could take full advantage of this outside knowledge and resources to complement and develop their own in-house R&D. But for low-tech firms, outsourced R&D may crowd out in-house R&D since they do not have enough ability to absorb and utilize the R&D from outside considering their limited absorptive capacity.

7 Robustness of Model Estimates

In this section, we extend our model to allow for potential cash flow effects of the R&D bonus to relax capacity constraints. Adding cash flow effects to directly impact inputs demand yields similar model estimates. A particular feature of the R&D bonus is that it creates cash flows for firms that purchase R&D from outside because of the lower purchasing cost. These additional cash flows may influence the demand for all the production inputs, especially in-house R&D which is harder to finance.

Firms choose the optimal quantity to maximize their profits but here we assume that firms are faced with constraints in the production cost that they can expand. In this situation, we change our model as follows

$$\max_{q(i)} p(q(i))q(i) - \mathrm{c}\left(\mathrm{w}, \mathrm{R}, P_{IN}, P_{EX}\right) q(i)$$

$$\text{st. } \mathrm{c}\ \left(\mathrm{w}, \mathrm{R}, P_{IN}, P_{EX}\right) q(i) \leq \bar{c} + bI_{out}$$

where total cost does not exceed the combination of a capacity constraint $\bar{c}$ plus cash flow from the deduction in R&D outsourcing stimulated by the BT-to-VAT reform. I_{out} represents the investment in R&D outsourcing and b here is the deduction percent induced by the R&D bonus. Assuming the constraint binds, we have

$$q(i) = \frac{\bar{c} + bI_{out}\left(\mathrm{w}, \mathrm{R}, P_{IN}, P_{EX}\right)}{\mathrm{c}\left(\mathrm{w}, \mathrm{R}, P_{IN}, P_{EX}\right)}$$

Taking the natural logarithm of q_i and taking the derivative with respect to the R&D bonus yields

$$\frac{\partial \ln q(i)}{\partial R\&D\_\mathrm{bonus}} = \frac{\partial q(i)}{\partial R\&D\_\mathrm{bonus}} \frac{1}{q(i)} = \frac{\partial q(i)}{\partial R\&D\_\mathrm{bonus}} \left\{ \frac{\mathrm{c}\left(\mathrm{w}, \mathrm{R}, P_{IN}, P_{EX}\right)}{\bar{c} + bI_{\mathrm{out}}\ \left(\mathrm{w}, \mathrm{R}, P_{IN}, P_{EX}\right)} \right\}$$

$$\frac{\partial \ln q(i)}{\partial R\&D\_\text{bonus}} = \phi P_{EX} \frac{c}{\bar{c} + bI_{out}} \frac{\partial q(i)}{\partial P_{EX}}$$

$$\frac{\partial \ln q(i)}{\partial R\&D\_\text{bonus}} = -\phi S_{EX}\{1 + \underbrace{\frac{S^b \phi^b \left(1 + \varepsilon_b^{I\ \text{out}}\right)}{-\phi S_{EX}}}_{\chi \geq 0}\} = -\phi S_{EX}(1 + \chi)$$

where S^b is the expenditure share of the increased cash flow from R&D bonus and ϕ^b measures the effect of R&D bonus on the deduction percent of invest in outsourced R&D; $\varepsilon_b^{I_{out}}$ is the investment in outsourced R&D elasticity with respect to the deduction percent. The term χ is treated as a measure of the relative importance of cash flow to the cost of R&D outsourcing effects of R&D bonus.

Then we separate the scale and substitution effects. Since firms are still minimizing their cost, the substitution effect of R&D bonus remains the same as the baseline model. However, the scale effect is now changed to the above expression for $\frac{\partial \ln q(i)}{\partial R\&D\_\text{bonus}}$. We obtain the following modified expressions of the model considering the capacity constraints

$$\frac{\partial \ln EX(i)}{\partial R\&D\_\text{bonus}} = [-S_L \sigma_{LEX} - S_K \sigma_{KEX} - S_{IN} \sigma_{INEX} - (1 + \chi) S_{EX}] \times \phi \tag{7}$$

$$\frac{\partial \ln IN(i)}{\partial R\&D\_\text{bonus}} = [S_{EX} \sigma_{INEX} - (1 + \chi) S_{EX}] \times \phi \tag{8}$$

The only difference between the modified model considering the cash flow effects and the baseline model is that $(1+\chi)$ has now replaced η. The scale effect in our baseline mode is determined by profit maximization, which depends on the elasticity of demand η. But in our modified model which considers the capacity constraints, the scale effect depends upon the degree to which cash flow effects of the R&D bonus allow firms to enlarge production. Similarly in the baseline model, the scale effect is identified by the cost-weighted average of inputs effects

$$\bar{\beta} = S_{EX}\beta^{EX} + S_{IN}\beta^{IN} + S_K\beta^K + S_L\beta^L = -S_{EX} \times \phi(1 + \chi) > 0 \tag{9}$$

Combining equations for $\bar{\beta}$ and $\frac{\partial \ln IN(i)}{\partial R\&D\_\text{bonus}}$, we have

$$\sigma_{INEX} = (1 + \chi)\left(1 - \frac{\beta^{IN}}{\bar{\beta}}\right) \tag{10}$$

For the elasticity of substitution between outsourced R&D and in-house R&D, since $\chi \geq 0$. The comparison of $\bar{\beta}$ and β^{IN} determines the sign of σ_{INEX}. That means even if the detailed value of elasticity of substitution changes, the conclusion that whether they are complements or not is unchanged. The analysis shows that the results about the relationship between outsourced and in-house R&D are robust to explicitly modeling the cash-flow effects of R&D bonus.

8 Conclusion

The relationship between in-house R&D and outsourced R&D is an important question in formulating efficient and reasonable fiscal policy about R&D. In this paper, we take advantage of the BT-to-VAT reform in China which lowers the cost of outsourced R&D to investigate this critical question. We show that both in-house R&D and outsourced R&D increase in response to the R&D bonus stimulated by the BT-to-VAT reform. Besides, we also find that other production inputs and output are also promoted by this bonus.

We set up a model to separate the scale and substitution effect induced by the R&D bonus. Moreover, we calculate the detailed elasticity of substitution based on the empirical results. In sum, we draw the conclusion that the relationship between outsourced R&D and in-house R&D is heterogeneous, which depends on the size and technology level of firms. We find that the complementarity relationship exists only in firms with large sizes or high technology levels. For firms with small sizes or low technology levels, outsourced R&D may crowd out the in-house R&D.

Since large firms can bear the uncertainty of returns on in-house R&D investment and have enough financial support for covering the sunk cost, in-house R&D and outsourced R&D are complements rather than substitutes for them. High-technology firms are more likely to own more skilled human resources, which will benefit their in-house R&D and enhance the absorptive capacity. The expected gain from outsourced R&D as an auxiliary means of innovation is greater. As such, outsourced R&D is complementary to in-house R&D in high-technology firms. In the meanwhile, for small firms or low-technology firms, outsourced R&D is more likely to be a substitute for in-house R&D.

Our research can help firms efficiently allocate their resources to different kinds of R&D investment. Moreover, our findings suggest that an effective R&D reform aimed at encouraging R&D investment should consider the heterogeneous relationship between outsourced and in-house R&D, which depends on firm size and technology level.

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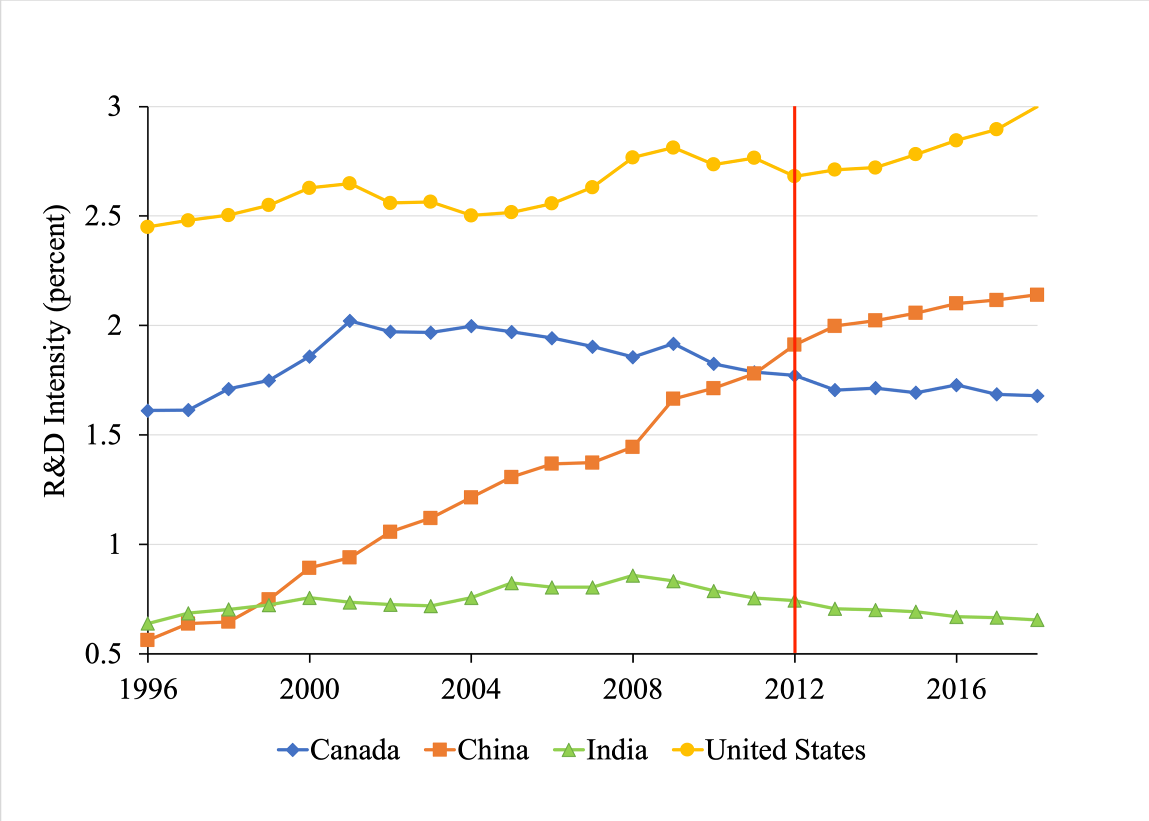
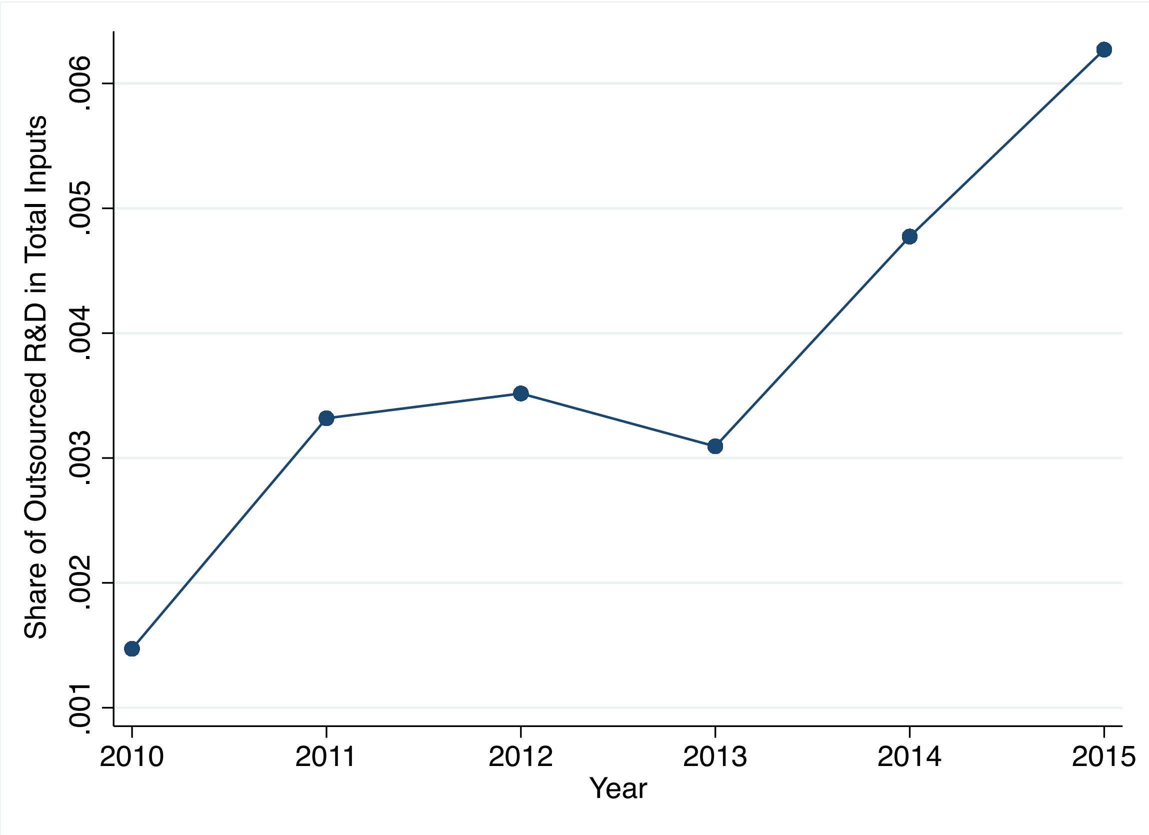
Figure 1: Cross-Country Comparison: R&D as Share of GDP



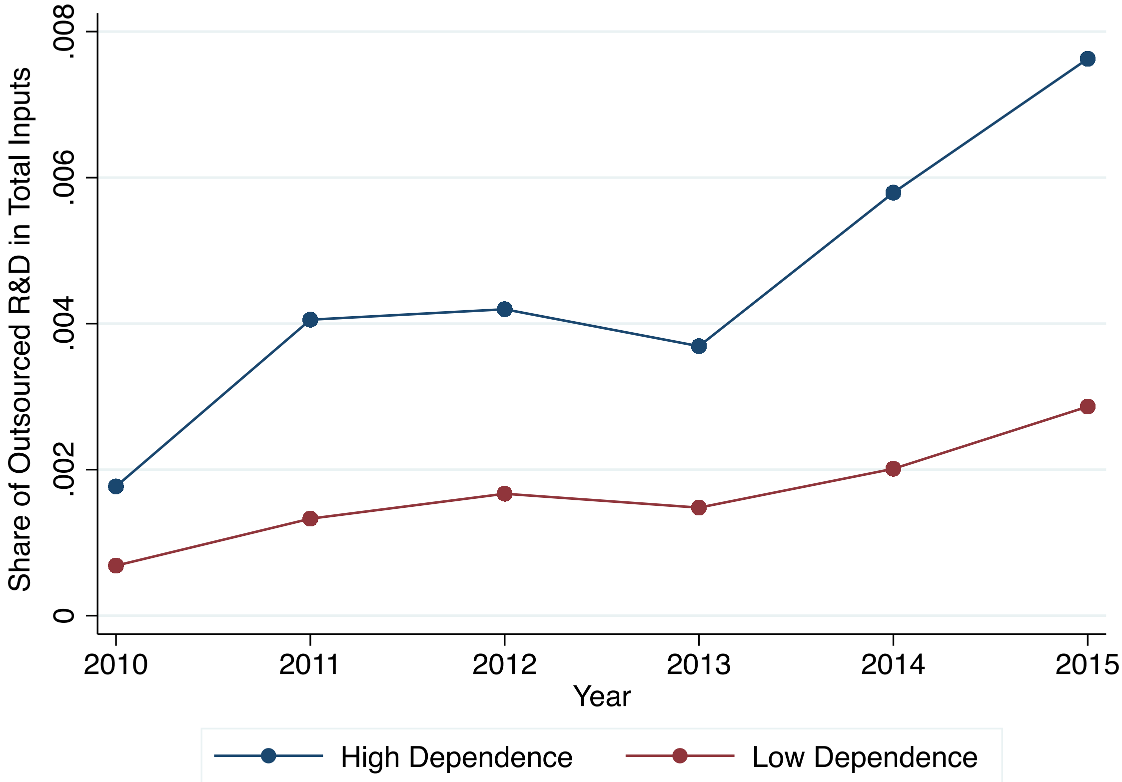
Notes: This figure plots the aggregate R&D intensity, i.e., R&D expenditure as a share of GDP for China, Canada, India and the Unites States. The red line marks the year of the R&D bonus. *Source:* World Bank

Figure 2: The Overall Trend of Outsourced R&D



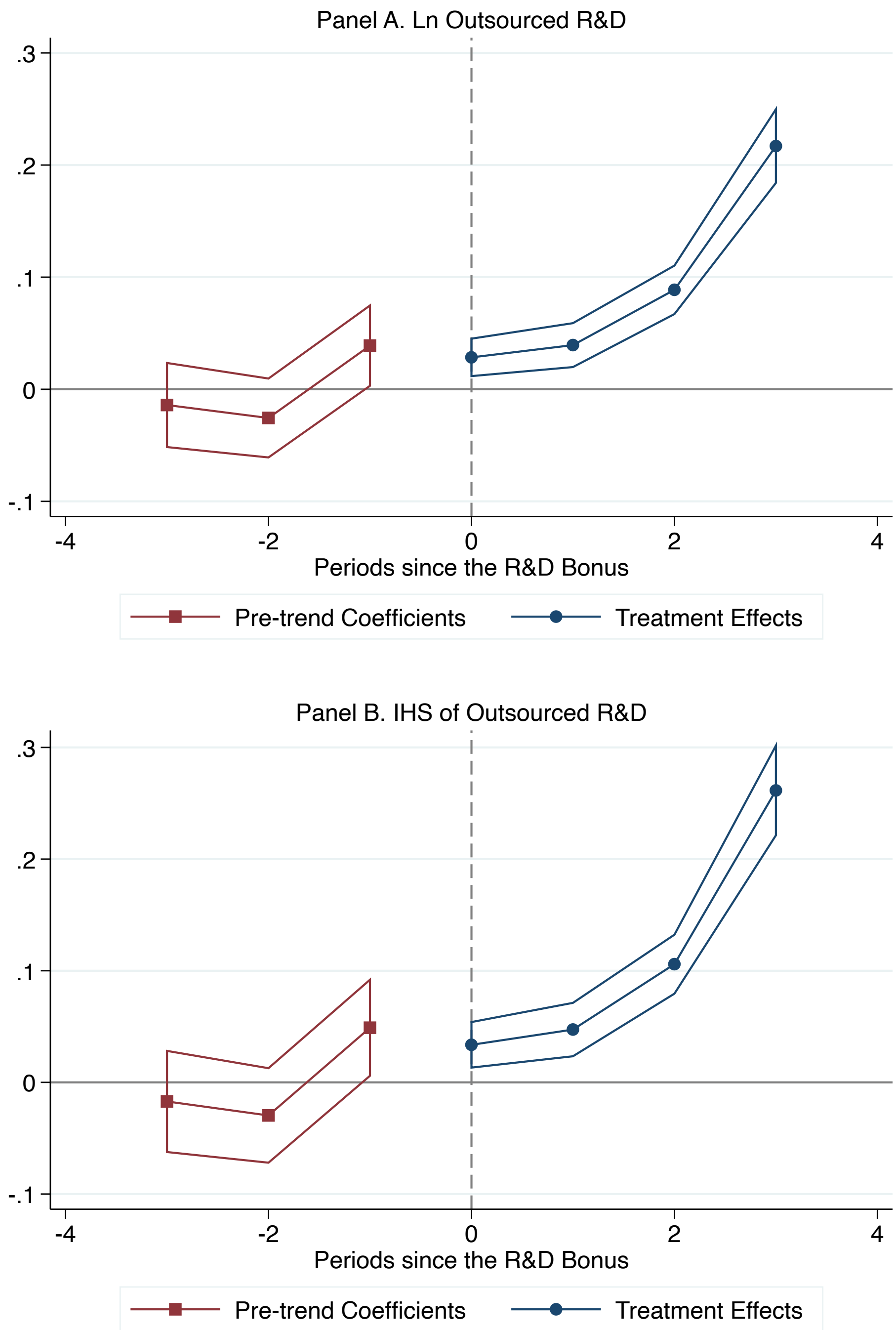
Notes: This figure plots the overall trend of outsourced R&D. The horizontal axis represents the time period, i.e., 2010-2015. The vertical axis represents the changes in the average value of the share of outsourced R&D in total inputs for the whole manufacturing sector. *Source:* Authors' calculations based on NTSD.

Figure 3: The Trend of Outsourced R&D for Different Groups



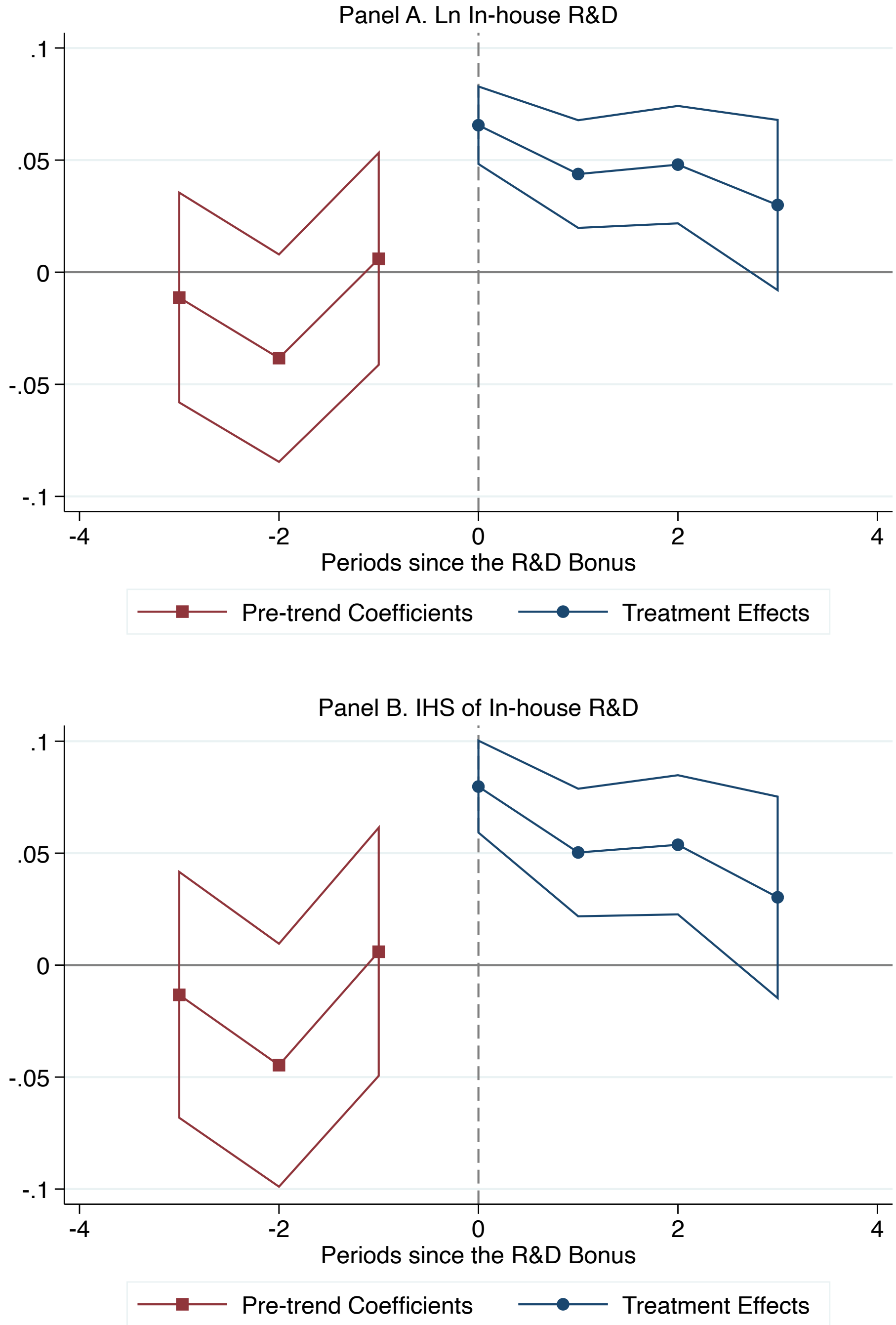
Notes: This figure plots the trend of outsourced R&D for the high dependence group and the low dependence group separately. The horizontal axis represents the time period, i.e., 2010-2015. The vertical axis represents the changes in the average value of the share of outsourced R&D in total inputs for the whole manufacturing sector. The blue line represents the manufacturing firms in the high dependence group and the red line represents the manufacturing firms in the low dependence group. The detailed division which determines whether the firm belongs to the high dependence sector or not is shown in the Table A7 of the Appendix. *Source:*Authors' calculations based on NTSD and 2012 input-output table.

Figure 4: Effects of R&D Bonus on Outsourced R&D



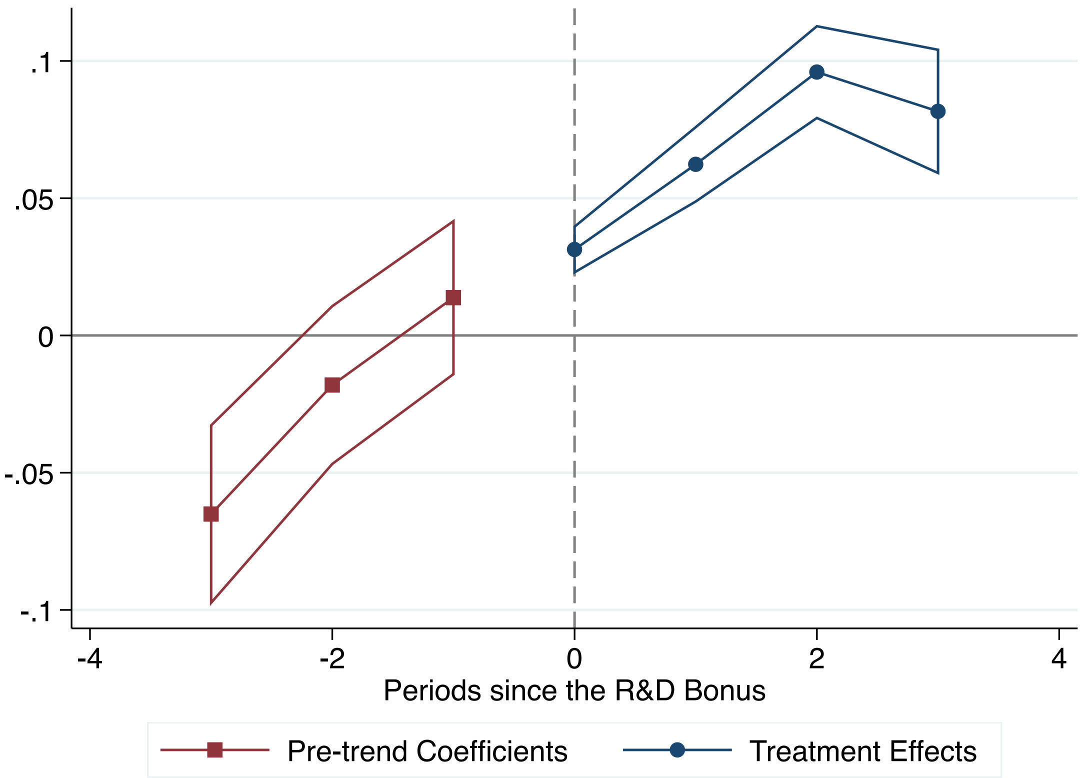
Notes: This figure plots the coefficients in the staggered-adoption difference-in-difference ("event study") estimates. Pre-trend coefficients along with confidence intervals (CIs) are shown in red and post-treatment effects with CIs are shown in blue. The estimated results have been produced by the imputation estimator of Borusyak et al. 2021 (did_imputation). The dependent variable in Panel A is ln(outsourced R&D). The dependent variable in Panel B is IHS of outsourced R&D. The horizontal axis represents the periods since the R&D bonus, and 0 represents the year 2012 in which the R&D bonus occurred. *Source:* Authors' calculations based on NTSD.

Figure 5: Effects of R&D Bonus on In-house R&D



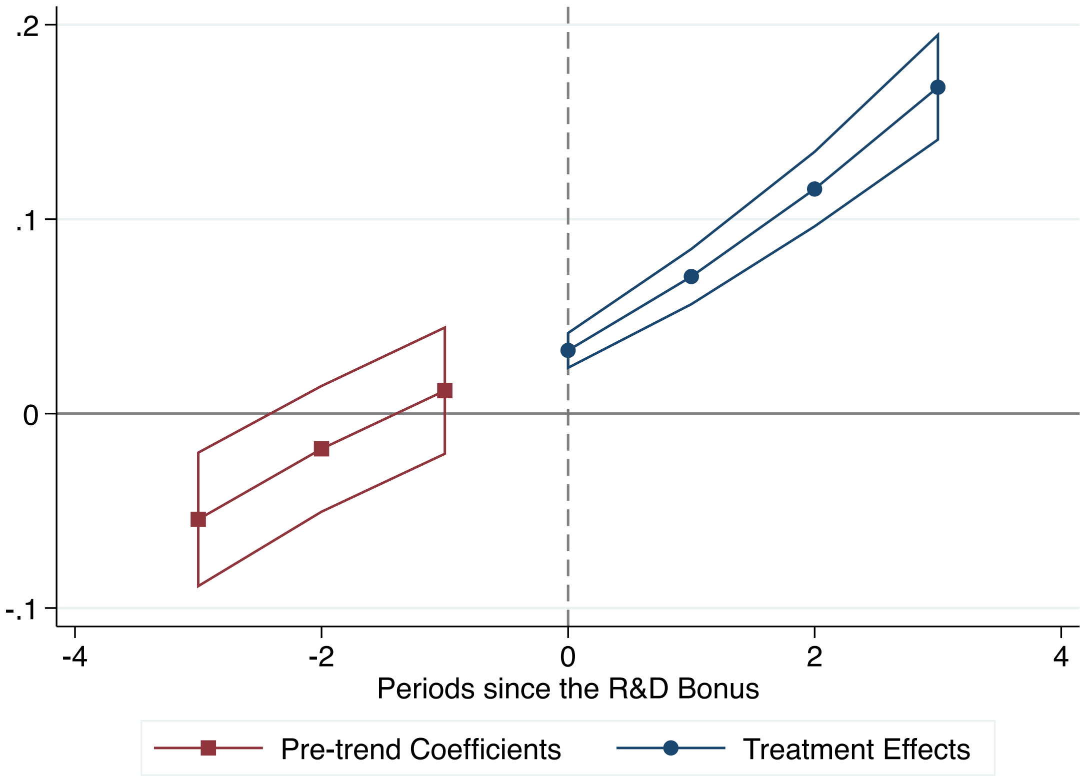
Notes: This figure plots the coefficients in the staggered-adoption difference-in-difference ("event study") estimates. Pre-trend coefficients along with confidence intervals (CIs) are shown in red and post-treatment effects with CIs are shown in blue. The estimated results have been produced by the imputation estimator of Borusyak et al. 2021 (did_imputation). The dependent variable in Panel A is ln(in-house R&D). The dependent variable in Panel B is IHS of in-house R&D. The horizontal axis represents the periods since the R&D bonus, and 0 represents the year 2012 in which the R&D bonus occurred. *Source:* Authors' calculations based on NTSD.

Figure 6: Effects of R&D Bonus on Capital Stock



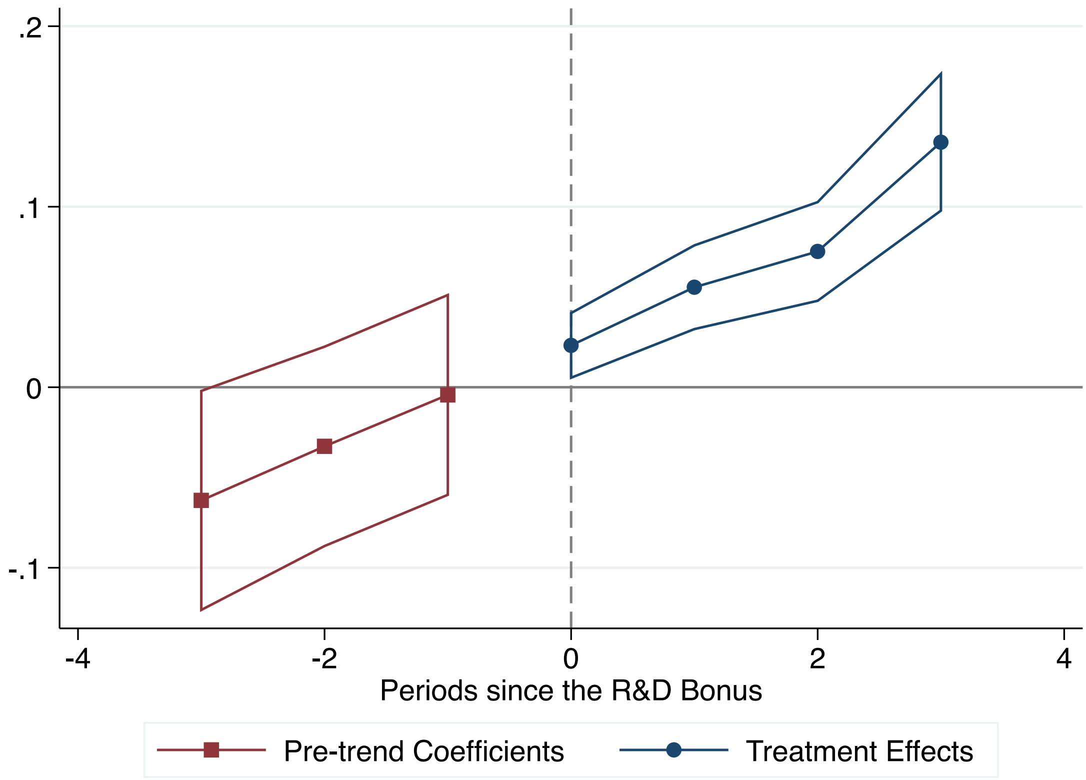
Notes: This figure plots the coefficients in the staggered-adoption difference-in-difference ("event study") estimates. Pre-trend coefficients along with confidence intervals (CIs) are shown in red and post-treatment effects with CIs are shown in blue. The estimated results have been produced by the imputation estimator of Borusyak et al. 2021 (did_imputation). The dependent variable is ln(real capital stock). The horizontal axis represents the periods since the R&D bonus, and 0 represents the year 2012 in which the R&D bonus occurred. *Source:* Authors' calculations based on NTSD.

Figure 7: Effects of R&D Bonus on Employment



Notes: This figure plots the coefficients in the staggered-adoption difference-in-difference ("event study") estimates. Pre-trend coefficients along with confidence intervals (CIs) are shown in red and post-treatment effects with CIs are shown in blue. The estimated results have been produced by the imputation estimator of Borusyak et al. 2021 (did_imputation). The dependent variable is ln(employment). The horizontal axis represents the periods since the R&D bonus, and 0 represents the year 2012 in which the R&D bonus occurred. *Source:* Authors' calculations based on NTSD.

Figure 8: Effects of R&D Bonus on Output



Notes: This figure plots the coefficients in the staggered-adoption difference-in-difference ("event study") estimates. Pre-trend coefficients along with confidence intervals (CIs) are shown in red and post-treatment effects with CIs are shown in blue. The estimated results have been produced by the imputation estimator of Borusyak et al. 2021 (did_imputation). The dependent variable is ln(output). The horizontal axis represents the periods since the R&D bonus, and 0 represents the year 2012 in which the R&D bonus occurred. *Source:* Authors' calculations based on NTSD.

Table 1: An overall view of BT-to-VAT reform expansion

Process	Date	Region	Industry	Regulation
Stage 1	January 1, 2012	Shanghai	Transportation industry (11%) (excluding railway transportation service) Selected modern service industry (6% or 17%)	Fiscal and Tax No. 2011 (111)
Stage 2	September 1 - December 1, 2012	Beijing, Tianjin, Jiangsu Anhui , Zhejiang, Fujian, Hubei, Guangdong	Transportation industry (11%) (excluding railway transportation service) Selected modern service industry (6% or 17%)	Fiscal and Tax No. 2012 (71)
Stage 3	August 1, 2013	Nationwide	Transportation industry (11%) (excluding railway transportation service) Selected modern service industry (6% or 17%) (including radio, film and television services)	Fiscal and Tax No. 2013 (37)
Stage 4	January 1, 2014	Nationwide	Transportation industry (11%) (excluding railway transportation service) Selected modern service industry (6% or 17%) (including radio, film and television services) Postal service industry (11%)	Fiscal and Tax No. 2013 (106)
Stage 5	June 1, 2014	Nationwide	Transportation industry (11%) (excluding railway transportation service) Selected modern service industry (6% or 17%) (including radio, film and television services) Postal service industry (11%) Telecommunications industry (6% or 11%)	Fiscal and Tax No. 2014 (43)
Stage 6	May 1, 2016	Nationwide	All industries covered by business tax before the BT-to-VAT reform	Fiscal and Tax No. 2016 (36)

Notes:
a.The transportation industry (11%) includes road transportation service, water transportation service, air transportation service, and pipeline transportation services in detail. Railway transportation service as one of the road transportation services was not covered under the BT-to-VAT policy until Stage 4.
b. Selected modern service industries include the following industries: 1. R&D and technical service (6%) 2. Information technology service (6%) 3. Cultural and creative service (6%) 4. Logistics support service (6%) 5. Tangible chattel leasing service (17%) 6. Attestation and consulting service (6%)
c. In Stage 2, different cities have different policy implementation dates. In detail, the implantation date for Beijing is September 1; October 1 for Jiangsu and Anhui; November 1 for Fujian and Guangdong; December 1 for Tianjin, Zhejiang, and Hubei
d. The above numbers in red and parentheses represent the statutory tax rate for each industry
e. The telecommunications industry, it includes basic telecommunication services and value-added telecommunication services. The statutory tax rate is 11% for basic telecommunication services and 6% for value-added telecommunication service

Table 2: Summary Statistics for Manufacturing Firms

Variable	N	Mean	SD	Min	P50	Max
Ln(Outsourced R&D)	147324	0.288	0.981	0	0	5.283
Ln(In-house R&D)	147319	0.468	1.295	0	0	5.675
IHS(Outsourced R&D)	147330	0.352	1.2	-4.672	0	12.209
IHS(In-house R&D)	147330	0.558	1.54	-5.688	0	12.233
Ln(Real capital stock)	137189	9.656	2.058	4.341	9.74	14.595
Ln(Employment)	147330	5.21	1.364	1.609	5.226	8.537
Ln(Output)	135777	6.498	1.902	1.383	6.542	11.107
Ln(TFP)	128252	-0.456	1.228	-4.254	-0.417	2.621
Ln(Total patents)	147330	0.393	0.905	0	0	3.970
Ln(Invention patents)	147330	0.209	0.621	0	0	3.178
R&D bonus	147330	0.43	0.495	0	0	1

Notes: All monetary values are in real terms. ln(outsourced R&D) and ln(in-house R&D) take the form of ln (1 + real outsourced R&D) and ln(1 + real in-house R&D) respectively given the existence of zero values of outsourced R&D and in-house R&D for many firms. IHS(outsourced R&D) is the inverse hyperbolic sine (IHS, i.e., ln (x+$\sqrt{x^2+1}$)) of outsourced R&D and IHS(in-house R&D) is the inverse hyperbolic sine of in-house R&D. And x here is the real value both outsourced R&D and in-house R&D. The inverse hyperbolic sine can help capture both intensive and extensive margins of response. TFP here is the calculated total factor productivity by LP method with ACF correction. "Patent" here is short for patent applications but not granted patents. "Total patents" represents the total number of patent applications including invention, utility model, and design patents. "Invention patents" represents the number of only invention patent applications. ln(total patents) is ln(1+number of total patent applications) and ln(invention patents) is ln(1+number of invention patent applications).

Table 3: Effects of R&D Bonus on Outsourced R&D

	Panel A: Ln Outsourced R&D				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0471***	0.0536***	0.0457***	0.0457***	0.0473***
	(0.0074)	(0.0075)	(0.0075)	(0.0075)	(0.0075)
Observations	147,324	147,324	147,324	147,324	147,324
R-squared	0.015	0.019	0.019	0.019	0.020
	Panel B: IHS Outsourced R&D				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0564***	0.0640***	0.0544***	0.0545***	0.0564***
	(0.0090)	(0.0092)	(0.0091)	(0.0092)	(0.0092)
Observations	147,330	147,330	147,330	147,330	147,330
R-squared	0.015	0.019	0.019	0.019	0.020
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Province×Year FE	No	Yes	Yes	Yes	Yes
AssetsSize×Year FE	No	No	Yes	Yes	Yes
TFP×Year FE	No	No	No	Yes	Yes
EmploymentSize×Year FE	No	No	No	No	Yes

Notes: Table 3 displays estimates describing the effects of R&D bonus on ln outsourced R&D in Panel (A), on the inverse hyperbolic sine (IHS, i.e., ln $(x+\sqrt{x^2+1})$) of outsourced R&D in Panel (B). Column 1 starts off the estimation including firm and year fixed effect. Column 2 augments Column 1 with province-by-year fixed effect considered. Columns 3, 4, and 5 progressively add assets size bins measured by pre-reform average assets interacted with year fixed effects, TFP bins measured by pre-reform average TFP interacted with year fixed effects, and employment size bins measured by pre-reform average employment interacted with year fixed effect, respectively, to the controls in the preceding column. All the monetary values are in real terms.

Table 4: Effects of R&D Bonus on In-house R&D

	Panel A: Ln In-house R&D				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0549***	0.0554***	0.0497***	0.0497***	0.0505***
	(0.0081)	(0.0081)	(0.0081)	(0.0081)	(0.0081)
Observations	147,319	147,319	147,319	147,319	147,319
R-squared	0.007	0.017	0.017	0.017	0.017
	Panel B: IHS In-house R&D				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0655***	0.0661***	0.0594***	0.0594***	0.0603***
	(0.0096)	(0.0096)	(0.0096)	(0.0096)	(0.0096)
Observations	147,330	147,330	147,330	147,330	147,330
R-squared	0.007	0.017	0.017	0.017	0.017
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Province×Year FE	No	Yes	Yes	Yes	Yes
AssetsSize×Year FE	No	No	Yes	Yes	Yes
TFP×Year FE	No	No	No	Yes	Yes
EmploymentSize×Year FE	No	No	No	No	Yes

Notes: Table 4 displays estimates describing the effects of R&D bonus on ln in-house R&D in Panel (A), on the inverse hyperbolic sine (IHS, i.e., ln $(x+\sqrt{x^2+1})$) of in-house R&D in Panel (B). Column 1 starts off the estimation including firm and year fixed effect. Column 2 augments Column 1 with province-by-year fixed effect considered. Columns 3, 4, and 5 progressively add assets size bins measured by pre-reform average assets interacted with year fixed effects, TFP bins measured by pre-reform average TFP interacted with year fixed effects, and employment size bins measured by pre-reform average employment interacted with year fixed effect, respectively, to the controls in the preceding column. All the monetary values are in real terms.

Table 5: Effects of R&D Bonus on Patent Applications

	Panel A: $Ln\ Total\ Patent_{t+1}$				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0195***	0.0173***	0.0169***	0.0168***	0.0165**
	(0.0064)	(0.0065)	(0.0065)	(0.0065)	(0.0065)
Observations	122,775	122,775	122,775	122,775	122,775
R-squared	0.002	0.004	0.004	0.004	0.004
	Panel B: $Ln\ Invention\ Patent_{t+1}$				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0122***	0.0105**	0.0095**	0.0095**	0.0096**
	(0.0046)	(0.0046)	(0.0046)	(0.0046)	(0.0046)
Observations	122,775	122,775	122,775	122,775	122,775
R-squared	0.003	0.006	0.006	0.006	0.006
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Province×Year FE	No	Yes	Yes	Yes	Yes
AssetsSize×Year FE	No	No	Yes	Yes	Yes
TFP×Year FE	No	No	No	Yes	Yes
EmploymentSize×Year FE	No	No	No	No	Yes

Notes: Table 5 displays estimates describing the effects of the R&D bonus on the number of total patent applications of year t+1 and the number of invention patent applications of year t+1 in Panel (A) and Panel (B) respectively. Column 1 starts off the estimation including firm and year fixed effect. Column 2 augments Column 1 with province-by-year fixed effect considered. Columns 3, 4, and 5 progressively add assets size bins measured by pre-reform average assets interacted with year fixed effects, TFP bins measured by pre-reform average TFP interacted with year fixed effects, and employment size bins measured by pre-reform average employment interacted with year fixed effect, respectively, to the controls in the preceding column. All the monetary values are in real terms.

Table 6: Effects of R&D Bonus on Capital Stock and Employment

	Panel A: Ln Real Capital Stock				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0485***	0.0431***	0.0436***	0.0451***	0.0444***
	(0.0051)	(0.0051)	(0.0051)	(0.0051)	(0.0051)
Observations	137,189	137,189	137,189	137,189	137,189
R-squared	0.048	0.056	0.056	0.059	0.059
	Panel B: Ln Employment				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0578***	0.0572***	0.0528***	0.0541***	0.0472***
	(0.0057)	(0.0056)	(0.0056)	(0.0056)	(0.0056)
Observations	147,330	147,330	147,330	147,330	147,330
R-squared	0.058	0.064	0.065	0.066	0.073
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Province×Year FE	No	Yes	Yes	Yes	Yes
AssetsSize×Year FE	No	No	Yes	Yes	Yes
TFP×Year FE	No	No	No	Yes	Yes
EmploymentSize×Year FE	No	No	No	No	Yes

Notes: Table 6 displays estimates describing the effects of R&D bonus on real capital stock and employment in Panel (A) and Panel (B) respectively. Column 1 starts off the estimation including firm and year fixed effect. Column 2 augments Column 1 with province-by-year fixed effect considered. Columns 3, 4, and 5 progressively add assets size bins measured by pre-reform average assets interacted with year fixed effects, TFP bins measured by pre-reform average TFP interacted with year fixed effects, and employment size bins measured by pre-reform average employment interacted with year fixed effect, respectively, to the controls in the preceding column. All the monetary values are in real terms.

Table 7: Effects of R&D Bonus on Output

	Ln Output				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0278***	0.0370***	0.0403***	0.0341***	0.0313***
	(0.0088)	(0.0088)	(0.0088)	(0.0088)	(0.0088)
Observations	135,777	135,777	135,777	135,777	135,777
R-squared	0.011	0.015	0.015	0.024	0.024
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Province×Year FE	No	Yes	Yes	Yes	Yes
AssetsSize×Year FE	No	No	Yes	Yes	Yes
TFP×Year FE	No	No	No	Yes	Yes
EmploymentSize×Year FE	No	No	No	No	Yes

Notes: Table 7 displays estimates describing the effects of R&D bonus on output. Column 1 starts off the estimation including firm and year fixed effect. Column 2 augments Column 1 with province-by-year fixed effect considered. Columns 3, 4, and 5 progressively add assets size bins measured by pre-reform average assets interacted with year fixed effects, TFP bins measured by pre-reform average TFP interacted with year fixed effects, and employment size bins measured by pre-reform average employment interacted with year fixed effect, respectively, to the controls in the preceding column. All the monetary values are in real terms.

Table 8: Model-Based Implications of Reduced-Form Estimates

	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline		Low η		High η	
	Panel A. Scale Effect Estimates					
Scale Effect, $\bar{\beta}$	0.0548	0.0528	0.0548	0.0528	0.0548	0.0528
	Panel B. Allen Elasticities of Substitution					
σ_{INEX}	-0.0089	-0.1711	-0.0051	-0.0977	-0.0127	-0.2444
Cost Shares:						
Outsourced R&D	0.0126	0.0126	0.0126	0.0126	0.0126	0.0126
In-house R&D	0.0258	0.0258	0.0258	0.0258	0.0258	0.0258
Capital	0.3042	0.3042	0.3042	0.3042	0.3042	0.3042
Labor	0.6574	0.6574	0.6574	0.6574	0.6574	0.6574
Demand Elasticity, η	3.50	3.50	2.00	2.00	5.00	5.00

Notes: Table 8 presents the results connecting the reduced form estimates to model outcomes across regression specifications and demand elasticities. Panel (A) shows estimates of the scale effect defined in equation (5). Panel (B) displays estimates of the Allen elasticities of substitution between outsourced R&D and in-house R&D using equation (3). Columns (1), (3), and (5) are based on regression considering only firm and year fixed effect. Columns (2), (4), and (6) are based on regression considering firm, year, and province-year fixed effect.

Table 9: Elasticity of Substitution Considering Heterogeneity

	(1) Large Size	(2) Small Size	(3) High Technology	(4) Low Technology
	Panel A. Scale Effect Estimates			
Scale Effect, $\bar{\beta}$	0.0606	0.0136	-0.0002	0.0413
	Panel B. Allen Elasticities of Substitution			
σ_{INEX}	<0	>0	<0	>0
Relationship	Complement	Supplement	Complement	Supplement
Cost Shares:				
Outsourced R&D	0.0137	0.0051	0.0228	0.0051
In-house R&D	0.0288	0.0068	0.0482	0.0094
Capital	0.3062	0.2915	0.2893	0.3154
Labor	0.6513	0.6966	0.6397	0.6701

Notes: Table 9 displays the results connecting the reduced form estimates to model outcomes considering the heterogeneity effect in terms of size and technology. The results are based on regression with only firm and year-fixed effects considered. Panel (A) shows estimates of the scale effect defined in equation (5). Panel (B) displays estimates of the Allen elasticities of substitution between outsourced R&D and in-house R&D using equation (3). The demand elasticity η is assumed to be 3.50.

A Appendix

A.1 Model Derivation

Firms minimize production costs subject to constant returns to scale technology; let $c(w, R, P_{IN}, P_{EX})$ denote the firm' s unit cost function, which depends on the wage w, the rental rate of capital R and the price of in-house R&D P_{IN} and the price of purchasing R&D from outside P_{EX}. With constant results to scale production technology, profit maximization for a firm producing variety i is determined by the following expression:

$$\max_{q(i)} p(q(i))q(i) - c(w, R, P_{IN}, P_{EX})q(i)$$

Solving and rearranging yields the following first order condition:

$$(\frac{\partial p(i)q(i)}{\partial q(i)p(i)} + 1)p(i) = c(w, R, P_{IN}, P_{EX})$$

From the consumer problem, the inverse elasticity of demand is $\frac{\partial p(i)q(i)}{\partial q(i)p(i)} = -\frac{1}{k}$, which allows us to express the optimal price for i as a function of fixed mark-up μ and input prices:

$$p(i) = \underbrace{\frac{k}{k-1}}_{\equiv \mu} c(w, R, P_{IN}, P_{EX})$$

Using this expression, first consider the effects of R&D bonus induced by the BT-to-VAT reform on firm production. First, consider the effect of an arbitrary change in the cost of purchasing R&D on prices charged by affected firms. Taking natural logarithms and differentiating with respect to P_{EX} gives

$$\frac{\partial lnp(i)}{\partial P_{EX}} = \frac{\partial lnc(w, R, P_{IN}, P_{EX})}{\partial P_{EX}} + \frac{\partial ln\mu}{\partial P_{EX}}$$

Given that the mark-up μ is constant, $\frac{\partial ln\mu}{\partial P_{EX}} = 0$. Shephard' s lemma ($\frac{\partial c(w,R,P_{IN},P_{EX})}{\partial P_{EX}} = c_{P_{EX}} = \frac{EX}{q}$) then implies that the elasticity of output prices with respect to the price of purchasing R&D from outside is equal to the share of R&D outsourcing cost in total cost, S_{EX}:

$$\frac{\partial lnp(i)}{\partial lnP_{EX}} = \frac{P_{EX} \times c_{P_{EX}}}{c} = \frac{P_{EX} \times EX}{cq(i)} \equiv S_{EX}$$

Then based on the above equation, we derive the analogous effect on total revenue:

$$\frac{\partial lnp(i)q(i)}{\partial lnP_{EX}} = \frac{\partial lnp(i)}{\partial lnP_{EX}} + \frac{\partial lnq(i)}{\partial lnP_{EX}}$$

$$\frac{\partial lnp(i)q(i)}{\partial lnP_{EX}} = \frac{\partial lnp(i)}{\partial lnP_{EX}} + \frac{\partial lnq(i)}{\partial lnp(i)}\frac{\partial lnp(i)}{\partial lnP_{EX}}$$

Letting $-\eta \equiv \frac{\partial lnq(i)}{\partial lnp(i)}$, the effect on total revenue of an arbitrary change in the cost of purchasing R&D is

$$\frac{\partial lnp(i)q(i)}{\partial lnP_{EX}} = (1-\eta)S_{EX}$$

Letting $\phi = \frac{\partial ln(P_{EX})}{\partial R\&D\_bonus} < 0$ denote the effect of BT-to-VAT reform on the cost of R&D outsourcing, we arrive at

$$\frac{\partial \ln p(i)q(i)}{\partial R\&D\_bonus} = (1-\eta)S_{EX} \times \phi$$

Next, we derive the effect of BT-to-VAT reform on the input decisions of affected firms. For each input, we use Shephard' s lemma to express the optimal choice of each input as a function of the optimal output quantity and the first derivative of the cost function. Taking lns and differentiating with respect to an arbitrary change in the cost of R&D outsourcing, we may arrive at expressions for the effect of BT-to-VAT reform on optimal input decisions as function of input elasticities of substitution, output demand elasticity, and input cost shares. For the optimal choice of R&D outsourcing, Shephard' s lemma gives $EX = c_{P_{EX}}q$. Therefore,

$$\frac{\partial \ln EX(i)}{\partial P_{EX}} = \frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}} + \frac{\partial \ln q(i)}{\partial P_{EX}}, c_{P_{EX}P_{EX}} = \frac{\partial c_{P_{EX}}}{\partial P_{EX}}$$

Multiplying both sides of the above expression by $\frac{\partial P_{EX}}{\partial lnP_{EX}} = P_{EX}$ and substituting for the previously derived expression for $\frac{\partial lnq(i)}{\partial lnP_{EX}} = -\eta S_{EX}$ yields

$$\frac{\partial \ln EX(i)}{\partial \ln P_{EX}} = P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}} - \eta S_{EX}$$

To write $\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}}$ in terms of elasticity of substitution, note that constant returns to scale and Shephard' s lemma imply that:

$$qc(w, R, P_{IN}P_{EX}) = wL + RK + P_{IN}IN + P_{EX}EX$$

$$qc(w, R, P_{IN}, P_{EX}) = wc_w q + Rc_R q + P_{IN}c_{P_{IN}}q + P_{EX}c_{P_{EX}}q$$

$$c(w, R, P_{IN}, P_{EX}) = wc_w + Rc_R + P_{IN}c_{P_{IN}} + P_{EX}c_{P_{EX}}$$

Differentiating with respect to the cost of R&D outsourcing (P_{EX}) implies

$$c_{P_{EX}} = wc_{wP_{EX}} + Rc_{RP_{EX}} + P_{IN}c_{P_{IN}P_{EX}} + c_{P_{EX}} + P_{EX}c_{P_{EX}P_{EX}}$$

$$1 = w\frac{c_{WP_{EX}}}{c_{P_{EX}}} + R\frac{c_{RP_{EX}}}{c_{P_{EX}}} + P_{IN}\frac{c_{P_{IN}P_{EX}}}{c_{P_{EX}}} + 1 + P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}}$$

$$P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}} = -w\frac{c_{wP_{EX}}}{c_{P_{EX}}} - R\frac{c_{RP_{EX}}}{c_{P_{EX}}} - P_{IN}\frac{c_{P_{IN}P_{EX}}}{c_{P_{EX}}}$$

$$P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}} = -\frac{wLc_{wP_{EX}}}{Lc_{P_{EX}}} - \frac{RKc_{RP_{EX}}}{Kc_{P_{EX}}} - \frac{P_{IN}INc_{P_{IN}P_{EX}}}{INc_{P_{EX}}}$$

$$P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}} = -\frac{wLc_{wP_{EX}}}{qc_w c_{P_{EX}}} - \frac{RKc_{RP_{EX}}}{qc_R c_{P_{EX}}} - \frac{P_{IN}INc_{P_{IN}P_{EX}}}{qc_{P_{IN}}c_{P_{EX}}}$$

$$P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}} = -\frac{wLcc_{wP_{EX}}}{qcc_w c_{P_{EX}}} - \frac{RKcc_{RP_{EX}}}{qcc_R c_{P_{EX}}} - \frac{P_{IN}INcc_{P_{IN}P_{EX}}}{qcc_{P_{IN}}c_{P_{EX}}}$$

$$P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}} = -\frac{wL}{qc} \times \frac{cc_{wP_{EX}}}{c_w c_{P_{EX}}} - \frac{RK}{qc} \times \frac{cc_{RP_{EX}}}{c_R c_{P_{EX}}} - \frac{P_{IN}IN}{qc} \times \frac{cc_{P_{IN}P_{EX}}}{c_{P_{IN}}c_{P_{EX}}}$$

$$P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{EX}} = -S_L\sigma_{LEX} - S_K\sigma_{KEX} - S_{IN}\sigma_{INEX}$$

Where the second and third line solves for $P_{EX}\frac{c_{P_{EX}P_{EX}}}{c_{P_{EX}}}$, the fourth line manipulates each ratio by multiplying and diving by the respective input, and the fifth line uses Shephard' s lemma and further multiplies and divides by c. The last line uses the definitions of cost shares $S_L = \frac{wL}{qc}$, $S_K = \frac{RK}{qc}$ and $S_{IN} = \frac{P_{IN}IN}{qc}$ and of the Allen partial elasticity of substitution between input m and n, which is given by $\sigma_{mn} = \frac{cc_{mn}}{c_m c_n}$. Based on the previous expression for $\frac{\partial lnEX(i)}{\partial lnP_{EX}}$, we can get

$$\frac{\partial \ln EX(i)}{\partial \ln P_{EX}} = -S_L\sigma_{LEX} - S_K\sigma_{KEX} - S_{IN}\sigma_{INEX} - \eta S_{EX}$$

Again letting $\phi \equiv \frac{\partial ln(P_{EX})}{\partial R\&D\_bonus} < 0$ and combining the above expression, we could have

$$\frac{\partial \ln EX(i)}{\partial R\&D\_\text{bonus}} = (-S_L\sigma_{LEX} - S_K\sigma_{KEX} - S_{IN}\sigma_{INEX} - \eta S_{EX}) \times \phi$$

We follow a similar procedure to derive the effect of BT-to-VAT reform on the optimal in-house R&D choice. Taking natural logarithms of Shephard' s lemma ($IN = c_{P_{IN}}q$)and differentiating with respect to P_{EX},

$$\ln IN(i) = \ln c_{P_{IN}} + \ln q(i)$$

$$\frac{\partial \ln IN(i)}{\partial P_{EX}} = \frac{c_{P_{IN}P_{EX}}}{c_{P_{IN}}} + \frac{\partial \ln q(i)}{\partial P_{EX}}$$

As before, we can write the above expression as

$$\frac{\partial \ln IN(i)}{\partial \ln P_{EX}} = P_{EX}\frac{c_{P_{IN}P_{EX}}}{c_{P_{IN}}} + P_{EX}\frac{\partial \ln q(i)}{\partial P_{EX}}$$

$$\frac{\partial \ln IN(i)}{\partial \ln P_{EX}} = \frac{P_{EX}cc_{P_{IN}P_{EX}}}{cc_{P_{IN}}} + \frac{\partial \ln q(i)}{\partial \ln P_{EX}}$$

$$\frac{\partial \ln IN(i)}{\partial \ln P_{EX}} = \frac{P_{EX}EXcc_{P_{IN}P_{EX}}}{EXcc_{P_{IN}}} + \frac{\partial \ln q(i)}{\partial \ln P_{EX}}$$

$$\frac{\partial \ln IN(i)}{\partial \ln P_{EX}} = \frac{P_{EX}EXcc_{P_{IN}P_{EX}}}{c_{P_{EX}}qcC_{P_{IN}}} + \frac{\partial \ln q(i)}{\partial \ln P_{EX}}$$

$$\frac{\partial \ln IN(i)}{\partial \ln P_{EX}} = \frac{P_{EX}EXcc_{P_{IN}P_{EX}}}{qcc_{P_{EX}}c_{P_{IN}}} + \frac{\partial \ln q(i)}{\partial \ln P_{EX}}$$

$$\frac{\partial \ln IN(i)}{\partial \ln P_{EX}} = \frac{P_{EX}EX}{qc} \times \frac{cc_{P_{IN}P_{EX}}}{c_{P_{EX}}c_{P_{IN}}} + \frac{\partial \ln q(i)}{\partial \ln P_{EX}}$$

$$\frac{\partial \ln IN(i)}{\partial \ln P_{EX}} = S_{EX}\sigma_{INEX} - \eta S_{EX}$$

Using Shephard' s lemma, definitions of the Allen partial elasticity of substitution and the share of R&D outsourcing in total costs, together with $\phi \equiv \frac{\partial ln(P_{EX})}{\partial R\&D\_bonus} < 0$, we arrive at

$$\frac{\partial \ln IN(i)}{\partial R\&D\_\text{bonus}} = (S_{EX}\sigma_{INEX} - \eta S_{EX}) \times \phi$$

A.2 Cash Flow Effects of R&D Bonus under Capacity Constraints

Our baseline model does not consider how the cash-flow effects of the R&D bonus induced by the BT-to-VAT reform may influence the choice of optimal input. Thus, we investigate the possibility that cash flow caused by the R&D bonus may expand the production capacity. Firms choose the optimal quantity to maximize their profits in our baseline model but here we assume that firms are faced with constraints in the production cost that they can expand. In this situation, we change our model as follows

$$\max_{q(i)} p(q(i))q(i) - \mathrm{c}\left(\mathrm{w}, \mathrm{R}, P_{IN}, P_{EX}\right) q(i)$$

$$\text{st. c } \left(\mathrm{w}, \mathrm{R}, P_{IN}, P_{EX}\right) q(i) \leq \bar{c} + bI_{out}$$

where total cost does not exceed the combination of a capacity constraint $\bar{c}$ plus cash flow from the deduction in R&D outsourcing stimulated by the BT-to-VAT reform. I_{out} represents the investment in R&D outsourcing and b here is the deduction percent induced by the R&D bonus. Assume the constraint binds and get

$$q(i) = \frac{\bar{c} + bI_{out}\left(\mathrm{w}, \mathrm{R}, P_{IN}, P_{EX}\right)}{\mathrm{c}\left(\mathrm{w}, \mathrm{R}, P_{IN}, P_{EX}\right)}$$

Then take natural logarithm of q_i and take derivative with respect to R&D bonus

$$\frac{\partial \ln q(i)}{\partial R\&D\_\mathrm{bonus}} = \frac{\partial q(i)}{\partial R\&D\_\mathrm{bonus}} \frac{1}{q(i)} = \frac{\partial q(i)}{\partial R\&D\_\mathrm{bonus}} \left\{ \frac{\mathrm{c}\left(\mathrm{w}, \mathrm{R}, P_{IN}, P_{EX}\right)}{\bar{c} + bI_{\mathrm{out}}\ \left(\mathrm{w}, \mathrm{R}, P_{IN}, P_{EX}\right)} \right\}$$

$$\frac{\partial \ln q(i)}{\partial R\&D\_\mathrm{bonus}} = \frac{c}{\bar{c} + bI_{out}} \frac{\partial q(i)}{\partial P_{EX}} \frac{\partial P_{EX}}{\partial R\&D\_\mathrm{bonus}}$$

$$\frac{\partial \ln q(i)}{\partial R\&D\_\mathrm{bonus}} = \phi P_{EX} \frac{c}{\bar{c} + bI_{out}} \frac{\partial q(i)}{\partial P_{EX}}$$

$$\begin{aligned} \frac{\partial \ln q(i)}{\partial R\&D\_\mathrm{bonus}} &= \phi P_{EX} \frac{c}{\bar{c} + bI_{\mathrm{out}}} \left\{ -c^{-2} \frac{\partial c}{\partial P_{EX}} \left(\bar{c} + bI_{\mathrm{out}}\ \right) \right\} \\ &+ \phi P_{EX} \frac{c}{\bar{c} + bI_{\mathrm{out}}} c^{-1} \left\{ \frac{\partial b}{\partial P_{EX}} I_{out} + b \frac{\partial I_{out}}{\partial P_{EX}} \right\} \end{aligned}$$

$$\frac{\partial \ln q(i)}{\partial R\&D\_bonus} = -\phi P_{EX} c^{-1} \frac{\partial c}{\partial P_{EX}} + \frac{\partial \ln P_{EX}}{\partial R\&D\_bonus} P_{EX} \frac{b I_{out}}{\bar{c} + b I_{out}} \left\{ \frac{\partial b}{\partial P_{EX}} \frac{1}{b} + \frac{\partial I_{out}}{\partial P_{EX}} \frac{1}{I_{out}} \right\}$$

$$\frac{\partial \ln q(i)}{\partial R\&D\_\text{bonus}} = -\phi S_{EX} + \frac{\partial \ln P_{EX}}{\partial R\&D\_bonus} \frac{b I_{out}}{\bar{c} + b I_{out}} \left\{ \frac{\partial \ln b}{\partial \ln P_{EX}} + \frac{\partial \ln I_{out}}{\partial \ln P_{EX}} \right\}$$

$$\frac{\partial \ln q(i)}{\partial R\&D\_\text{bonus}} = -\phi S_{EX} + S^b \left\{ \frac{\partial \ln b}{\partial R\&D\_bonus} + \frac{\partial \ln I_{out}}{\partial R\&D\_bonus} \right\}$$

$$\frac{\partial \ln q(i)}{\partial R\&D\_bonus} = -\phi S_{EX} + S^b \left\{ \frac{\partial \ln b}{\partial R\&D\_bonus} + \frac{\partial \ln I_{out}}{\partial \ln b} \frac{\partial \ln b}{\partial R\&D\_bonus} \right\}$$

$$\frac{\partial \ln q(i)}{\partial R\&D\_\text{bonus}} = -\phi S_{EX} + S^b \phi^b \left\{ 1 + \frac{\partial \ln I_{out}}{\partial \ln b} \right\}$$

$$\frac{\partial \ln q(i)}{\partial R\&D\_\text{bonus}} = -\phi S_{EX} \{ 1 + \underbrace{\frac{S^b \phi^b \left(1 + \varepsilon_b^{I \text{ out}} \right)}{-\phi S_{EX}}}_{\chi \geq 0} \} = -\phi S_{EX} (1 + \chi)$$

where S^b is the expenditure share of the increased cash flow from R&D bonus and ϕ^b measures the effect of R&D bonus on the deduction percent of invest in outsourced R&D; $\varepsilon_b^{I_{out}}$ is the investment in outsourced R&D elasticity with respect to the deduction percent. The term χ is treated as a measure of the relative importance of cash flow to the cost of R&D outsourcing effects of R&D bonus. Then we could derive the effect of R&D bonus on revenue as follows:

$$\frac{\partial \ln p(i) q(i)}{\partial R\&D\_bonus} = \frac{\partial \ln p(i)}{\partial \ln q(i)} \frac{\partial \ln q(i)}{\partial R\&D\_bonus} + \frac{\partial \ln q(i)}{\partial R\&D\_bonus}$$

$$\frac{\partial \ln p(i) q(i)}{\partial R\&D\_bonus} = \left\{ 1 + \frac{\partial \ln p(i)}{\partial \ln q(i)} \right\} \frac{\partial \ln q(i)}{\partial R\&D\_bonus} = -\phi S_{EX} (1 + \chi) \left(1 - \frac{1}{\eta} \right)$$

By separating the scale and substitution effects, since firms are still minimizing their cost, the substitution effect of R&D bonus remains the same as our baseline model. However, the scale effect is now changed to the above expression for $\frac{\partial \ln q(i)}{\partial R\&D\_\text{bonus}}$. Therefore, we obtain the following modified expressions of the model considering the capacity constraints

$$\frac{\partial \ln EX(i)}{\partial R\&D\_\text{bonus}} = [-S_L \sigma_{LEX} - S_K \sigma_{KEX} - S_{IN} \sigma_{INEX} - (1 + \chi) S_{EX}] \times \phi$$

$$\frac{\partial \ln IN(i)}{\partial R\&D\_\text{bonus}} = [S_{EX}\sigma_{INEX} - (1+\chi)S_{EX}] \times \phi$$

We could find the only difference between the modified model considering the cash flow effects and the baseline model is that $(1+\chi)$ has now replaced η. The scale effect in our baseline mode is determined by profit maximization, which depends on the elasticity of demand η. But in our modified model which considers the capacity constraints, the scale effect depends upon the degree to which cash flow effects of the R&D bonus allow firms to enlarge production. Similarly in the baseline model, the scale effect is identified by the cost-weighted average of inputs effects

$$\bar{\beta} = S_{EX}\beta^{EX} + S_{IN}\beta^{IN} + S_K\beta^K + S_L\beta^L = -S_{EX} \times \phi(1+\chi) > 0$$

Combine equations for $\bar{\beta}$ and $\frac{\partial \ln IN(i)}{\partial R\&D\_\text{bonus}}$, we could get

$$\sigma_{INEX} = (1+\chi)\left(1 - \frac{\beta^{IN}}{\bar{\beta}}\right)$$

For the elasticity of substitution between outsourced R&D and in-house R&D, since $\chi \geq 0$. The comparison of $\bar{\beta}$ and β^{IN} determines the sign of σ_{INEX}. So, the conclusion that in-house R&D complements outsourced R&D is robust even if more cash flow caused by R&D bonus are allowed to relax the capacity constraints for firms in the manufacturing sector.

A.3 Rental Rates

According to the David Romer(2009) we can get a formula about rental rate:

$$\text{Rental Rate}_{\ t} = \left[r_t + \delta_t - \frac{q_t - q_{t-1}}{q_{t-1}} \right]$$

Assume that the real market purchase price of capital at time t is q_t , r_t is the real interest rate, δ_t is the depreciation rate. r_t is the nominal interest rate on medium term loan minus the inflation rate, relevant data is from China Statistical Yearbook. q_t uses fixed asset investment price index to measure. Assume the depreciation rate is 8 percent for structures and 24 percent for machinery. We arrive at these estimates of depreciation rates from estimates of the useful lives of structures and buildings (thirty-eight years) and machinery and equipment (twelve years) in Wang and Wu (2003).

Table A1: High Dependence by Sector

Sector Name	High Dependence	Sector Name	High Dependence
Grain products	0	Vegetables, fruits, nuts and other processed agricultural and sideline food products	1
Feed processed products	0	Dairy products	1
Vegetable oil processing products	0	Alcohol and wine	1
Butchery and meat processing products	0	Beverages and refined tea processed products	1
Instant foods	0	Tobacco products	1
Condiments, fermented products	0	Knitting or crocheting and its articles	1
Other food	0	Textile products	1
Cotton, chemical fiber textile and printing and dyeing finishing products	0	Furniture	1
Wool textile and dyeing and finishing products	0	Paper and Paper Products	1
Hemp and silk textiles and processed products	0	Printed and recorded media reproductions	1
Textile and Apparel	0	Coking products	1
Leather, fur, feathers and their products	0	Basic chemical raw materials	1
Shoe	0	Fertilizer	1
Wood processing products and wood, bamboo, rattan, palm and grass products	0	Pesticide	1
Culture and education, art and crafts, sports and entertainment supplies	0	Paints, inks, pigments and similar products	1

Continued on next page

Table A1 – continued from previous page

Sector Name	High Dependence	Sector Name	High Dependence
Refined petroleum and nuclear fuel processing products	0	Synthetic material	1
Chemical fiber products	0	Specialty chemical products and explosives, pyrotechnics, pyrotechnics products	1
Cement, lime and plaster	0	Daily chemical products	1
Gypsum, cement products and similar products	0	Pharmaceutical products	1
Brick, stone and other building materials	0	Rubber products	1
Ferroalloy products	0	Plastic products	1
Auto parts and accessories	0	Glass and glassware	1
Battery	0	Ceramics	1
Audiovisual equipment	0	Refractory products	1
Metalwork, machinery and equipment repair services	0	Graphite and other non-metallic mineral products	1
Sugar and sugar products	1	Steel, iron and castings thereof	1
Aquatic products	1	Steel rolled products	1
Non-ferrous metals and their alloys and castings	1	Non-ferrous metal rolled products	1
Metalwork	1	Boiler and prime moving equipment	1
Metal processing machinery	1	Material handling equipment	1
Pumps, valves, compressors and similar machinery	1	Culture and office machinery	1
Other general equipment	1	Special equipment for mining, metallurgy and construction	1
Special equipment for chemical, wood and non-metal processing	1	Special machinery for agriculture, forestry, animal husbandry and fishery	1

Continued on next page

Table A1 – continued from previous page

Sector Name	High Dependence	Sector Name	High Dependence
Other special equipment	1	Vehicle	1
Railway transportation and urban rail transit equipment	1	Ships and related installations	1
Other transportation equipment	1	Motor	1
Power transmission and distribution and control equipment	1	Wires, cables, optical cables and electrical equipment	1
Household appliance	1	Other electrical machinery and equipment	1
Computer	1	Communication device	1
Radio and television equipment and radar and supporting equipment	1	Electronic components	1
Other electronic equipment	1	Instrument and meter	1
Other manufacturing products	1	Waste resources and recycled waste materials	1

Notes: Table A1 shows the detailed value of high dependence for each sector in the 2012 input-output table from NBS.

Table A2: Event Study Estimates: Firms' Response to R&D Bonus

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	Ln Outsourced R&D	Ln In-house R&D	IHS Outsourced R&D	IHS In-house R&D	Ln Real Capital Stock	Ln Employment	Ln Output
Post0	0.0284***	0.0656***	0.0336***	0.0797***	0.0313***	0.0325***	0.0232**
	(0.00852)	(0.00881)	(0.0104)	(0.0105)	(0.00424)	(0.00456)	(0.00914)
Post1	0.0394***	0.0438***	0.0473***	0.0503***	0.0623***	0.0705***	0.0554***
	(0.0100)	(0.0122)	(0.0122)	(0.0145)	(0.00691)	(0.00724)	(0.0118)
Post2	0.0887***	0.0480***	0.106***	0.0538***	0.0960***	0.115***	0.0752***
	(0.0110)	(0.0134)	(0.0135)	(0.0159)	(0.00853)	(0.00978)	(0.0139)
Post3	0.217***	0.0300	0.261***	0.0303	0.0816***	0.168***	0.136***
	(0.0168)	(0.0194)	(0.0205)	(0.0230)	(0.0114)	(0.0137)	(0.0193)
Pre1	0.0389**	0.00596	0.0489**	0.00598	0.0138	0.0118	-0.00425
	(0.0183)	(0.0241)	(0.0220)	(0.0283)	(0.0142)	(0.0166)	(0.0282)
Pre2	-0.0256	-0.0383	-0.0296	-0.0447	-0.0181	-0.0181	-0.0327
	(0.0180)	(0.0236)	(0.0216)	(0.0277)	(0.0147)	(0.0165)	(0.0282)
Pre3	-0.0141	-0.0113	-0.0171	-0.0133	-0.0651***	-0.0544***	-0.0627**
	(0.0191)	(0.0239)	(0.0231)	(0.0280)	(0.0165)	(0.0175)	(0.0310)
Observations	147,324	147,319	147,330	147,330	137,076	147,330	135,469

Notes: Table A2 represents the estimation results for the event year study based on the balanced sample. The dependent variable for each estimation is indicated at the top of each column All the monetary values are in real terms. All regressions include firm-fixed effects and year-fixed effects.

Table A3: Effects of R&D bonus on Outsourced R&D

	Panel A: Ln Outsourced R&D				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0202***	0.0194***	0.0156***	0.0165***	0.0179***
	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)
Observations	847,957	847,957	847,957	847,957	847,957
R-squared	0.009	0.012	0.013	0.013	0.013
	Panel B: IHS Outsourced R&D				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0282***	0.0269***	0.0218***	0.0232***	0.0252***
	(0.0032)	(0.0032)	(0.0032)	(0.0032)	(0.0033)
Observations	847,970	847,970	847,970	847,970	847,970
R-squared	0.009	0.012	0.013	0.013	0.013
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Province×Year FE	No	Yes	Yes	Yes	Yes
AssetsSize×Year FE	No	No	Yes	Yes	Yes
TFP×Year FE	No	No	No	Yes	Yes
EmploymentSize×Year FE	No	No	No	No	Yes

Notes: Table A3 displays estimates describing the effects of R&D bonus on ln outsourced R&D in Panel (A), on the inverse hyperbolic sine of outsourced R&D in Panel (B), which are based on the unbalanced sample. Column 1 starts off the estimation including firm and year fixed effect. Column 2 augments Column 1 with province-by-year fixed effect considered. Columns 3, 4, and 5 progressively add assets size bins measured by pre-reform average assets interacted with year fixed effects, TFP bins measured by pre-reform average TFP interacted with year fixed effects, and employment size bins measured by pre-reform average employment interacted with year fixed effect, respectively, to the controls in the preceding column. All the monetary values are in real terms.

Table A4: Effects of R&D Bonus on In-house R&D

			Panel A: Ln In-house R&D		
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0248***	0.0247***	0.0197***	0.0198***	0.0213***
	(0.0028)	(0.0028)	(0.0028)	(0.0028)	(0.0029)
Observations	847,934	847,934	847,934	847,934	847,934
R-squared	0.007	0.011	0.012	0.012	0.013
			Panel B: IHS In-house R&D		
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0313***	0.0312***	0.0250***	0.0253***	0.0273***
	(0.0035)	(0.0035)	(0.0035)	(0.0035)	(0.0035)
Observations	847,970	847,970	847,970	847,970	847,970
R-squared	0.007	0.012	0.013	0.013	0.013
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Province×Year FE	No	Yes	Yes	Yes	Yes
AssetsSize×Year FE	No	No	Yes	Yes	Yes
TFP×Year FE	No	No	No	Yes	Yes
EmploymentSize×Year FE	No	No	No	No	Yes

Notes: Table A4 displays estimates describing the effects of R&D bonus on ln in-house R&D in Panel (A), on the inverse hyperbolic sine (IHS, of in-house R&D in Panel (B), which are based on the unbalanced sample. Column 1 starts off the estimation including firm and year fixed effect. Column 2 augments Column 1 with province-by-year fixed effect considered. Columns 3, 4, and 5 progressively add assets size bins measured by pre-reform average assets interacted with year fixed effects, TFP bins measured by pre-reform average TFP interacted with year fixed effects, and employment size bins measured by pre-reform average employment interacted with year fixed effect, respectively, to the controls in the preceding column. All the monetary values are in real terms.

Table A5: Effects of R&D Bonus on Patent Applications

	Panel A: *Ln Total Patent*$_{t+1}$				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0116***	0.0103***	0.0094***	0.0094***	0.0094***
	(0.0035)	(0.0036)	(0.0036)	(0.0036)	(0.0036)
Observations	504,054	504,054	504,054	504,054	504,054
R-squared	0.001	0.002	0.002	0.002	0.002
	Panel B: *Ln Invention Patent*$_{t+1}$				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0123***	0.0099***	0.0083***	0.0085***	0.0088***
	(0.0024)	(0.0025)	(0.0025)	(0.0025)	(0.0025)
Observations	504,054	504,054	504,054	504,054	504,054
R-squared	0.002	0.004	0.004	0.004	0.005
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Province×Year FE	No	Yes	Yes	Yes	Yes
AssetsSize×Year FE	No	No	Yes	Yes	Yes
TFP×Year FE	No	No	No	Yes	Yes
EmploymentSize×Year FE	No	No	No	No	Yes

Notes: Table A5 displays estimates describing the effects of the R&D bonus on the number of total patent applications of year t+1 in Panel (A), on the number of invention patent applications of year t+1 in Panel (B), which are based on the unbalanced sample. Column 1 starts off the estimation including firm and year fixed effect. Column 2 augments Column 1 with province-by-year fixed effect considered. Columns 3, 4, and 5 progressively add assets size bins measured by pre-reform average assets interacted with year fixed effects, TFP bins measured by pre-reform average TFP interacted with year fixed effects, and employment size bins measured by pre-reform average employment interacted with year fixed effect, respectively, to the controls in the preceding column. All the monetary values are in real terms.

Table A6: Effects of R&D Bonus on Capital Stock and Employment

	Panel A: Ln Real Capital Stock				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0281***	0.0265***	0.0282***	0.0330***	0.0324***
	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)
Observations	790,558	790,558	790,558	790,558	790,558
R-squared	0.042	0.046	0.047	0.049	0.049
	Panel B: Ln Employment				
	(1)	(2)	(3)	(4)	(5)
R&D bonus	0.0403***	0.0402***	0.0368***	0.0415***	0.0340***
	(0.0027)	(0.0027)	(0.0027)	(0.0027)	(0.0027)
Observations	847,970	847,970	847,970	847,970	847,970
R-squared	0.049	0.053	0.054	0.056	0.061
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Province×Year FE	No	Yes	Yes	Yes	Yes
AssetsSize×Year FE	No	No	Yes	Yes	Yes
TFP×Year FE	No	No	No	Yes	Yes
EmploymentSize×Year FE	No	No	No	No	Yes

Notes: Table A6 displays estimates describing the effects of R&D bonus on real capital stock and employment in Panel (A) and Panel (B) respectively, which are based on the unbalanced sample. Column 1 starts off the estimation including firm and year fixed effect. Column 2 augments Column 1 with province-by-year fixed effect considered. Columns 3, 4, and 5 progressively add assets size bins measured by pre-reform average assets interacted with year fixed effects, TFP bins measured by pre-reform average TFP interacted with year fixed effects, and employment size bins measured by pre-reform average employment interacted with year fixed effect, respectively, to the controls in the preceding column. All the monetary values are in real terms.

Table A7: Division of Technology Level

Technology Type	Industry Name	Industry Code
High-technology industries	Aircraft and spacecraft	374, 4343
	Pharmaceuticals	27
	Office, accounting, and computing machinery	347, 391
	Radio, TV, and communications equipment	392, 393, 3940, 395
	Medical, precision, and optical instruments	358, 404
Medium-high-technology industries	Electrical machinery and apparatus	38, 396, 397, 401, 402, 4030, 4090, 4350, 4360
	Motor vehicles, trailers, and semi-trailers	36
	Chemicals excluding pharmaceuticals	26, 28
	Railroad equipment and transport equipment	371, 3720, 373, 375, 376, 379, 4341, 4349
	Machinery and equipment	341, 342, 343, 344, 345, 346, 348, 351, 352, 353, 354 355, 356, 357, 359, 320, 4330, 4390
Medium-low-technology industries	Building and repairing of ships and boats	4342
	Rubber and plastics products	29
	Coke, refined petroleum products and nuclear fuel	25
	Other non-metallic mineral products	30
	Basic metals and fabricated metal products	31, 32, 33, 4310
Low-technology industries	Manufacturing; Recycling	21, 24, 41, 42
	Wood, pulp, paper, paper products, printing, and publishing	20, 22, 23
	Food products, beverages, and tobacco	13, 14, 15, 16
	Textiles, textile products, leather, and footwear	17, 18, 19

Source: OECD Directorate for Science, Technology, and Industry Economic Analysis and Statistics Division (2011), ISIC REV. 3 Technology Intensity Definition