# The Effects of Computerizing VAT Invoices in China*

Haichao Fan†, Yu Liu‡, Nancy Qian§and Jaya Wen¶

January 28, 2020

**Abstract**

This paper documents that an increase in the enforcement of VAT caused by the adoption of a new technology significantly increased payments by large firms. The reform contributed to 23.5% of VAT revenues and 11.2% of total government revenues in the five subsequent years. The main mechanism was a reduction in (formerly exaggerated) deductions. The dynamic effects of the reform suggest that the rise in tax revenues is non-monotonic over time, with large short-run gains and smaller, though still positive, long-run gains. The reform also reduced firm revenues and inputs, and increased productivity.

**Keywords:** State Capacity, Technology, Firm Growth
**JEL:** H25, H26, O12

*We thank Esther Duflo, Mike Golosov, Jessica Leight, Magne Mostad, Matt Notowidigdo, Dina Pomeranz, Stefanie Stantcheva and Daniel (Yi) Xu for their insights; and the participants of the MIT/Harvard Development Workshop, Northwestern Applied Micro Workshop, University of Zurich Macro and Development Seminar, MSU Development Workshop, University of Chicago Development Lunch, CEPR Development and Taxation Workshop, IMF and Atlanta Federal Reserve Bank's conference on the Chinese Economy, CEPR Development Workshop, M&M Conference at the Chicago Federal Reserve Bank, Fudan University TED Conference, and Chicago Area Development Mini Conference for useful comments. We are grateful to Joris Mueller and Zhentao Jiang for excellent research assistance. All mistakes are our own.

†Fudan University, fan_haichao@fudan.edu.cn
‡Fudan University, dav.yu.liu@gmail.com
§*Corresponding author. Northwestern University, nancy.qian@kellogg.northwestern.edu
¶Yale University, jaya.wen@yale.edu

# 1 Introduction

Limited administrative capacity is one of the key challenges facing governments of developing economies. There is much excitement among policymakers today that high-tech tools can help. This paper studies the effect of a new technology on tax compliance, a very important and relevant context since all governments tax and face the difficulty of enforcing payment. This is particularly challenging in low and middle income countries, which typically have less established systems for taxation. In such contexts, the Value Added Tax, VAT, is often one of the most important sources of tax revenues.[1] VAT is generally levied as a fraction of the difference between eligible sales and input costs. This framework creates incentives for firms to understate sales and overstate inputs. In principle, since the sales of one firm become the inputs of another along the production chain, upstream and downstream firms are incentivized to check each other's tax evasion. However, in practice, firms can still evade because transactions are not linked in many countries (e.g. Pomeranz, 2015; Waseem, 2019). A common method for evasion in such contexts, and one which is most relevant to our study, is to falsify invoices for eligible deductions.

This paper examines the impact of the adoption of a new technology – digital invoice encryption, which we often refer to as *computerization* for brevity – on VAT in China. Encrypted invoices improved enforcement by increasing the difficulty of falsifying invoices. VAT is the largest source of Chinese government revenue, peaking at 47.6% in 2002.[2] China has relatively high administrative capacity for a middle-income country.[3]

[1]For example, as a share of total government revenues, VAT accounts for 18.7% in Mexico, 9.5% in the Philippines and 17% in South Korea (OECD, 2016). The popularity of VAT is partly due to its perceived enforceability(Gordon and Li, 2009; Kleven et al., 2016). Kopczuk and Slemrod (2006) argue that VAT is easier to enforce than sales tax, to which it is otherwise equivalent. Besley and Persson (2009, 2010) use the ratio of income tax revenues to GDP as a measure of bureaucratic capacity, with the underlying idea that VAT (as opposed to income tax) requires much less capacity to administer than other types of taxes.

[2]Source: China Tax Policy Department, Ministry of Finance 2007.

[3]In 2000, there were approximately 93,000 audits per year per province, which represent an average audit rate of 17.9%. In comparison, the audit rate in the United States was 1.12 percent in the same year (Internal Revenue Service, 2001). See Section 2.

Thus, the benefits of the new encryption technology were not obvious ex ante: enforcement through traditional means, such as manual audits, could have been high enough that the reform brings little improvement.

The empirical analysis aims to address two questions. First, what is the effect of digital encryption on VAT in the short and longer run? Second, how does the increase in tax enforcement affect firm behavior other than tax payment?

Our study faces three main challenges. First, very little has been written about the operational details of the Chinese tax system. Second, dis-aggregated administrative VAT data for this period are not available to researchers.[4] Finally, we face the challenge of establishing causality. Since we study a nationwide reform, a key difficulty is disentangling enforcement-generated increases in VAT revenue from increases that arise from economic growth or other macro-economic or policy changes.

The principal contribution of our paper is to address these challenges. To understand the practical realities of tax enforcement, we spent several years reading an extensive number of government documents and policy reports and conducting field interviews with firm managers and tax officials at all levels of government, from the central tax office in Beijing to field officers in numerous counties spread across several provinces. To overcome the lack of dis-aggregated administrative tax data, we use the *Annual Survey of Industrial Production*, 1998-2007, which reports VAT payment, as well as the breakdown of gross VAT and deductibles. The latter is useful in providing evidence on the mechanism – i.e., showing how the reform increased VAT. Our main analysis uses a balanced panel of firms that exist throughout the period that we study.

For causal inference, we implement a difference-in-differences strategy. Prior to the reform, firms evaded VAT by understating sales and overstating deductibles with falsified invoices. The reform forced sellers to record transactions on a digital smart card and to give buyers encrypted invoices that were difficult to falsify. The increased difficulty in

[4]Better data for later periods have been used by studies such as Liu and Mao (2017).

falsifying invoices should reduce the amount of false deductible claims.[5] The increase in VAT due to the reform should be more prominent for firms that have more deductibles as a share of sales because firms with a high share of true deductibles would not need to falsify in the first place.

Our empirical strategy exploits two sources of variation. First, we compare outcomes before and after the 2001 reform. Second, we exploit cross-sectional variation in the firm's non-deductible share, with the intensity of treatment being higher for firms with higher non-deductible shares. Since evasion can confound the pre-reform non-deductible share measures from our firm survey data, we proxy for non-deductible share with sector-level measures calculated from the 1997 Chinese Input-Output Tables. These data are constructed using an independent data source by the National Statistics Bureau. The baseline estimates will include firm fixed effects to account for all time-invariant differences across firms (e.g., firm size), and year fixed effects to account for all economy-wide changes over time (e.g., macroeconomic growth). To allow for firms of different sizes to evolve differentially over time, the baseline also controls for the interaction of the average firm size in the pre-reform period and the full set of year fixed effects.

We show that the reform significantly increased VAT on average. This is driven by a reduction in deductible inputs, which is consistent with the belief that the digital encryption of invoices significantly increased the difficulty of falsifying deductible claims. We show that there are no pre-tends and that VAT diverges between firms with high versus low non-deductible shares starting at the time of the reform. Taken literally, the estimates imply that the reform contributed 23.5% of all VAT and 11.2% of all government revenue during 2002-2007. In other words, more than one-tenth of total government revenues for what was the world's sixth largest economy at the time is due to improved technology in recording VAT transactions.

[5]The tax authorities were meant to link the digitized information and use these to verify transactions. However, logistical difficulties prevented the creation of a nationally linked database. We discuss this more in the Background section.

There are several caveats to keep in mind. First, there may be cross-sector transactions such that improving enforcement in firms with high non-deductible shares will also improve the information chain in firms with low non-deductible shares (i.e., spillover effects) (e.g. Gadenne et al., 2019). This is not likely to play a big role in our context because the reform did not induce systematic linking of the transactions. If present, this force will attenuate our estimates and cause them to understate the true increase in VAT from the reform. Second, the occurrence of the reform may have coincided with other events that can affect high non-deductible share sectors differently. We are mostly concerned that China's entry into the World Trade Organization in 2001 may confound our estimates. To address this, we introduce a large number of sector-year specific controls for import and export tariffs and the share of imports and exports in that sector. Finally, our reform occurs amidst the "enterprise reforms" (1998-2003) which partially privatized the Chinese economy (Hsieh and Song, 2017). We address this by showing that our main results are qualitatively similar with a balanced panel of firms and the full sample which allows for firm entry and exit, as well as control for ownership-year fixed effects in the robustness exercises.

We conduct many additional sensitivity tests. For example, to check that our estimates are not confounded by spurious cross-sector changes over time, we conduct a placebo test, where we only examine exporters that are eligible for VAT rebates. Indeed, we find no effect on exporters. Finally, one may be concerned that despite the best efforts of government statisticians, the raw data used to generate the 1997 Chinese I-O tables are still confounded by evasion. To address this, we calculate the non-deductible shares of each sector using Chinese tax laws and input-output tables from other countries and use these alternative measures as instrumental variables. The instrumented results are qualitatively similar and show that the main results are not likely to be driven by measurement error.

Next, we examine the effect on other firm outcomes. We find that the reform reduced

output, labor input, the share of deductible intermediate inputs and employment, and increased TFPR. In principle, these findings could be due to changes in reporting on the part of the firm (e.g., *less* truthful to evade VAT after the reform, or *more* truthful reporting for all economic measures because of the reform) and/or changes in economic behavior (i.e., changes in production, i.e., real effects). In practice, it is difficult for a change in reporting to provide an internally consistent explanation for all of the results. For example, on the one hand, the decline in deductible intermediate inputs is difficult to explain if firms are misreporting after the reform to evade VAT since lower deductions increase VAT. On the other hand, not finding a positive effect on VAT eligible sales is difficult to explain if firms (that previously mis-reported to evade VAT) are forced to report more truthfully since such firms would have previously understated VAT eligible sales and therefore experience an increase in the measure after the reform. Moreover, measures such as labor input and TFPR are difficult to explain with changes in reporting since the former is unrelated to the calculation of VAT throughout the period, and the latter would be hard to explain with any simple story about reporting.

In light of this and the importance of the question, we supplement the main analysis by exploring the possibility that our findings on output, inputs and productivity reflect real economic changes. We extend a textbook theoretical model to show that all of our results follow from standard assumptions. The simple model also makes several empirically testable predictions for the dynamic effects of an increase in taxation for firms. For example, it predicts that the effect of the reform on VAT is non-monotonic over time: it will first increase, then decrease slightly, but still be higher than prior to the reform. We show that the dynamic effects of the reform are consistent with these predictions. While we cannot conclusively rule out alternative explanations, the empirical findings and simple model, taken together, are consistent with the reform causing firms to change their economic behavior in the medium/long run.

For policymakers, our results provide several important takeaways. First, high-tech

tools can dramatically boost tax revenues, even if the government has reasonable capacity for audits such as in China. Second, the dynamic effects provide suggestive evidence that tax revenue gains may be slightly lower in the long run than the short run, but will still be positive. Thus, even if there were real economic responses to the tax increase, tax revenue gains are likely to remain positive, at least in the Chinese context.

Our study contributes to several literatures. First, we add to studies that empirically estimate responses to tax changes in developing countries. In examining VAT, our study is most similar to Pomeranz (2015), which conducts a large randomized experiment in Chile to show that third-party information improves VAT enforcement; and Gadenne et al. (2019), which uses linked transaction-level data from Bengal to study supply chain responses to increased taxation. We complement these studies in showing that even a partial improvement (e.g., encrypting invoices without nationally linking transactions) can have significant effects on tax compliance.[6] Our examination of dynamic effects complements the recent study by Benzarti et al. (2017), which finds that VAT has short- and long-run effects on prices in Finland. Our finding that firms downsize in response to value-added taxation is consistent with a recent study by Harju et al. (2015), which finds that VAT reduces the growth of small firms in Finland.[7]

Finally, we contribute to the literature on state capacity and development (Besley and Persson, 2009, 2010). We add to recent studies that have shown the effectiveness of high-tech tools in contexts such as the delivery of state subsidies in rural India (Muralidharan et al., 2016), and teacher and nurse performance in India (Banerjee et al., 2008; Duflo et al., 2012).

[6]For studies of other types of taxes in developing countries, see, for example, Naritomi (2015) or Mittal and Mahajan (2017). In the Chinese context, existing studies have examined the relationship between VAT and firm investment (e.g. Bai and Liu, 2017; Cai and Harrison, 2017), and between VAT and exports (Fan et al., 2017; Garred, 2014; Chandra and Long, 2013; Gourdon et al., 2015; Liu and Lu, 2015).

[7]See Keen and Lockwood (2010) for an overview of the VAT literature, and the review article by Saez et al. (2012) for a review of empirical estimates of responses to taxes. Also see, for example, Kleven and Waseem (2013) and Piketty et al. (2014), which study income tax in Pakistan and the United States, respectively. Most existing studies focus on short-run effects and do not find real effects.

This paper is organized as follows. Section 2 discusses the relevant institutional background. Section 3 presents the empirical strategy. Section 4 describes the data. Section 5 presents the main results. Section 6 interprets the results and examines the dynamic effects. Section 7 concludes.

# 2 Background

The Chinese government introduced VAT, which is administered by the central government, in its modern form in 1994 in what is commonly known as the first phase of the Golden Tax Project. By 2002, VAT had grown to be the largest source of tax revenue and was 47.6% of total government revenues (National Bureau of Statistics, 2003).[8] All formal manufacturing firms were required to register within the VAT system, either as a "small VAT taxpayer" or a "general VAT taxpayer". Within the manufacturing sector, firms with less than one million RMB (120,772 USD) in annual sales were categorized as "small", and larger firms were categorized as "general" (Ministry of Finance, 1993).[9] Because our dataset contains only firms much larger than this cutoff (i.e., annual revenues exceeding five million RMB, or 603,864 USD), we focus the rest of our discussion on general VAT taxpayers.

For general VAT taxpayers, the final VAT bill is 17% of the VAT tax base, which equals the difference between total VAT eligible sales and total eligible input deductions.[10] To the best of our knowledge, there were no major changes in the VAT formula during the period of our study.

Chinese tax law is precise about which inputs are deductible and the rate at which they may be deducted (Ministry of Finance, 1993). In our study period, full deduc-

[8] See the "Regulations of the People's Republic of China on Value-Added Tax" (State Council, 1993) and the "Detailed Rules for the Implementation of the Regulations of the People's Republic of China on Value-Added Tax" (Ministry of Finance, 1993).

[9] We use the 1 USD = 8.28 RMB conversion rate from 2000 in this paper.

[10] An exception of a reduced rate of 13% was made for basic staples or household necessities such as food, fuel, electricity, books, newspapers and magazines, and primary agricultural products (State Council, 1993). This does not affect our study, which examines large manufacturing firms.

tions were awarded for purchases of manufactured inputs, repair inputs, retail inputs and wholesale inputs. Partial deductions were given for agricultural goods (13%), transportation costs (10%) and procured waste goods (10%). To obtain deduction, firms provide corresponding official receipts for transaction.[11] No deductions were given for labor costs, fixed asset purchases (until 2009 nationally), capital depreciation, abnormal losses, rent, fringe benefits, interests from bank loans, and operating expenses (overhead).[12] For any deductible imported inputs, firms could deduct purchases using VAT completion receipts issued by the customs office (State Council, 1993). Exports are partially exempt from VAT.

A typical VAT-relevant transaction is a firm-to-firm sale of some input. An official invoice with carbon copies is generated: one copy for the buying firm and the other one for the selling firm. Registered firms can purchase these invoices from the tax office at any time. Firms pay VAT and obtain deductions monthly. Each month, someone from the firm would go to the local tax office and give the tax official all of the invoices for her VAT eligible sales from the past month. These are used to calculate her VAT obligations, which she will need to pay on the same day. During the same visit, she will give the tax official all of the invoices for her VAT eligible deductibles. Her deductions are calculated and paid to her on the same day.

In the pre-computerization period, VAT fraud was prevalent (Lu, 1997; Jin, 2002).[13] There were two main loopholes. First, VAT invoices were handwritten and lacked effective anti-counterfeit technology. Second, cross-checking invoices, especially across locations, was prohibitively costly with manual auditing. As a result, firms could fabricate input purchase invoices and be fairly certain that they would not be caught. Similarly, firms could use real invoices of canceled transactions to file for deductions and be confi-

[11] Note that transactions of partially deductible goods do not use VAT invoices. They were not affected by the reform that we study.

[12] The Appendix provides a detailed list of deductible and non-deductible items.

[13] Between January and September of 2001, there were in total 10,041 criminal cases on taxes nationally in China and 59% of these cases were related to over-reporting input VAT (page 632 of China's Tax Audit Yearbook, 2003).

dent that the tax authority would not know that the other party never filed the sales.

Although the law stipulated financial and criminal punishments for VAT evasion, firms were, in practice, rarely subject to those penalties.[14] This lax behavior on the part of the authorities was largely due to the inability of the auditor to conclusively prove evasion or estimate the amount of evasion without a clear paper trail.

## 2.1 Reform

### Encrypted Invoices

The goal of the second phase of the Golden Tax Project in 2000 was to address these two central problems of VAT enforcement with a fully digitized invoice system coupled with a national database of firm VAT filings. The two most important components of this reform were: 1) replacing hand-written invoices with digitally encrypted invoices, and 2) digitally linking transactions.[15] Firms were required to install a special-purpose IC smart card in their computers. The IC card would encrypt seven key pieces of transaction information (invoice ID, invoice code, invoice date, buyer's tax ID, seller's tax ID, value, and VAT) into an 84-digit code.[16] When a transaction took place, the transaction information was stored in the IC card. The seller would then print the VAT invoice and give it to the buyer. The encrypted code is printed on the right corner of the invoice.[17]

During the monthly visit to the State Administration of Tax (SAT) office, firms now submit the IC card to calculate gross VAT obligations and carbon copies of digitally

[14] On page 633 of China's Tax Audit Yearbook (2003), two auditors from Shenzhen write that "There exists a gap between the tax laws and their enforcement in practice. Tax agencies often downgrade their punishment for firms involved in VAT frauds; seldom do they prosecute criminal cases against firms."

[15] See Jin (2002).

[16] The technology has been in constant upgrade. For example, in later years, the government extended the 84-digit code into a 108-digit code. In 2011, the government added a new technology onto the VAT paper invoice in a few designated sectors (e.g., gold, gasoline, rare earth, etc.) in three provinces (Shanghai, Shaanxi, and Shenzhen). Previously, only the numerical values were encrypted. The new technology is able to encrypt Chinese characters into a QR code on the paper invoice. The information in Chinese characters includes seller's name, buyer's name, product name, and product quantity unit.

[17] Appendix Figures A.1 and A.2 show the paper invoices before and after the digital encryption.

encrypted invoices to calculate VAT deductions. As before, the net payment (gross VAT minus deductions) is made at the tax office the same day of the visit.

In principle, the deduction invoices were supposed to be cross-checked with a national database with the transactions that are downloaded from all IC cards in the nation, effectively linking all transactions. However, in practice, the national database was not linked until around 2015 because of logistical implementation issues.[18] Interviews with province-level SAT officials indicate that some provinces linked within-province transactions and used the information to verify select deductions. However, we were unable to detect any systematic determinants for when/which provinces linked transactions, or obtain systematic data on provincial implementation of linking transactions. In any case, the fact that many transactions cross provinces means that such ad hoc within-province linking cannot enforce VAT by itself.

Our empirical strategy will not exploit cross-province variation in linking invoices. Instead, we will interpret the 2001 reform as a nation-wide reform that mainly increased the difficulty to falsify invoices used to file deductions. In the provinces and years where intra-provincial transactions were linked, the reform also reduced the ability to understate sales. In the robustness section, we show that our results are robust to controlling for province-year fixed effects.

**Timing**

The encryption of invoices took some time to implement. Starting from January 1, 2000, invoices of transactions exceeding 100,000 RMB (12,077 USD) were printed out using the new encryption software. Handwritten invoices for these large transactions were banned at the end of 2001. Large transactions are very common for the large manufacturing firms that we study. Thus, we interpret 2001 as the first year that the reform became relevant (State Administration of Taxation, 2000).

[18]This is based on interviews we conducted with SAT officials in Beijing.

Existing descriptive studies show that the technology has had a remarkable deterrence effect on VAT frauds in China, mainly by reducing exaggerated deductions. For example, in February 2001, the fraud rate of input VAT invoices, which is measured as the number of invoices determined to be "problematic" over the total number of invoices audited, was 8.51%. By August 2002, the fraud rate dropped to 0.062% (Jin, 2002). On January 20, 2003, the former deputy head of SAT, Xu Shanda, stated that the over-invoicing (over-reporting VAT input taxes) problem had been basically resolved.[19] Beyond tax officials, it is widely believed by firms and other policy makers that fake invoices have almost completely disappeared.

Generally speaking, the reform made VAT evasion much costlier, but some loopholes remained. According to our interviews with tax officials, the main methods of evading VAT after the reform are the following. First, because transactions were not systematically linked, firms could still understate sales by simply not producing a sales receipt (i.e., no record on the IC card). This needs to be done carefully since large changes in sales can trigger an audit. The scope of such evasion is also limited because only a purchaser not intending to file deductions would be willing to forgo the receipt. Second, a subset of receipts (including procurement receipts for agricultural goods, customs VAT completion receipts, transportation receipts, and waste goods) were never digitally encrypted as part of the reform. Thus, it was still possible to falsify these invoices. Third, firms can buy genuine VAT invoices from the black market because some of the final customers did not claim the VAT input invoices. Finally, firms in the entire value chain could opt for off-book cash transactions. This is difficult because it requires coordination across many firms. Furthermore, by switching to cash transactions, firms would record a drop in sales, which elicits the attention of tax officials and can also trigger audits.[20] We will keep these caveats in mind when we interpret the empirical results and motivate

[19] See China Tax Audit Yearbook Committee (2004).

[20] The government aimed to resolve these remaining loopholes through an improved tax enforcement technology. The third phase of the Golden Tax Project was piloted in Chongqing in 2013 and applied nationwide in 2016. It is outside of the scope of our study.

the robustness exercises.

### 2.1.1 Imports and Exports

The VAT rule that we have described thus far applies to almost all goods in China. Two notable special cases are imports and exports (State Council, 1993). Import tariffs existed in China throughout this period, and those tariffs were deductible in the same manner as the original input value. Similarly, exports were awarded VAT rebates throughout the period of our study. Unlike many other countries with VAT, Chinese export rebates are typically less than the total sum owed – i.e., firms pay some VAT on exports (Chandra and Long, 2013). Both import tariffs and export rebates vary across sectors (products) and over time. We will pay special attention to this issue in the robustness exercises.

## 2.2 Other Policy Changes

The main policy change that could confound our study was China's entry to the WTO in 2001. A possible threat to our identification strategy is that WTO-led changes in tariffs and rebates systematically affected high- and low-NDS sectors after 2001. We will address this possibility later in the paper by explicitly controlling for rebates and tariffs for each sector and year.

Another important policy for our context is the privatization of state-owned firms, often referred to as the "enterprise reforms", which took place during 1998-2003. The manufacturing sector changed from nearly entirely publicly (state) owned to partly privately (not state) owned, with some firms closing down. See, for example, Hsieh and Song (2017) for a detailed discussion. To understand the implications for our study, note that our main analysis focuses on a panel of firms which are not affected by entry or exit. We will also later show that the results are qualitatively similar if we allow for entry and exit and expand the sample to all manufacturing firms, as well as control for ownership-year fixed effects in the robustness exercises.

In the years after computerization, several other potentially relevant policy changes took place. First, in 2004, the central government changed how it split the burden of VAT export rebates with local governments (Chandra and Long, 2013; Bai and Liu, 2017). Another potentially relevant policy change was the abolition of agricultural taxes in 2005, which Chen (2017) argues to have increased the enforcement of other taxes to compensate for lost revenues. Finally, VAT policies were changed slightly in 2009. Though this policy reform falls outside our time frame (Cai and Harrison, 2017; Liu and Mao, 2017; Liu and Lu, 2015), some of the changes were piloted in three provinces (Liaoning, Jilin, and Heilongjiang) starting in 2004.

We will investigate the robustness of our results to each of these policy changes after the main results.

## 2.3 Other Enforcement Mechanisms (Audits)

The Chinese SAT has high administrative capacity for a developing economy in that it has an organized and capable bureaucracy. This can be seen in the data reported by the China Tax Audit Yearbook Committee (2007). The dashed blue line in Figure 1 presents the number of tax officials per province over time. On average, there are $12,688$. The spike in 2002 reflects the additional personnel hired to implement the reform that we study. The solid red line in Figure 1 shows the rate of audits per province over time from 2000-2007, the only years for which such data are available.[21] On average, the SAT conducted $22,999$ audits per province per year, and the value declined steadily through this time period. The decline is consistent with anecdotal evidence that the computerization was meant to relieve some of the demand on tax officials and manual audits.

The China Tax Audit Yearbook Committee (2007) also reports the number of audits which indicate problematic behavior as well as the number of cases which are fined. The

[21] The personnel data come from Tax Yearbooks of China; the audit rate data come from Tax Audit Yearbooks of China.

dashed black line in Figure 1 plots the rate of problematic audits over the years for which such data are available. On average, the percentage of problematic cases before computerization is very high, at 7.7% of all filings (China Tax Audit Yearbook Committee, 2007). However, very few of these are prosecuted and fined. This is reportedly due to the difficulty of providing conclusive evidence and the inability of tax authority to accurately estimate the amount of evasion without the linked transactions. For example, in 1997, the penalty rate was below 5% (penalty as a share of SAT's estimate of unpaid taxes), which was below the interest rate (China Tax Audit Yearbook Committee, 2002); in 2002, among the 112,984 tax-fraud cases investigated by tax officials, only 2,658 cases were prosecuted (China Tax Audit Yearbook Committee, 2003).

# 3 Empirical Strategy

Our specification uses two sources of variation. First, we exploit time variation in the introduction of computerization and encrypted invoices in 2001. Second, we exploit cross-sector variation in the intensity of the treatment effect. The reform, for the most part, increased the difficulty of evasion similarly across firms (see Section 2). However, the incentives of firms to evade vary depending on the amount of true deductibles. Firms with many true deductibles need to pay little VAT in net, and thus have less incentive to evade. When the reform is implemented, they are therefore less affected. Since the cost-benefit of evading a dollar of VAT depends on total revenues, our independent variable is pre-reform non-deductibles as a share of sales.

Note that because the pre-reform reported VAT deductions in our firm data may be confounded by evasion, we construct our main explanatory variable using data on inputs and outputs from the 1997 Chinese Input-Output table, which is available at the sector level. These data are constructed by the National Bureau of Statistics using a survey that is independent of the firms survey we examine.

The cross-sectional measure of intensity, non-deductible input share, is denoted as $\widetilde{NDS}_s$ :

$$\widetilde{NDS}_s = \left( \frac{\widetilde{NonDeductible\ Inputs}}{Total\ Sales} \right)_s . \tag{1}$$

The second term, $\left( \frac{\widetilde{NonDeductible\ Inputs}}{Total\ Sales} \right)_s$, is the median of the ratio of non-deductible inputs to total sales in sector $s$. We calculate this measure at the firm level and then take the median for each sector.[22] $\widetilde{NDS}_s$ is increasing with gross VAT and decreasing with deductions.

The baseline estimating equation can be written as the following:

$$VAT_{ist} = \alpha + \beta \widetilde{NDS}_s \times Post_t + \Gamma X_{ist} + \tau_t + \phi_i + \epsilon_{ist}. \tag{2}$$

VAT paid by firm $i$, in sector $s$, and year $t$, $VAT_{ist}$, is a function of: the interaction of a dummy which takes the value of one if it is 2002 or later, and the measure of intensity at the sector level, $\widetilde{NDS}_s$ ; firm fixed effects, $\phi_i$; and year fixed effects, $\tau_t$. We choose 2002 to define the post-period because hand written invoices were not banned until the end of 2001.[23] Since non-deductible share varies at the sector level, the standard errors are clustered at the sector level. Note that sector fixed effects are absorbed by firm fixed effects. In other words, the identifying variation is at the sector and year level. But we can control for firm fixed effects because our data are a panel of firms.

$X_{ist}$ is a vector of controls. In the baseline, the only additional controls are the interactions of year fixed effects and average pre-reform firm size (i.e., average annual sales during 1998-2000 for each firm interacted with year fixed effects). This is motivated by recent findings that compliance to tax policy varies by firm size (Bachas and Jensen, 2017; Kleven et al., 2016).

[22] Our results are similar if we use the sector average instead of the median. We prefer the latter because it avoids being affected by outlier firms. Results using sector averages are available upon request.

[23] In Section 6, we separately consider firm responses in 2001-2002.

We are interested in the estimate of $\beta$. If the reform increased compliance and VAT, then $\beta > 0$.

Our DiD strategy assumes parallel trends – i.e., absent the reform, the outcomes of interest across sectors with different non-deductible shares would have evolved along parallel trends (conditional on the controls). We will provide support for this assumption by conducting the standard pre-trend analysis, as well as a number of robustness tests to address potential omitted variable concerns.

We acknowledge two caveats to our identification strategy. The first is that we do not have a pure control group. Sectors with low non-deductible shares may still have evaded VAT prior to the reform (albeit less than sectors with higher non-deductible shares). Thus, the reform will also increase their VAT compliance (though less than for sectors with higher non-deductible shares). The second caveat arises from the presence of cross-sector transactions. This is particularly relevant in provinces and years when the transactions are linked, when cross-sector transactions mean that higher compliance in sectors with high non-deductible shares will lead to higher compliance in sectors with low non-deductible shares for firms in the same province. Both of these caveats will lead to our estimates under-estimating the effect of the reform on increasing VAT.

Another issue is the measurement of $\widetilde{NDS}_s$. One might be concerned that despite their best effort, the raw data used to generate the 1997 Chinese I-O tables are confounded by evasion. To address this, we conduct a robustness check where we alternatively construct the measure using data from U.S. input-output tables, as well as input-output tables from Mexico, South Korea and other medium-income countries. We then use these alternative measures as instrumental variables for our main measure. We will discuss this in more detail when we present the results in the Robustness section.

# 4 Data

The main sample is a balanced panel of firms for the years 1998-2007 constructed from China's *Annual Survey of Industrial Production*. These data are collected by the National Bureau of Statistics and are often referred to as the "Census of Manufacturing Firms". The unit of observation is the firm. Subsidiaries are coded as separate entities as long as they are unique legal units.[24] The inclusion and exclusion criteria for non-state-owned firms are asymmetric. The dataset includes all state-owned manufacturing firms (regardless of size) and non-state manufacturing firms with sales greater than five million RMB (603,864 USD). These data have been used by several recent studies. The most well-known is probably Hsieh and Klenow (2009), which used all of the years available when their paper was written, 1998-2005.

The five-million revenue threshold for non-state-owned firms does not seem to be systematically imposed: we observe many private firms below this threshold (with no apparent pattern in firm attributes). To avoid selective sampling, we impose a uniform cutoff and drop all observations with less than five million RMB (603,864 USD) in revenues.

The data contain a rich set of variables. Most importantly, firms report VAT payment, and also gross VAT and VAT deductions. The availability of the two component measures of VAT is useful in that it allows us to examine the mechanisms through which the reform improves enforcement. It is important to note that the VAT payment variable reflects the amount of VAT paid, and therefore accounts for export rebates. We will discuss and motivate other variables as they become relevant.

All of the values in the paper are reported in real terms.[25] The main sample is a balanced panel of 180,148 firms that operate from 1998-2007.[26] To avoid outlier-driven

[24]For regulatory reasons, most subsidiaries are separate legal entities in China.

[25]We use deflators provided by the Penn World Tables. To the extent that one is concerned about region-specific changes in prices, we show that our result are robust to controlling for province-year fixed effects in the robustness section.

[26]Note that the panel is not perfectly balanced because some variables are missing for some years.

results, our sample excludes observations with the top and bottom 1% values of VAT and sales each year.[27] We use 4-digit Chinese Industry Classification sector definitions.

We use the *1997 Chinese Input-Output (I-O) Table* obtained from the China's National Bureau of Statistics (1999) to compute a sector-level non-deductible share. The I-O Tables report the exact share of inputs by sector required in order to deliver one dollar of output. We use the 1997 tables so that the measures cannot be outcomes of the reform. The data used to create the Chinese I-O tables were independently collected by the National Bureau of Statistics (NBS). To the best of our knowledge, they are unrelated to either the firm data or the State Administration of Taxation.[28]

## 4.1 Descriptive Statistics

To illustrate the variation behind our empirical strategy, Figure 2 plots average VAT over time for firms with above and below the sample median of non-deductible share. Since average VAT payments are much higher from the high share group (2.19 million RMB, or 603,864 USD) than the low share group (1.88 million RMB, or 227,053 USD), we normalized the data to the 1998 mean for both groups to better visually compare the trends over time. Consistent with macro-economic growth, the figure shows that VAT increased throughout the entire sample period for both groups. Importantly, the

All firms in the sample have non-missing values for the key variables for at least nine of the ten years that we study.

[27] The results are qualitatively similar without dropping the outliers, but slightly less precise. They are available upon request.

[28] To construct NDS by sector, we map each sector in the input-output tables into two groups, deductible or non-deductible, according to the rules of the Chinese VAT deductions. In practice, we consider inputs from manufacturing industries to be materials, and thus deductible under Chinese VAT rules. We treat inputs from service industries, overhead, and labor inputs to be non-deductible. To obtain the final measure, we sum the fractions of inputs from deductible industries to obtain a single fraction for each industry that represents the share of inputs deductible under Chinese VAT rules. This object can be characterized by the following equation, where $D$ represents the set of deductible industries:

$$\widetilde{NDS}_s = 1 - \sum_{d \in D} Input\ fraction_{sd}. \tag{3}$$

Appendix Table A.1 lists the fifty sectors with the highest and lowest values for $\widetilde{NDS}$.

increase was similar between the two groups prior to the reform, and diverged after 2001, with the high-share group experiencing a larger increase. Conceptually, our empirical strategy will compare the average difference between the two lines after the reform to the average difference before the reform. (In practice, the regressions will exploit all of the variation in non-deductible share instead of breaking it up into only two groups). The similarity in the pre-reform increase supports the parallel trends assumption of our empirical strategy. The timing of the divergence supports our interpretation that the second difference captures the effects of computerization rather than other changes that occurred before or afterwards.

### 4.2 Correlates of Non-deductible Share

Since non-deductible share is not randomly assigned, one of the main concerns for our identification strategy is omitted variables. Table 1 documents the differences between high and low share sectors by estimating the correlation coefficient of non-deductible share and a number of pre-reform firm characteristics averaged at the sector level. Confirmed, they are pre-reform variables. JW For brevity, we focus on variables which we later examine as outcomes. These cross-sector correlation coefficients show that, on average, firms in sectors with high non-deductible shares pay higher VAT, pay higher VAT as a share of sales, and pay fewer VAT deductions. On average, firms in high non-deductible share sectors are more productive, have lower sales, fewer intermediate inputs, a lower ratio of intermediate inputs to sales, and a lower ratio of deductible inputs to sales.

## 5 Average Effect of the Reform

### 5.1 VAT

Table 2 examines the effect of computerization on VAT. The sample means of the dependent variables are stated at the top of the table. In this subsection, we focus on the

OLS estimates in Panel A. We will discuss Panels B and C in subsection 5.2.3. Column (1) shows that the effect on VAT eligible sales (gross VAT) is statistically zero. Column (2) examines deductions, and shows that the reform reduces deductions. The estimate is statistically significant at the 5% level and is larger in magnitude than the estimated reduction in gross VAT in column (1). The reform, on average, reduced VAT deductions by $5,312 \times 1,000$ RMB (5.3 million RMB, or 640,096 USD) for a firm in a sector with no deductibles (i.e., the non-deductible share is 100% of sales) relative to a firm in a sector where all sales are deductible (i.e., the non-deductible share is 0% of sales). In terms of magnitudes, a back of the envelope calculation shows that a firm with the sample mean non-deductible share of 0.40 would have experienced a 34.67% decline in VAT deductions after computerization.[29]

Column (3) shows that the reform increased VAT payment, which is unsurprising since the effect on reducing deductions is larger than the effect on sales. The estimate is statistically significant at the 5% level. In terms of magnitudes, this coefficient implies that the treatment contributed to 23.5% of total VAT revenues and 11.2% of total Chinese government revenues in the period after 2002 until 2007.[30]

The results show that the reform increased VAT paid by firms. Moreover, the fact that the increased VAT payment is driven by a decline in deductions is consistent with

[29]The figure of 34.67% is calculated as the average treatment effect on VAT deductions divided by the cumulative VAT deductions from the average firm, both for the post-2002 period. The average treatment effect for VAT deductions equals $-5,312 \times 0.4042 \times 5 \times 1000 = -10,736,158$ RMB and the cumulative VAT deductions for the average firm equal $6,194 \times 5 \times 1,000 = 30,970,000$ RMB. Note that 0.4042 is the average Chinese NDS in the regression sample. There are five years (2003, 2004, 2005, 2006, and 2007) in the post period. VAT is measured in 1,000 RMB. 6,194 are the average annual firm deductions in sample. The percentage change is treatment effect divided by initial cumulative. Hence $100 \times 10,736,158/30,970,000 = 34.67\%$.

[30]The figure of 23.5% arises from the average treatment effect on VAT payments divided by the cumulative VAT payments from the average firm, both for the post-2002 period. The average treatment effect for VAT payments equals $1,187 \times 0.4042 \times 5 \times 1000 = 2,399,062$ RMB and the cumulative VAT payments for the average firm equal $2,043 \times 5 \times 1,000 = 10,215,000$ RMB. Because VAT revenues represented 47.6% of total government revenues in 2002, the treatment is responsible for a $23.5\% \times 0.476 = 11.2\%$ increase in government revenues. $1,187 \times 0.4042 \times 5 \times 1000 = 2,399,062$ is the average cumulative VAT treatment effect. 2,043 is the VAT bill of the average firm in sample. $2,043 \times 5 \times 1,000 = 10,215,000$ is the average cumulative post-period VAT bill. $100 \times 2,399,062/10,215,000 = 23.49$ is the average cumulative VAT treatment effect divided by the average cumulative VAT bill.

conventional wisdom that the reform mainly impacted firms by removing their ability to falsify invoices for deductions.

Column (4) examines VAT as a share of sales. If VAT payments increase because of a change in enforcement, we may expect it to increase as a share of sales. Indeed, the coefficient is positive and statistically significant at the 10% level.[31]

## 5.2 Robustness and Sensitivity Analysis

### 5.2.1 Pre-trend Analysis

To investigate the validity of the parallel-trends assumption, we re-estimate the baseline equation except that we replace the interaction term $\widetilde{NDS}_s \times Post_t$ with the interaction of $\widetilde{NDS}_s$ and each year dummy variable. We plot the interaction coefficients in Figure 3. It shows no pre-trend. The coefficients for the years prior to the reform are zero. The effect of the reform begins after 2001. This figure is consistent with the raw data illustrated earlier in Figure 2.

### 5.2.2 Additional Controls

Next, we consider potential omitted variables. As we discussed earlier, the main confounding event was China's entry into the WTO in 2001 and the ensuing changes in tariffs. This will confound our estimates if entry differentially changed the effective VAT rate according to non-deductible share. (The economy-wide effect of entry into the WTO is already controlled for by the year fixed effects). To investigate this possibility, we construct measures of import tariffs, export VAT rebates and export duties for each sector and year.[32] Table 3 column (2) shows the results are very similar in magnitude

[31]The denominator here is total firm revenues, which is reported in a different module of the firm survey. We use this measure instead of VAT eligible sales because the latter could be affected by the reform if the reform increased the difficulty of understating gross VAT. However, given that total revenues include VAT eligible sales and that we find that the reform had no effect on the latter, the distinction is not very important in practice.

[32]Rebate data are from (Garred, 2016). We use the method presented in Fan et al. (2015, 2018) to obtain output and input tariffs.

to the baseline, which is restated in column (1) for comparison. Note that the number of observations changes slightly because we are unable to obtain data on tariffs for all sector-years.

Related to this idea, we address sector-specific changes in exposure to changes in the export market by controlling for average export growth rates in each sector in the pre-reform years interacted with year fixed effects. The coefficient in column (3) is very similar to the baseline.

Column (4) shows that our estimates are very similar if we control for the competitiveness of the sector measured using the Herfindahl-Hirschman Index (HHI) variable interacted with year fixed effects.

To address the possibility that there are province-specific policy changes or differences in the implementation of the reform (e.g., some provinces linked transactions in some years), or changes in province-specific economic conditions, we control for province-year fixed effects. For example, Chen (2017) argued that the abolition of agricultural taxes in 2005 led tax authorities to supplement their lost income with other tax sources such as VAT. Although the reform was a national level policy change, the extent to which provincial governments relied on agricultural taxes varied. Province-year fixed effects control for the potentially confounding influences of this reform to the extent that the revenue loss differed across provinces. Similarly, recall that we deflate the main dataset with a national deflator. But one may be concerned that prices change differentially across provinces. Column (5) shows that our results are very robust to the inclusion of province-year fixed effects.

Another way to address the possible confounding influences of the abolition of Agricultural Taxes in 2005 is to control for the extent to which each county relied on agricultural taxes as a source of revenue before the VAT reform. We use the county-level share of government revenue from agricultural taxes in 2000, and then control for this cross-sectional measure interacted with year fixed effects. The results from this regression are

reported in Column (6), and they are similar in magnitude and precision to the baseline.

One may also be concerned that the main results spuriously capture differences in global demand or supply shocks between sectors with high and low non-deductible shares. We address this concern by controlling for the total amount of imports and exports in each sector and year.[33] The estimate in column (7) is very robust to these additional controls.

As we discussed in Section 2, further changes in VAT policy made in 2009 (increasing the number of inputs that qualified for deductions) were piloted in three northeastern provinces (Liaoning, Heilongjiang and Jilin) starting in 2004 (Cai and Harrison, 2017; Liu and Lu, 2015). To investigate whether our main results are confounded by the pilot, we omit all observations from these provinces starting in 2004. Column (8) of Table 3 shows that the resulting estimate is very similar to the baseline.

Finally, in column (9), we control for ownership interacted with year fixed effects. This addresses the possibility that privately owned firms and state-owned firms may have evolved differently over time or that state-owned firms were affected by the reform differently from privately owned firms. For example, the enterprise reforms are usually considered to have taken place during 1998-2003. During this period, many state-owned firms were restructured, shut down, or privatized (e.g. Hsieh and Song, 2017). One may naturally wonder whether such restructuring confound the VAT reform that we study. Our estimates when controlling for ownership-year fixed effects are very similar to the baseline.

#### 5.2.3 Measurement Error

To address the possibility that the non-deductible share calculated using our firm survey prior to the reform may capture evasion in addition to the true level of non-deductible share, we use 1997 Chinese I-O Tables to construct proxy measures. To the best of our

[33]These data are reported by China's General Administration of Customs, 1998-2007.

knowledge, the latter dataset is constructed from an independent data source. However, the lack of transparency in how the I-O tables are generated leaves open the concern that they may nevertheless still be confounded by evasion in the pre-reform years. This is a concern for our analysis if the evasion captured in the data changes the cross-sector rank in terms of non-deductible shares. This seems unlikely ex ante. However, to be cautious, we address this issue by instrumenting for the OLS measure with non-deductible shares calculated from 2007 U.S. Input-Output Tables. U.S. non-deductible shares across sectors will not reflect evasion under pre-period Chinese tax rules.

Table 2 Panel C presents the reduced from estimates. Panel B shows the 2SLS estimates and the first stage Kleibergen-Paap F-statistic, 26.65. The instrumented estimates are similar or larger in magnitude than the OLS estimates in Panel A, which goes against the concern that the main OLS results are driven by measurement error in the explanatory variable. The statistical precision varies across columns.

One concern in using the U.S. non-deductible shares to instrument for Chinese non-deductible shares is that the former may be influenced by the reform that we study via trade connections between the United States and China. We address this issue by showing that 2SLS results are robust when we exclude sectors for which trade exposure, measured as the share of U.S. imports or exports from/to China, is high. See Appendix Table A.2. In the Appendix, we also show that using the I-O tables of Mexico and South Korea produce similar results.[34]

## 5.3 Additional Results for VAT

### 5.3.1 Spillover Effects in Enforcement

Here, we consider whether improved enforcement of VAT had positive spillover effects in the enforcement of other types of taxes. We examine corporate tax payments, which

[34]We report the correlations among sectoral non-deductible shares from China, Mexico, South Korea, and the United States in Appendix Table A.3. We report 2SLS and reduced form estimates using the non-deductible shares from Mexico and South Korea in Appendix Table A.4.

are also reported in our survey data. Table 4, column (1) shows that the interaction coefficients are positive but statistically insignificant. Thus, there is no evidence of positive spillovers, which is perhaps unsurprising if the main mechanism for increased VAT is the reduction of false deduction invoices.

The result on corporate tax is also interesting for another reason – it provides evidence against the concern that our main finding that computerization increased VAT is confounded by general improvements/changes in the tax system.

### 5.3.2 Heterogeneous Effects for Exporters and Importers

Next, we divide the sample according to export shares and imported input shares. This dimension of heterogeneity is interesting given the importance of trade to China's manufacturing sector. We divide the sample according to whether export or import shares in the sector are lesser or greater than the sample median in 1998-2000.[35] Columns (2) and (3) test whether the treatment effect differed by the pre-period sectoral export share. Note that the sample median export share is zero, which is why the subsample in Table 4 column (2) is much larger than that of column (3). In columns (4) and (5), we test whether the treatment effect differed by the pre-period sectoral imported input share. The estimates show that the reform increased VAT more for firms in sectors that exported and imported less. The p-values at the bottom of the table show that the estimates from the different sub-samples are almost statistically different at conventional levels. The results are consistent with the presence of significant export rebates for VAT. It is also reassuring because it goes against the concern that our findings are confounded by global demand shocks that are spuriously correlated with the non-deductible share of sectors. If that were the case, omitting the sectors that trade more with the outside world should weaken our results.

[35]Export shares are calculated using our data. Imported input shares are calculated using Chinese Customs Administration data.

### 5.3.3 Heterogeneous Effects According to Distance from End Consumers

Another interesting dimension of heterogeneity to examine is the distance to the end consumer. Sellers of raw materials are supposed to pay sales taxes, and face incentives to under-report sales, while the purchasers of raw materials face incentives to overstate inputs. In China, since the main binding component of the reform was to reduce exaggerated deductions, one may expect the reform to be more binding for firms that are further away from the top of the chain and closer to consumers (e.g., a firm at the very top of the chain may use raw materials and not have deductible inputs).[36] The p-value at the bottom of Table 4 columns (6) and (7) is close to one, which shows that the effect of computerization is very similar for firms that are closer versus further away from the final consumer. These results should be interpreted cautiously. Because our sample contains large manufacturing firms, we do not observe firms at the very top or bottom of the supply chain.

### 5.3.4 Heterogeneous Effects by Ownership

We use the official ownership registration definition to divide the sample into two categories: state-owned and domestic privately-owned firms. The estimates in Table 4 columns (8) and (9) show that the estimates are very similar for the two types of firms, although the small sample size of state-owned firms results in a statistically insignificant estimate.

[36]Studies such as Pomeranz (2015) have found that in Chile, the strength of enforcement weakens towards the end consumer because the end consumer is not incentivized to ask for receipts. This point has also been made by other studies. See Slemrod (2007) for a discussion. Unlike the Chilean context, the Chinese government incentivizes end consumers to ask for receipts by making each official receipt a lottery ticket. In this sense, the environment is similar to the the Brazilian one studied by Naritomi (2015). However, it is widely believed that retail sales tax in China is not well enforced.

### 5.3.5 Heterogeneous Effects by Size and Fixed Assets

Given recent studies which find that compliance to tax policy varies by firm size (Bachas and Jensen, 2017; Kleven et al., 2016), we investigate whether the effect of computerization differs for large and small firms in our context. In columns (10) and (11) of Table 4, we observe a larger coefficient for small firms, but the difference between the two coefficients is not statistically significant.[37]

### 5.3.6 All Firms

The main results examine a balanced panel of firms, which has advantages for identification and interpretation (e.g., we can control for firm fixed effects, and there are no compositional effects from entry and exit of firms). To address the issue of external validity, we re-estimate our baseline specification using all firms and compare those results to those from the balanced panel. We organize the data to be a panel of sectors.[38] Since the right-hand side variation in equation (2) is at the sector level, the only change to the estimation when we expand the sample is that we control for sector instead of firm fixed effects. We weight the regressions with the number of firms in each sector-year cell such that the estimated coefficients and standard errors are numerically identical to a regression using firm-year observations. Appendix Table A.6 presents the results. These results suggest that the findings from the balanced sample are qualitatively generalizable to large manufacturing firms as a whole, even if we allow for entry and exit.

## 5.4 Other Firm Behavior

Table 5 examines other measures of firm behavior. Column (1) examines total sales (not just VAT eligible sales), which are reported in a different module of the survey and

[37] We also divide the sample according to the share of fixed assets for the median firm in a sector. We find no difference. These results are available upon request.

[38] Appendix Table A.5 presents descriptive statistics for firms in the balanced panel and all firms.

are generally believed by existing studies to reflect true output.[39] Columns (2) and (3) examine two proxies of labor input: the number of employees and the total wage bill. The latter is typically problematic to interpret in China because of the high amount of non-wage benefits (e.g., housing). Columns (4)-(5) examine intermediate inputs, first in levels, and then as share of total inputs. Column (6) examines intermediate inputs which are deductible from VAT as a share of total inputs. The results show that the reform reduced sales, employees and deductible input share. The coefficients for the other outcomes are also negative, but imprecisely estimated.

In columns (7) and (8), we examine TFPR, calculated as in Hsieh and Klenow (2009) and as in De Loecker and Warzynski (2012), which accounts for endogenous inputs. We find that the reform increased productivity in both cases. Since productivity is intuitively output normalized by input, this conceptually reflects the fact that the reform reduced inputs more than it reduced output.

In column (9), we examine exports as a share of total sales for each firm as the outcome variable to investigate whether firms shifted towards exports to reduce VAT after the reform. On the one hand, the reform incentivized firms to switch to exports which are eligible for VAT rebates. On the other hand, the earlier results show that the firm is contracting. This may disproportionately reduce exports given the conventional wisdom that there are high fixed costs to exporting (e.g. Das et al., 2007; Roberts and Tybout, 1997). The estimate in column (9) shows that the net effect of the reform on export share is negative and statistically significant.

[39]Many studies have used this variable to measure firm output. The most well-known is perhaps Hsieh and Klenow (2009), which uses this variable to compute firm-level TFP.

### 5.5 Mechanisms

# 6 Dynamic Effects

The main results shown in the previous section provide evidence that the reform significantly improved compliance and increased VAT. Consistent with conventional wisdom that the most binding component of the reform was to increase the difficulty of falsifying deduction invoices, we find that the increase in VAT is driven by a decline in deductions. We also find that the increase in tax payment was accompanied by a decline is output, input, deductible inputs, export share and an increase in productivity.

This section supplements the main analysis with two complementary inquiries. The first is to ask whether the dynamic effect of the reform on VAT is monotonic or stable over time. This is obviously relevant for policymakers who are interested in longer-run tax revenue gains. The second is to ask whether the effects we observed earlier on sales, inputs and productivity reflect real economic effects or a change in misreporting.

It will be beyond the scope of this paper be conclusive about the latter point. But given the importance of the question, we feel it worthwhile to further our understanding of the issue as much as the data will allow. To motivate the analysis in this section, consider the possibility that our findings on sales, inputs and productivity are driven by a change in what firms report rather than real economic changes. This could occur for two reasons. The first is that firms are motivated to evade VAT. The second is that the new system put in place by the reform has a spillover effect in causing firms, who previously misreported to evade VAT, to report all measures of performance more truthfully. The decline in labor inputs and deductible inputs are inconsistent with the first explanation because labor inputs are not deductible and lower deductible inputs increases VAT payment. Finding that the decline in total revenues is larger than the decline on VAT eligible sales is also inconsistent since evasive behavior should induce a larger decline in VAT eligible sales. At the same time, the second explanation is

inconsistent with finding that the reform had a negative (2SLS) or no (OLS) effect on VAT eligible sales, and a negative effect on sales. Firms which previously misreported to evade VAT would have underreported VAT eligible sales, such that an improvement in reporting should increase VAT eligible sales. And as with the first explanation, the decline in labor inputs is difficult to explain since it is unrelated to VAT throughout our study period. Finally, the increase in TFPR is difficult to reconcile with a simple story of evasion.

In other words, the results, taken together are inconsistent with the most obvious changes in reporting behavior that could result from the reform. In light of this, we develop a simple model illustrating how the reform can induce real changes, which will have empirically testable predictions for the dynamic effects of the increase in taxation. We will present the conceptual framework and then examine whether the empirical predictions are consistent with our data.

## 6.1 Conceptual Framework

To provide positive evidence that the findings on firm behavior in the previous section are real effects, we develop a simple model. The formal model is presented in Appendix Section D. The intuition is summarized here.

Demand is downward sloping and short-run supply is upward sloping. With no taxes, pre-tax and tax-inclusive prices are similar in period 0, $q_0 = p_0$. When the tax, $\tau$, is imposed, the supply shifts upwards by the amount of the tax, since the marginal cost of production has increased by $\tau$. This shift increases the pre-tax equilibrium price to $q_1 > q_0$. Producers receive the pre-tax price minus the tax, $p_1 = q_1 - \tau$. The figure shows that the tax-inclusive price will decrease to $p_1 < p_0$.

In the long run, the supply curve becomes more elastic, because we assume that capital (i.e., intermediate inputs) can only be adjusted in the long run. For simplicity, Figure 4 illustrates a perfectly elastic long-run supply curve. Since $q_0 = p_0$ is optimal,

we simply rotate the supply curve around the initial point where supply and demand intersect. As with the short-run, the long-run response to the increase in taxes can be illustrated by shifting the supply curve up by the amount of the tax. The long-run pre-tax price will be $q_2 > q_1 > q_0$, while the long-run tax-inclusive price will be $p_2 = p_0$. Figure 4 illustrates the key intuition.

The simple model also predicts that labor input will decline over time. The intuition for this result comes from the observation that the short-run elasticity of labor is smaller than the long-run elasticity of labor (because capital can also be adjusted in the long run) *holding pre-tax prices fixed*. This effect implies that labor should react even more in the long run to the tax change than in the short run. In our setting, there is also an offsetting effect, since the increase in pre-tax prices calls for larger inputs, all things being equal. If demand is elastic, prices react little to changes in output, so that the first effect dominates. It follows with a little algebra that other inputs also decline over time.

Several empirically testable implications emerge from the model. First, tax revenues will increase from period zero to period one, and then decline in period 2 to a level between that of periods 0 and one, such that $0 = \text{taxes}_0 < \text{taxes}_2 < \text{taxes}_1$.[40] Second, the pre-tax price, which is algebraically equivalent to $TFPR$ as formulated in Hsieh and Klenow (2009), increases every period, $q_2 > q_1 > q_0$. Third, if the elasticity of demand, $\sigma$, is greater than 1, sales decline each period, $q_2 y_2 < q_1 y_1 < q_0 y_0$. Fourth, labor and intermediate inputs decline each period, $l_0 > l_1 > l_2$ and $k_0 \geq k_1 > k_2$.

The baseline model assumes a Cobb-Douglas production function with two factors, labor and intermediate inputs, and perfect competition. We provide several extensions to show that all of the main insights carry through with imperfect competition, endogenous input prices, or with three factors of production (labor, capital, and deductible inputs).[41]

[40] $\text{Taxes}_t = \tau q_t y_t$

[41] Note that because our empirical strategy relies on cross-sector as well as time variation, the results, taken literally, will also reflect the ability of factors to reallocate across sectors. For simplicity, our baseline model does not take this additional mechanism into account. The extension is straightforward and available upon request. All of the insights carry through.

See Appendix Section D.

## 6.2 Results

The first prediction of the simple model is that tax revenues should increase after the reform, but the long-run level – though still positive – will be slightly lower than the short-run level. Recall that Figure 3 indicates that this is the case.

We can also examine this by re-estimating an OLS equation similar to the baseline, except that we divide the seven-year post-reform period into three sub-periods: 2001-2002, 2003-2005, and 2006-2007.[42] Table 6 column (1) examines gross VAT. Column (2) examines deductions. These results are consistent with the average effects of the reform shown earlier. The estimates for gross VAT are statistically zero. The estimates for deductions are negative, statistically significant starting in 2003 and larger in magnitude than the decline in sales.

Column (3) shows that the reform increases VAT payment in all three post-reform periods. However, the increase is largest in levels during 2003-2005 and declines in the third period. The non-monotonic pattern over time is consistent with the predictions of our model. The p-values at the bottom of the table show that the change from period one to period two is statistically significant at the 1% level. The decline from period two to period three is almost significant at the 15% level. The coefficients from periods one and three are statistically similar. The evidence suggests that the gains in VAT from the reform decline slightly in the long run, but remain positive.

Column (4) examines VAT as a share of sales. The temporal patterns are consistent with those in column (3).

Table 7 columns (1) and (6) show that the increase in taxes is accompanied by a monotonic decline in sales and deductible input share. The other coefficients are also

[42]Recall that for the earlier estimates of the average effect of the reform, we defined the post-reform period as 2002 and afterwards because the reform was only partly phased in during 2001. Here, in the dynamic estimation, we allow both 2001 and 2002 to be the first treatment period so that we can observe the effects during the entire period of program rollout.

declining monotonically over time, but are statistically insignificant. Columns (7) and (8) show that TFPR increases over time. All of these results are consistent with the theory which predicts real effects.

In column (9), we examine export share and see that the negative effect of the reform is monotonic over time. This is consistent with our conjecture that it parallels the reduction in output.

As with our earlier results, we show that the estimates exhibit similar patterns when we instrument for Chinese non-deductible shares with U.S. non-deductible shares. The results are presented in Appendix Table A.7. We do not show the results instrumenting with Mexican and South Korean non-deductible shares because the first-stage F-statistics for these alternative instruments are very small in the dynamic estimate. We also report the robustness of dynamic effects subject to the same large set of controls we examined earlier in Appendix Table A.8.

# 7 Conclusion

This paper provides novel and rigorous empirical evidence on the effects of a large-scale nation-wide, but relatively simple reform. We document that a reform which computerized and digitally encrypted VAT invoices significantly increased VAT revenues by reducing false deductions. This reform substantially increased fiscal capacity: it contributed to 23.5% of total VAT revenues and 11.2% of total Chinese government revenues during 2001-2007. Given that this increase was realized despite the inability of the tax authority to link transactions nationally, our results show that even a partial reform can result in huge gains for government revenues. The findings illustrate the power of high-tech tools for improving state capacity and provide support for recent studies such as Barnwal (2016), Banerjee et al. (2008), Duflo et al. (2012) and Muralidharan et al. (2016) with data and a policy reform from a very different context.

We also find that the reform reduced firm output and provide evidence that firms could be contracting production in response to the increase in effective tax rate. At the same time, we find that productivity increases. Thus, from the perspective of the government or economy as a whole, this is not necessarily bad. As a result of firms being able to adjust production in the long run, the dynamic effects of the reform on tax revenues are nuanced. The gains in revenues are smaller in the long run than the short run, but important for policy makers, they remain positive.

It is important to keep in mind that the magnitudes of our estimates are specific to the context of our study. However, the findings that a simple technology can have a large effect on state capacity, or that firms may change their economic behavior in the longer run as a response to increased taxes are generally interesting.

There are several promising questions for future study. For China, the obvious next question is to examine the marginal gains to nationally linking VAT transactions, which will strengthen the information chain. Another new and quickly spreading technology relevant to state capacity is the mobile wallet, which policy makers hope will reduce tax evasion by replacing cash transactions between consumers and retailers.[43] The effect of mobile wallets on taxes is a very promising question for future research. For developing economies in general, an interesting question is whether taxation hampers the formalization of firms by causing small firms on the threshold of formality to scale down and exit the formal sector to avoid paying taxes. Our study cannot speak to this question because our data are limited to very large formal firms. Studies such as dePaula and Scheinkman (2010) argue that better enforcement of VAT can induce more formalization. This question is central to policy makers of developing economies since a movement of firms into the informal sector could reduce a government's bureaucratic and regulatory capacity for taxation and many other policies.

[43]The rapid expansion of the mobile wallet technology, which is seen to increase the convenience for consumers and businesses, reduce tax evasion by leaving a paper trail, and promote rural financial inclusion (Aveni and Roest, 2017).

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Table 1: Correlates of Non-deductible Share and Pre-Reform Firm Characteristics

| Pre-Reform Means | Sector-Level Non-Deductible Share |
|---|---|
| VAT | .1924*** |
| VAT / Sales | .443*** |
| VAT Gross | -.0764 |
| VAT Deductions | -.159** |
| TFPR OLS | .3933*** |
| TFPR DLW | .2412*** |
| Sales | -.1443** |
| Empl | .0071 |
| Wage Bill | .0325 |
| Intermediate Inputs | -.1774** |
| Intermediate Input Share | -.3046*** |
| Total Deductible Inputs | -.1082* |
| Export Share | -.0778 |

*Notes* : This table presents the standardized bivariate correlation coefficients between the non-deductible share and key variables measured in 1998-2000. *** p<0.01, ** p<0.05, * p<0.1

Table 2: The Effect of Computerization on VAT: Average Effects

| | Dependent Variables | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| | VAT Gross | VAT Deductions | VAT | VAT/Sales |
| **Dep Var Mean** | **7,758** | **6,194** | **2,043** | **1.043** |
| | A. OLS | | | |
| Non-deductible share x Post-2002 | -3,881 | -5,312** | 1,187** | 0.00976* |
| | (2,544) | (2,234) | (490.7) | (0.00562) |
| Observations | 180,148 | 180,148 | 180,148 | 180,148 |
| R-squared | 0.626 | 0.500 | 0.692 | 0.560 |
| | B. 2SLS | | | |
| Non-deductible share x Post-2002 | -14,637*** | -16,526*** | 1,336 | 0.0347** |
| | (5,625) | (4,973) | (1,234) | (0.0138) |
| Observations | 180,148 | 180,148 | 180,148 | 180,148 |
| □Kleibergen-Paap F-statistic | 26.65 | 26.65 | 26.65 | 26.65 |
| | C. Reduced Form | | | |
| U.S. Non-deductible share x Post-2002 | -3,468*** | -3,915*** | 316.5 | 0.00823*** |
| | (1,309) | (1,131) | (288.8) | (0.00301) |
| Observations | 180,148 | 180,148 | 180,148 | 180,148 |
| R-squared | 0.626 | 0.500 | 0.692 | 0.560 |

*Notes:* The sample is a balanced panel of firms covering 1998-2007. All regressions include firm fixed effects, year fixed effects, and average 1998-2000 firm sales times year fixed effects. Standard errors are clustered at the sector level. *** p<0.01, ** p<0.05, * p<0.1 In Panel B, the instrument is the U.S. non-deductible share x post-2002.

Table 3: The Effect of Computerization on VAT: Robustness to Export/Import Intensity, Province-Year-Specific Shocks, and Global Demand Shocks

| | Dependent Variable: VAT | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Controls: | Baseline | Export Rebates, Import and Export Duties | Export Growth 1998-2000 x Year FE | HHI 1998-2000 x Year FE | Province FE x Year FE | Agricultural Tax Share 2000 x Year FE | Sector-Year Imports and Exports | Omit Liaoning, Jiling and Heilongjiang 2004-2007 | Ownership Category x Year FE |
| Non-deductible share x Post-2002 | 1,187** | 978.5** | 1,179** | 1,203** | 1,142** | 1,300** | 1,149** | 1,202** | 1,145** |
| | (490.7) | (462.2) | (490.1) | (491.7) | (471.4) | (537.1) | (477.3) | (503.4) | (470.2) |
| Observations | 180,148 | 180,057 | 180,148 | 180,148 | 180,120 | 139,863 | 180,148 | 177,066 | 180,147 |
| R-squared | 0.692 | 0.693 | 0.692 | 0.692 | 0.697 | 0.699 | 0.692 | 0.694 | 0.693 |

*Notes:* The sample is a balanced panel of firms covering 1998-2007. All regressions include firm fixed effects, year fixed effects, and average 1998-2000 firm sales times year fixed effects. Additional controls are stated in the column headings. Standard errors are clustered at the sector level. *** p<0.01, ** p<0.05, * p<0.1

## Table 4: The Effect of Computerization on VAT: Spillover Effects and Heterogeneity

| | Dependent Variable | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VAT (1000 RMB) | | | | | | | | | |
| Sample Restrictions: | Corporate Tax (1000 RMB) | Non-Exporters (pre-2001 export share < median) | Exporters (pre-2001 export share > median) | Imported input share < median | Imported input share > median | Distance to final consumer < median | Distance to final consumer > median | State Owned | Privately Owned | Pre Sales < median | Pre Sales > median |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
| **Dep Var Mean** | **0.0431** | **2233** | **1250** | **2077** | **2010** | **2036** | **2051** | **2097** | **2038** | **1742** | **2340** |
| Non-deductible share x Post-2002 | 493.1 | 1,193** | 63.13 | 1,713** | 335.7 | 1,255* | 1,607** | 1,030 | 1,233** | 1,884*** | 876.4 |
| | (310.3) | (503.6) | (635.8) | (684.9) | (566.5) | (751.5) | (758.7) | (760.7) | (509.0) | (519.9) | (731.1) |
| Observations | 180,148 | 145,330 | 34,818 | 88,554 | 91,594 | 93,382 | 86,228 | 16,625 | 163,523 | 89,309 | 90,839 |
| R-squared | 0.454 | 0.708 | 0.525 | 0.709 | 0.674 | 0.715 | 0.686 | 0.746 | 0.687 | 0.680 | 0.695 |
| H0: col 1 = col 2 (SUR p-value) | | 0.158 | | 0.122 | | 0.747 | | 0.662 | | 0.262 | |

*Notes:* The sample is a balanced panel of firms covering 1998-2007, conditioned on the inequalities in the column headings. The conditioning variables are measured at the firm, sector-year, and sector level respectively. All regressions include firm fixed effects, year fixed effects, and average 1998-2000 firm sales times year fixed effects. Standard errors are clustered at the sector level. *** p<0.01, ** p<0.05, * p<0.1

Table 5: The Effect of Computerization on Firm Outcomes: Average Effects

| | Dependent Variable | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Sales | Employees | Wage Bill | Intermediate Inputs | Intermediate Inputs as a Share of Total Input | | TFPR OLS | TFPR DLW | Export Share |
| | | | | | All | Deductible | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| **Dep Var Mean** | **58,545** | **355** | **3,848** | **40,590** | **0.835** | **0.764** | **117.1** | **34.34** | **0.212** |
| Non-deductible share x Post-2002 | -23,917* | -190.4*** | -405.1 | -14,643 | -0.0237 | -0.291*** | 0.457*** | 0.470*** | -0.0888* |
| | (13,524) | (71.70) | (879.7) | (9,249) | (0.0310) | (0.0990) | (0.153) | (0.144) | (0.0513) |
| Observations | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 |
| R-squared | 0.764 | 0.814 | 0.731 | 0.782 | 0.637 | 0.145 | 0.874 | 0.978 | 0.834 |

*Notes:* The sample is a balanced panel of firms covering 1998-2007. All regressions include firm fixed effects, year fixed effects, and average 1998-2000 firm sales times year fixed effects. Standard errors are clustered at the sector level. *** p<0.01, ** p<0.05, * p<0.1 In Panel B, the instrument is the U.S. non-deductible share x post-2002.

Table 6: The Effect of Computerization on VAT: Dynamic Effects

| | Dependent Variable | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| | VAT Gross | VAT Deductions | VAT | VAT/Sales |
| Non-deductible share x 2001-2002 ($\beta$1) | -455.5 | -1,129 | 618.8* | 0.00364 |
| | (930.2) | (820.2) | (364.2) | (0.00351) |
| Non-deductible share x 2003-2005 ($\beta$2) | -3,021 | -3,615** | 1,667*** | 0.0125** |
| | (2,029) | (1,781) | (599.9) | (0.00618) |
| Non-deductible share x 2006-2007 ($\beta$3) | -5,584 | -8,901** | 1,100* | 0.00943 |
| | (4,049) | (3,512) | (666.1) | (0.00733) |
| Observations | 180,148 | 180,148 | 180,148 | 180,148 |
| R-squared | 0.626 | 0.500 | 0.692 | 0.560 |
| H0: $\beta$1=$\beta$2 (p-value) | 0.100 | 0.0800 | 0.00400 | 0.0660 |
| H0: $\beta$2=$\beta$3 (p-value) | 0.323 | 0.0230 | 0.159 | 0.443 |
| H0: $\beta$1=$\beta$3 (p-value) | 0.170 | 0.0210 | 0.359 | 0.350 |

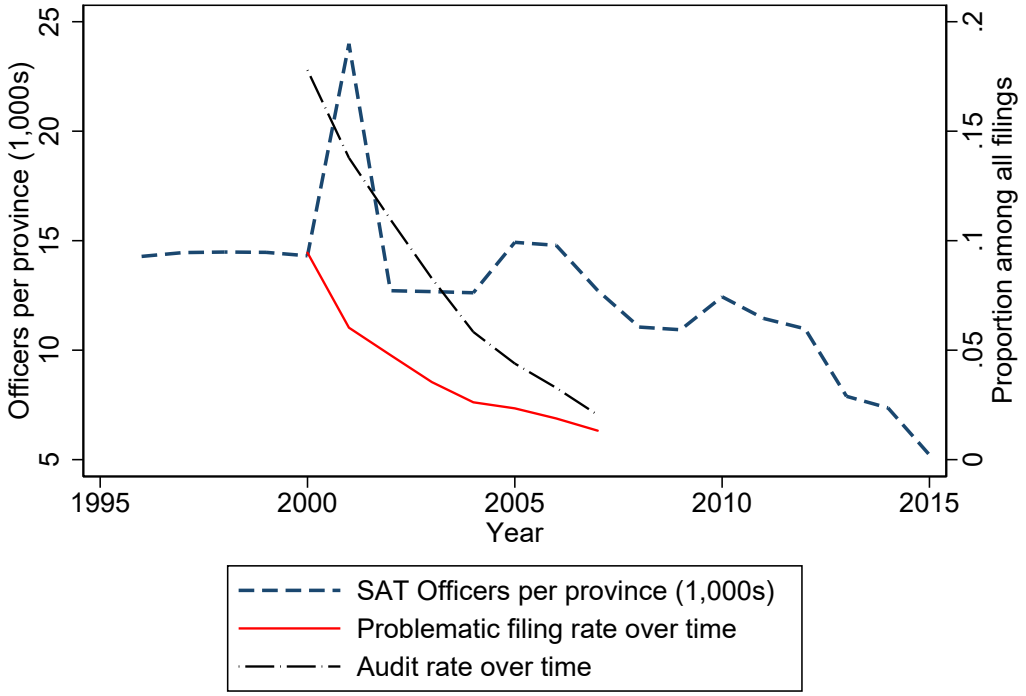
*Notes:* The sample is a balanced panel of firms covering 1998-2007. All regressions include firm fixed effects, year fixed effects, and average 1998-2000 firm sales times year fixed effects. Standard errors are clustered at the sector level. *** p<0.01, ** p<0.05, * p<0.1

Table 7: The Effect of Computerization on Firm Outcomes: Dynamic Effects

| | Dependent Variable | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Sales | Employees | Wage Bill | Intermediate Inputs | Intermediate Inputs as a Share of Total Input | | TFPR OLS | TFPR DLW | Export Share |
| | | | | | All | Deductible | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Non-deductible share x 2001-2002 | -4,439 | -104.2** | 838.6 | -1,954 | 0.00749 | -0.0622 | -0.00777 | -0.0617 | -0.0357* |
| | (5,266) | (51.97) | (516.9) | (3,885) | (0.0136) | (0.0796) | (0.0389) | (0.0431) | (0.0210) |
| Non-deductible share x 2003-2005 | -16,087 | -204.6** | 304.0 | -11,023 | -0.00367 | -0.208** | 0.216* | 0.177 | -0.0687* |
| | (10,620) | (79.19) | (905.1) | (8,044) | (0.0293) | (0.0989) | (0.121) | (0.118) | (0.0394) |
| Non-deductible share x 2006-2007 | -39,707* | -272.7** | -609.7 | -21,846 | -0.0456 | -0.472*** | 0.800*** | 0.834*** | -0.153* |
| | (22,202) | (106.2) | (1,217) | (13,977) | (0.0454) | (0.146) | (0.226) | (0.216) | (0.0863) |
| Observations | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 |
| R-squared | 0.764 | 0.814 | 0.731 | 0.782 | 0.637 | 0.145 | 0.875 | 0.978 | 0.834 |
| H0: $\beta 1=\beta 2$ (p-value) | 0.126 | 0.0110 | 0.392 | 0.128 | 0.550 | 0.0750 | 0.0360 | 0.0140 | 0.195 |
| H0: $\beta 2=\beta 3$ (p-value) | 0.108 | 0.0450 | 0.0580 | 0.184 | 0.0280 | 0.00400 | 0 | 0 | 0.105 |
| H0: $\beta 1=\beta 3$ (p-value) | 0.0840 | 0.0120 | 0.131 | 0.117 | 0.132 | 0.00300 | 0 | 0 | 0.108 |

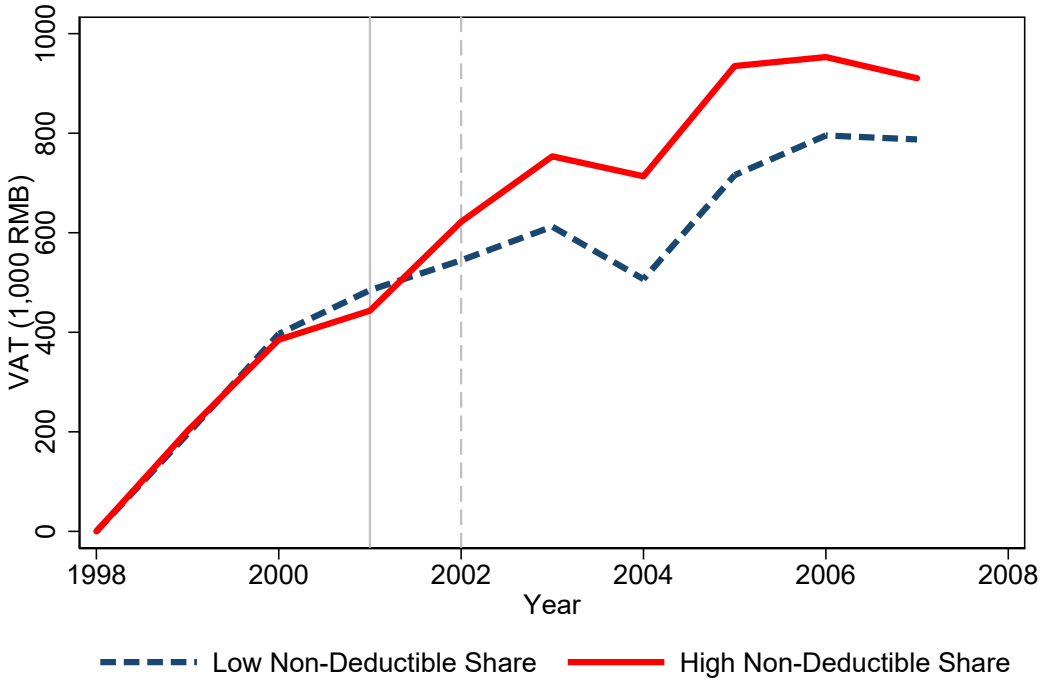
*Notes:* The sample is a balanced panel of firms covering 1998-2007. All regressions include firm fixed effects, year fixed effects, and average 1998-2000 firm sales times year fixed effects. Standard errors are clustered at the sector level. *** p<0.01, ** p<0.05, * p<0.1

Figure 1: Tax Personnel, Audit Rates and "Problematic" Cases Over Time



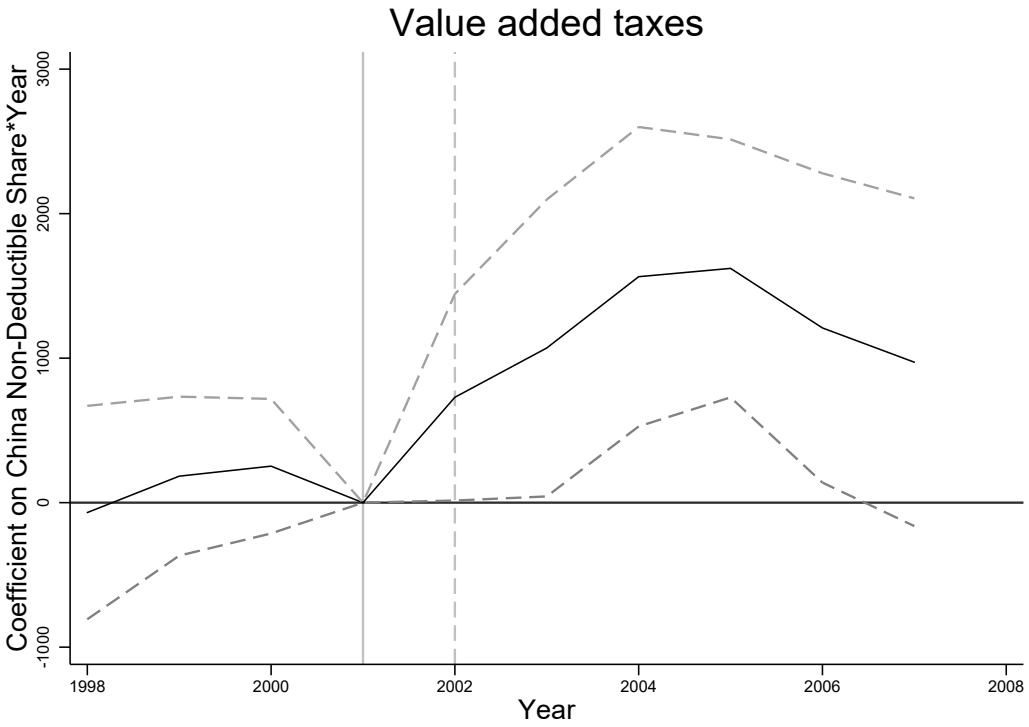

Data: Tax Audit Yearbook of China

Figure 2: VAT Over Time for Firms with Non-deductible Shares Above and Below the Sample Median



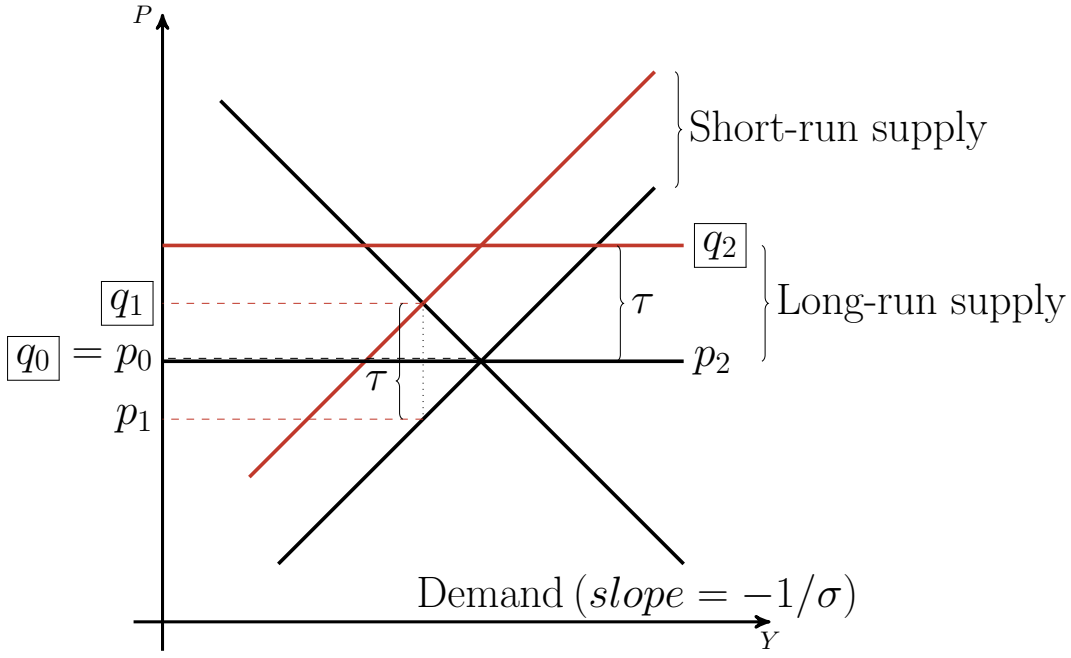

*Notes:* For each of the two groups of firms, the 1998 mean is subtracted from the yearly value.

Figure 3: The Yearly Effect of Computerization on VAT since Computerization




*Notes:* This figure plots the interaction coefficients of non-deductible share and year dummy variables (controlling for year and firm fixed effects) and their 95% confidence intervals. The sample is a balanced panel of firms, 1998-2007. The reference year is 2001. The coefficients and their standard errors are shown in Appendix Table A.9.

Figure 4: Illustration of Short- and Long-run Responses to VAT



# ONLINE APPENDIX – Not for Publication

## A VAT Deductibles

The regulation that governs VAT remittance rules during the study period is the *Provisional Regulations of the People's Republic of China on Value-Added Tax* (State Council Order 134, published in December 1993). The rules were effective between Jan 1, 1994, and Jan 1, 2009, when these *Regulations* were amended for the first time. The *Regulations* specifies the deductible items for VAT, which are not exactly the same as in other countries. The general principle is that any purchases that come with VAT special invoices, regardless of whether they originate from a domestic or international seller, can be deducted from the VAT duty. Full deductions are allowed for manufactured inputs, repair inputs, retail inputs, and wholesale inputs. Partial deductions are allowed for some "necessity goods" (including agricultural products, oils, gas, book, fertilizers, salt, and etc.) at a rate of 13%, for old and waste materials at a rate of 10%, and for transportation costs at a rate of 7%. No deductions are allowed for labor costs, fixed asset purchases, capital depreciation, abnormal losses, rent, fringe benefits, interests from bank loans, and overhead/operating expenses. Three Northeastern provinces, namely Liaoning, Jilin, and Heilongjiang, experimented with variants of VAT reforms in eight sectors in 2004 that allowed for deductions of fixed asset purchases. However, this did not affect other regions until 2009.

# B Data

We follow the standard procedure for cleaning the Manufacturing Censuses, as first used in Cai and Liu (2009). We drop observations for which any reported sub-component of assets is greater than total assets, as well as observations for which the start month does not fall between 1 and 12. We also drop observations for which the founding year of the firm is greater than the year of the survey.

We remove the influence of extreme outliers, which are likely to represent coding errors in these self-reported data. We drop the top and bottom 1% of observations for the variables VAT and sales.

We construct measures of non-deductible share for several countries using the World Input-Output Tables (Dietzenbacher et al., 2013; Timmer et al., 2016). We use input-output tables from the year 2000 to construct these alternative country non-deductible shares, as that is the first available year for which the tables are reported with 56 sectors. For years prior to 2000, the World Input-Output Tables are reported at an aggregation of 35 sectors. We create a correspondence between the 56 input sectors and whether each sector would legally be considered a non-deductible input type under Chinese tax law in the year 2000. Then, we compute the sector-and-country-specific share of each industry's inputs that are not deductible.

# C 2SLS

To calculate the United States non-deductible shares, we use the *United States Input-Output Accounts Data* from the U.S. Bureau of Economic Analysis (2017). These tables report the share of inputs by sector required in order to deliver one dollar of output. The sectors are coded with the North American Industry Classification System (NAICS) at three levels of disaggregation: a 13-sector coding, a 71-sector coding and a 405-sector coding. The 13- and 71-sector tables are available for each year from 1997 to 2017. The

finest level of disaggregation, with 405 sectors, is only available for 2007 and 2012. In selecting which U.S. I-O table to use, we balance two priorities.

First, we want the most disaggregated data in order to lose as little information as possible in the concordance process. To assess the importance of disaggregation, we tabulated how much information would be lost in moving from 405 to 71 sectors. When we hand-match sectors in the 71-sector NAICS codes to the CIC, each NAICS code is matched with an average of 13.7 Chinese sectors. On the other hand, when we match the 405-sector NAICS codes with the CIC, each NAICS code is matched with an average of 1.9 Chinese sectors. As a result, significantly more information is lost when harmonizing the 71-sector NAICS codes to CIC codes.

Second, we would like to use pre-computerization data to avoid the inclusion of endogenous treatment effects in our measurement of U.S. non-deductible share. Specifically, the Chinese computerization in 2001-2002 may have precipitated changes in the Chinese economy, and in turn, those changes may have altered the composition of U.S. firm inputs in the years after 2001, perhaps through international trade linkages or competition.

However, there are no pre-computerization U.S. Tables that report at the 405-sector level. At this stage, we use our best judgment. Because the problems of using more aggregated data are so stark and the threat of endogenous U.S. input share responses seem a priori quite small, we choose to use the *2007 Detailed Input U.S. Tables* (U.S. Bureau of Economic Analysis, 2007). To address concerns of endogeneity, we perform robustness checks in which we control for U.S. sectoral trade exposure to China. We also perform a robustness check using 2000 U.S. Use Tables.

The *2007 Detailed Input U.S. Table* reports the share of inputs required for one unit of production in industry $s$ from all other industries. Hence, the elements of the table report $Input\ fraction_{sr}$, for $r$, $s \in S$, where $S$ represents the universe of all sectors. For each sector $s$, $\sum_{r=1}^{S} Input\ fraction_{sr} = 1$.

To construct our measure of U.S. NDS, we map each sector in the input-output tables

into two groups, deductible or non-deductible, according to the rules of the Chinese VAT deductions. In practice, we consider inputs from manufacturing industries to be materials, and thus deductible under Chinese VAT rules. We treat inputs from service industries to be non-deductible. To obtain the final measure, we sum the fractions of inputs from deductible industries to obtain a single fraction for each industry that represents the share of inputs deductible under Chinese VAT rules. This object can be characterized by the following equation, where $D$ represents the set of deductible industries:

$$\widetilde{NDS}_s^{US} = 1 - \sum_{d \in D} Input\ fraction_{sd}. \tag{4}$$

We acknowledge that the U.S. NDS will measure Chinese NDS with error, which if classical, will attenuate the results.[44]

# D A Model of VAT Enforcement

## D.1 Benchmark

We present here a simple model that generates all of the main dynamic effects. In the simple benchmark case, we begin by considering one sector, populated by identical, perfectly competitive firms. We assume that all firms in the given sector have the Cobb-Douglas technology $k^{\alpha}l^{1-\alpha}$ and factor prices of $k$ and $l$ are given by $r$ and $w$. The pre-tax price of output of the sector is $q$, and the tax-inclusive price of the output of the sector is $p$, with $q = (1+\tau)\,p$. Demand for the output of the sector is given by $y = q^{-\sigma}$ where $\sigma > 0$ is the elasticity of demand.

We assume that there are three periods. In period 0, there is no tax on the sector, $\tau_0 = 0$. The tax is introduced in period 1, and $\tau_2 = \tau_1$. Period 1 represents "short run", when only one factor, $l$, can be adjusted freely. Period 2 represents "long run", when

[44] A list of sectors and the estimated NDS is available upon request.

both factors can be adjusted. We assume that neither $k$ nor $l$ can be deducted from VAT, so that VAT is a pure sales tax. In addition, we assume that the sector is "small", so that $r$ and $w$ are not affected by the introduction of taxes on the given sector. Sector prices $q$ and $p$ will naturally be affected by taxation.

There are a few important points regarding these assumptions. (i) It is straightforward to write a full GE model with multiple sectors, so that taxes on sector $i$ are economy-wide and affect $r, w$. It requires much more algebra, but the results are the same as in this model, just less transparent. (ii) It is similarly straightforward to add intermediate inputs that can be deducted from the VAT, so that technology is $k^{\alpha}l^{1-\alpha-\beta}x^{\beta}$, where $x$ is the deductible input. All the results from the simpler model below will hold, but again there will be more algebra, and, moreover, one must take a stand on whether $x$ is adjusted in the long or short run. After we present the baseline model, we will show that all of the main insights follow through with extensions, and demonstrate that the results follow through under monopolistic competition.

Also note that while we will refer to $k$ as capital in the model, it does not correspond to the "assets" in the data (which do not change much), but rather to inputs that firms can change over time (e.g. intermediate inputs). Later, we will extend this model to three factors, one of which can be adjusted in period 1 and 2, another in period 2 only, and third that can never to be changed. All the key results will hold.

### D.1.1 Period 0

Consider the cost function in period 0:

$$\begin{aligned} C_0(y) &= \min_{k,l} rk + wl, \\ s.t.\ y &= k^{\alpha}l^{1-\alpha}. \end{aligned}$$

The first order conditions will be:

$[k] : r = \eta\alpha k^{\alpha-1} l^{1-\alpha}$,

$[l] : w = \eta\,(1-\alpha)\, k^{\alpha} l^{-\alpha}$.

These conditions yield the optimal capital-labor ratio:

$$\frac{k_0}{l_0} = \frac{\alpha}{1-\alpha}\frac{w}{r}.$$

We can also obtain marginal costs:

$$C_0'(y) = \eta = \frac{r}{\alpha k^{\alpha-1} l^{1-\alpha}}.$$

In equilibrium, we have

$$C_0'(y_0) = \frac{r}{\alpha\left(\frac{\alpha}{1-\alpha}\frac{w}{r}\right)^{\alpha-1}} \equiv \omega,$$

where $\omega$ does not depend on anything under firm's control.

When firms are perfectly competitive, their tax-inclusive price is equal to their marginal cost:

$$p_0 = C_0'(y_0).$$

Consumer demand gives $y_0 = q_0^{-\sigma} = p_0^{-\sigma}$. We substitute this object into the expression above to obtain

$$y_0^{-1/\sigma} = C_0'(y_0).$$

The solution to this equation characterizes the output in period 0. In particular, we have

$$y_0 = \omega^{-\sigma}.$$

Since $y_0 = k_0^{\alpha} l_0^{1-\alpha} = \left(\frac{k_0}{l_0}\right)^{\alpha} l_0 = \left(\frac{\alpha}{1-\alpha}\frac{w}{r}\right)^{\alpha} l_0$, we also obtain an expression for labor:

$$l_0 = \omega^{-\sigma}\left(\frac{\alpha}{1-\alpha}\frac{w}{r}\right)^{\alpha}.$$

We can find $k_0$ and $p_0$ from the above equations.

### D.1.2 Short-run equilibrium

Suppose a VAT is introduced. Since under our assumptions, firms cannot deduct anything, so the VAT is equivalent to a sales tax. Suppose that in the short run, the firm cannot adjust $k$, so that $k_1 = k_0$.

Then we have

$$\begin{aligned} C_1(y) &= \min_l rk_0 + wl, \\ s.t.\ y &= k_0^{\alpha} l^{1-\alpha}, \end{aligned}$$

which gives

$[l] : w = \eta(1-\alpha) k_0^{\alpha} l^{-\alpha}$.

Therefore, marginal costs are

$$C_1'(y) = \eta = \frac{w}{(1-\alpha) k_0^{\alpha} l^{-\alpha}}.$$

Competition gives

$$p_1 = C_1'(y).$$

The demand is determined by the pre-tax price $q_1 = (1+\tau) p_1$. Hence, the equilibrium condition is

$$y_1^{-1/\sigma} = q_1 = (1+\tau) C'(y_1).$$

We are interested in deriving the effect of taxation on inputs, prices, sales, tax revenues, and TFPR. The sales that we observe in the data are $qy$; tax revenues are $\tau py$; and TFPR is $\frac{qy}{k^{\alpha} l^{1-\alpha}} = q$.

**Lemma 1.** *In the short run,* $y_1 < y_0$, $p_1 < p_0$, $l_1 < l_0$, $q_1 > q_0$, $TFPR_1 > TFPR_0$, *and* $taxes_1 > taxes_0 = 0$. *If* $\sigma > 1$, *then* $sales_1 < sales_0$.

**Proof.** Suppose $y_1 \geq y_0$. Then $l_1 \geq l_0$, and hence $C_1'(y_1) \geq C_0'(y_0)$. This implies that $p_1 \geq p_0$. But $y_1 = [(1+\tau)p_1]^{-\sigma}$, so $y_1$ and $p_1$ must go in the opposite directions, a contradiction. Therefore, $y_1 < y_0$.

$y_1 < y_0$ implies $l_1 < l_0$, $C_1'(y_1) < C_0'(y_0)$, $p_1 < p_0$. From $y_1 = q_1^{-\sigma}$ we get $q_1 > q_0$.

Tax revenues are $\tau p_1 y_1 = \tau(1+\tau)^{-\sigma} p_1^{1-\sigma} > 0$, so tax revenues increase.

Sales are $q_1 y_1 = q_1^{1-\sigma}$, they decline if $\sigma > 1$.

Labor goes down $l_1 < l_0$.

Capital does not change $k_1 = k_0$.

TFPR is equal to $q$ in this model, so TFPR goes up. ■

For the next section, we need to find explicitly $l_1$. From the previous equation, we get that

$$\left[k_0^{\alpha} l_1^{1-\alpha}\right]^{-1/\sigma} = (1+\tau)\frac{w}{(1-\alpha)k_0^{\alpha} l_1^{-\alpha}}.$$

### D.1.3 Long-run Equilibrium

Now consider the long-run equilibrium, when capital can also be adjusted. Therefore $C_2(y) = C_0(y)$ (the cost function is the same) and in the long run we have

$$\frac{k_2}{l_2} = \frac{\alpha}{1-\alpha}\frac{w}{r} = \frac{k_0}{l_0}.$$

This gives us

$$C_2'(y_2) = C_0'(y_0) > C_1'(y_1).$$

Therefore,

$$p_2 = p_0 > p_1.$$

Since

$$\begin{aligned} q_2 &= (1+\tau)\, p_2, \\ q_1 &= (1+\tau)\, p_1 > p_{0,} \\ q_0 &= p_0, \end{aligned}$$

this implies that

$$q_2 > q_1 > q_0,$$

$$TFPR_2 > TFPR_1 > TFPR_0.$$

**Remark 2.** *The intuition behind this result is as follows: since not all factors can be adjusted immediately, the marginal costs fall: there is too much capital relative to labor in the short run, so the marginal cost of labor (the only factor that can be adjusted in period 1) is low. Therefore, the tax-inclusive price falls, although less than one for one with the tax rate, so that pre-tax price $q$ increases. Over time, as firms adjust other factors, their marginal costs rise. This implies that $p$ rises, and therefore, $q$ rises even further. Since TFPR is just $q$, the same is true about TFPR.*

Demand is

$$y_2 = [(1+\tau)\, p_2]^{-\sigma} < [(1+\tau)\, p_1]^{-\sigma} < y_1.$$

Therefore,

$$y_2 < y_1 < y_0.$$

Sales are $qy = q^{1-\sigma}$. Therefore, if $\sigma > 1$ , we have

$$\begin{aligned} q_2^{1-\sigma} &< q_1^{1-\sigma} < q_0^{1-\sigma}, \\ \text{sales}_2 &< \text{sales}_1 < \text{sales}_0. \end{aligned}$$

Tax revenues are $\tau py = \tau \frac{p}{q} qy = \frac{\tau}{1+\tau} \times$sales. Since $\tau_0 = 0$, $\tau_1 = \tau_2 > 0$, this gives us, if $\sigma > 1$, that

$$0 = \text{taxes}_0 < \text{taxes}_2 < \text{taxes}_1.$$

**Remark 3.** *The intuition behind these results comes from the previous remark and the assumption that $\sigma > 1$. As $q$ increases in each period, $y$ must fall in each period. If demand is elastic, $y$ falls faster than $q$ rises, which implies that sales, $qy$, fall. Since tax revenues are $\frac{\tau_t}{1+\tau_t} \times sales_t$, it first increases between periods 0 and 1 (since taxes are increased from 0 to $\tau$) and then falls between periods 1 and 2 (since sales fall between periods 1 and 2).*

Finally, we examine what happens to labor. We have

$$l_0 > l_1 \text{ and } l_0 > l_2.$$

The remaining comparison of interest is between $l_1$ and $l_2$.

In both cases, we have $y^{-1/\sigma} = (1+\tau) C'(y)$. Thus, we have

$$l_1^{(\alpha-1)/\sigma-\alpha} = (1+\tau) \frac{w}{(1-\alpha)} k_0^{\alpha/\sigma-\alpha},$$

$$l_2^{(\alpha-1)/\sigma-\alpha} = (1+\tau) \frac{w}{(1-\alpha)} k_2^{\alpha/\sigma-\alpha}.$$

We must have $k_2 < k_0$ (since $k_2/l_2 = k_0/l_0$ and $k_2 (k_2/l_2)^{\alpha-1} = y_2 < y_0 = k_0 (k_0/l_0)^{\alpha-1}$). Therefore, if $\sigma > 1$, we have $k_2^{\alpha/\sigma-\alpha} > k_0^{\alpha/\sigma-\alpha}$ and therefore $l_2^{(\alpha-1)/\sigma-\alpha} > l_1^{(\alpha-1)/\sigma-\alpha}$. Since $\alpha < 1$, this implies that $l_2 < l_1$. Therefore we have

$$l_0 > l_1 > l_2.$$

**Remark 4.** *The intuition for this result comes from the following observation. We know from the Le Chatelier Principle (Samuelson, 1949) that the short-run elasticity of labor*

*should be smaller than the long-run elasticity of labor (because capital can also be adjusted in the long run)* holding pre-tax prices fixed. *This effect implies that labor should react even more in the long run to the tax change than in the short run. In our setting, there is an offsetting effect, since the pre-tax price increases which, all things being equal, calls for more inputs. If demand is elastic, prices react little to changes in output, and the first effect dominates.*

### D.1.4 Empirical Implications

This model has several empirically testable implications. First, tax revenues will increase from period zero to period one, and then decline in period 2 to a level between the levels of period 0 and one: $0 = \text{taxes}_0 < \text{taxes}_2 < \text{taxes}_1$. Second, the pre-tax price, or $TFPR$, increases every period, $q_2 > q_1 > q_0$. Third, sales decline each period, $q_2 y_2 < q_1 y_1 < q_0 y_0$. Fourth, labor inputs decline each period, $l_0 > l_1 > l_2$ and $k_0 \geq k_1 > k_2$. The empirical analysis will examine whether these implications are borne out in the data.

In the following sections, we show that these results hold when we introduce a third deductible good, allow for monopolistic competition, and endogenize input prices.

## D.2 Intermediate Goods

Suppose we have technology $k^\alpha l^{1-\alpha-\beta} x^\beta$ where $x$ can be deducted from the VAT. Let the price of $x$ be $z$. The profits of the firm without VAT are

$$qy - rk - wl - zx,$$

and profits with VAT tax $\tau$ are

$$\begin{aligned} & (1-\tau)\left[qy - zx\right] - rk - wl, \\ = \; & (1-\tau)\, qy - rk - wl - (1-\tau)\, zx. \end{aligned}$$

Note that we have changed the pricing convention. Before, we used $(1+\tau)p = q$, where $p$ is tax-inclusive price. Now we use $p = (1-\tau)\,q$, where $q$ is pre-tax price. The connection to the data is more clear with this notation, since we directly observe $q$.

### D.2.1 Period 0

Consider the cost function in period 0:

$$\begin{aligned} C_0(y) &= \min_{k,l,x} rk + wl + zx, \\ s.t.\ y &= k^{\alpha} l^{1-\alpha-\beta} x^{\beta}. \end{aligned}$$

It obviously gives

$[k] : r = \omega\alpha k^{\alpha-1} l^{1-\alpha-\beta} x^{\beta},$

$[l] : w = \omega\,(1-\alpha-\beta)\, k^{\alpha} l^{-\alpha-\beta} x^{\beta},$

$[x] : z = \omega\beta k^{\alpha} l^{1-\alpha-\beta} x^{\beta-1}.$

This gives the optimal input ratio

$$\begin{aligned} \frac{k_0}{l_0} &= \frac{\alpha}{1-\alpha-\beta}\frac{w}{r}, \\ \frac{x_0}{l_0} &= \frac{\beta}{1-\alpha-\beta}\frac{w}{z}. \end{aligned}$$

We also have marginal costs

$$\begin{aligned} C_0'(y_0) &= \omega_0 = \frac{w}{(1-\alpha-\beta)\, k_0^{\alpha} l_0^{-\alpha-\beta} x_0^{\beta}} \\ &= \frac{w}{(1-\alpha-\beta)\left(\frac{k_0}{l_0}\right)^{\alpha}\left(\frac{x_0}{l_0}\right)^{\beta}} \\ &= \frac{w}{(1-\alpha-\beta)\left(\frac{\alpha}{1-\alpha-\beta}\frac{w}{r}\right)^{\alpha}\left(\frac{\beta}{1-\alpha-\beta}\frac{w}{z}\right)^{\beta}}. \end{aligned}$$

Competitive firms set the tax-inclusive price to equal its marginal cost. Since there

are no taxes in period 0, we have

$$q_0 = \omega_0.$$

Then, the first order conditions immediately imply

$$\begin{aligned} rk_0 &= \alpha q_0 y_0, \\ zx_0 &= \beta q_0 y_0, \\ wl_0 &= (1-\alpha-\beta)\, q_0 y_0. \end{aligned}$$

Finally, the quantities are determined from the downward sloping demand curve

$$y_0 = q_0^{-\sigma}.$$

This equation gives

$$\begin{aligned} \left(\frac{k_0}{l_0}\right)^{\alpha}\left(\frac{x_0}{l_0}\right)^{\beta} l_0 &= \left[\frac{w}{(1-\alpha-\beta)\left(\frac{k_0}{l_0}\right)^{\alpha}\left(\frac{x_0}{l_0}\right)^{\beta}}\right]^{-\sigma}, \\ l_0 &= \left(\frac{w}{1-\alpha-\beta}\right)^{-\sigma}\left(\frac{k_0}{l_0}\right)^{\alpha(\sigma-1)}\left(\frac{x_0}{l_0}\right)^{\beta(\sigma-1)}, \end{aligned}$$

or

$$l_0 = \left(\frac{w}{1-\alpha-\beta}\right)^{-\sigma}\left(\frac{\alpha}{1-\alpha-\beta}\frac{w}{r}\right)^{\alpha(\sigma-1)}\left(\frac{\beta}{1-\alpha-\beta}\frac{w}{z}\right)^{\beta(\sigma-1)}.$$

It then follows that

$$\begin{aligned} k_0 &= \frac{\alpha}{1-\alpha-\beta}\frac{w}{r} l_0, \\ x_0 &= \frac{\beta}{1-\alpha-\beta}\frac{w}{z} l_0. \end{aligned}$$

### D.2.2 Period 2

We analyze period 2 before period 1, since period 2 is almost identical to period 0. With VAT, the firm's profits are

$$\begin{aligned} & (1-\tau)\left[qy - zx\right] - rk - wl, \\ = \; & (1-\tau)\, qy - rk - wl - (1-\tau)\, zx. \end{aligned}$$

So the cost function is

$$\begin{aligned} C_2(y) &= \min_{k,l,x} rk + wl + (1-\tau)\, zx, \\ s.t.\ y &= k^{\alpha} l^{1-\alpha-\beta} x^{\beta}. \end{aligned}$$

and now the tax-inclusive price is equal to the marginal cost:

$$\begin{aligned} (1-\tau)\, q_2 &= C_2'(y_2) = \omega_2, \\ q_2 &= \frac{C_2'(y_2)}{1-\tau} = \frac{\omega_2}{1-\tau}. \end{aligned}$$

So we have

$$\begin{aligned} \frac{k_2}{l_2} &= \frac{\alpha}{1-\alpha-\beta}\frac{w}{r}, \\ \frac{x_2}{l_2} &= \frac{\beta}{1-\alpha-\beta}\frac{w}{(1-\tau)\, z}. \end{aligned}$$

$$\begin{aligned} \omega_2 &= \frac{w}{(1-\alpha-\beta)\left(\frac{k_2}{l_2}\right)^{\alpha}\left(\frac{x_2}{l_2}\right)^{\beta}} \\ &= \frac{w}{(1-\alpha-\beta)\left(\frac{\alpha}{1-\alpha-\beta}\frac{w}{r}\right)^{\alpha}\left(\frac{\beta}{1-\alpha-\beta}\frac{w}{(1-\tau)z}\right)^{\beta}} \\ &= (1-\tau)^{\beta}\,\omega_0. \end{aligned}$$

Finally,

$$y_2 = q_2^{-\sigma} = \left(\frac{\omega_2}{1-\tau}\right)^{-\sigma}$$

gives

$$\begin{aligned}
\left(\frac{k_2}{l_2}\right)^{\alpha}\left(\frac{x_2}{l_2}\right)^{\beta} l_2 &= (1-\tau)^{\sigma}\left[\frac{w}{(1-\alpha-\beta)\left(\frac{k_2}{l_2}\right)^{\alpha}\left(\frac{x_2}{l_2}\right)^{\beta}}\right],^{-\sigma} \\
l_2 &= (1-\tau)\left(\frac{w}{1-\alpha-\beta}\right)^{-\sigma}\left(\frac{k_2}{l_2}\right)^{\alpha(\sigma-1)}\left(\frac{x_2}{l_2}\right),^{\beta(\sigma-1)}
\end{aligned}$$

or

$$\begin{aligned}
l_2 &= (1-\tau)^{\sigma(1-\beta)+\beta}\left(\frac{w}{1-\alpha-\beta}\right)^{-\sigma}\left(\frac{\alpha}{1-\alpha-\beta}\frac{w}{r}\right)^{\alpha(\sigma-1)}\left(\frac{\beta}{1-\alpha-\beta}\frac{w}{z}\right)^{\beta(\sigma-1)} \\
&= (1-\tau)^{\sigma(1-\beta)+\beta} l_0.
\end{aligned}$$

Similarly, we have

$$\begin{aligned}
k_2 &= \frac{\alpha}{1-\alpha-\beta}\frac{w}{r} l_2 = (1-\tau)^{\sigma(1-\beta)+\beta} k_0, \\
x_2 &= \frac{\beta}{1-\alpha-\beta}\frac{w}{(1-\tau)z} l_2 = (1-\tau)^{(\sigma-1)(1-\beta)+\beta} x_0.
\end{aligned}$$

This result generates clear predictions about the long run.

**Lemma 5.** *Suppose $\sigma > 1$. Then,*

1. $TFPR_2 > TFPR_0$,
2. $sales_2 < sales_0$,
3. $k_2 < k_0, x_2 < x_0, l_2 < l_0, \omega_2 < \omega_0$,
4. $0 = taxes_0 < taxes_2$.

**Proof.** 1. In our model $TFPR \equiv \frac{qy}{k^{\alpha} l^{1-\alpha-\beta} x^{\beta}} = q$. We have

$$q_2 = \frac{\omega_2}{1-\tau} = \frac{(1-\tau)^{\beta} \omega_0}{1-\tau} = (1-\tau)^{(\beta-1)} q_0 > q_0.$$

2. In our model, $sales = qy = q^{1-\sigma}$. We have, when $\sigma > 1$,

$$q_2^{1-\sigma} = \left[(1-\tau)^{(\beta-1)} q_0\right]^{1-\sigma} = (1-\tau)^{(1-\beta)(\sigma-1)} q_0^{1-\sigma} < q_0^{1-\sigma}.$$

3. We have

$$\frac{k_2}{k_0} = \frac{l_2}{l_0} = (1-\tau)^{\sigma(1-\beta)+\beta} < 1$$

and

$$\frac{x_2}{x_0} = (1-\tau)^{(\sigma-1)(1-\beta)+\beta} < 1.$$

Note that the latter follows from $\sigma > 1$ and we showed the result about $\omega$ earlier.

4. Note that in our model, collected taxes are $taxes = \tau [qy - zx]$. So

$$taxes_2 = \tau [q_2 y_2 - z x_2] = \tau [q_2 y_2 - \beta q_2 y_2] = \tau (1-\beta) q_2 y_2 > 0 = taxes_0.$$

■

### D.2.3 Period 1

Now consider period 1 problem. We assume that intermediate goods can be adjusted in period 1, which simplifies the analysis.[45]

We have

$$\begin{aligned} C_1(y) &= \min_{l,x} rk_0 + wl + (1-\tau) zx, \\ s.t.\ y &= k_0^{\alpha} l^{1-\alpha-\beta} x^{\beta}. \end{aligned}$$

[45] If they cannot, there is a lot more algebra involved although the result about taxes will hold under additional assumptions about the parameters.

Which gives

$[l] : w = \omega\left(1-\alpha-\beta\right)k_0^{\alpha}l^{-\alpha-\beta}x^{\beta}$,

$[x] : \left(1-\tau\right)z = \omega\beta k_0^{\alpha}l^{1-\alpha-\beta}x^{\beta-1}$.

We have

$$\frac{x_1}{l_1} = \frac{\beta}{1-\alpha-\beta}\frac{w}{\left(1-\tau\right)z}.$$

As before, we have

$$q_1 = \frac{C_1'\left(y_1\right)}{1-\tau} = \frac{\omega_1}{1-\tau}.$$

Hence, we have

$$\begin{aligned} wl_1 &= \left(1-\alpha-\beta\right)\left(1-\tau\right)q_1y_1, \\ \left(1-\tau\right)zx_1 &= \beta\left(1-\tau\right)q_1y_1. \end{aligned}$$

The marginal costs are

$$\begin{aligned} \omega_1 &= C_1'\left(y_1\right) = \frac{1}{1-\alpha-\beta}\frac{w}{k_0^{\alpha}l_1^{-\alpha-\beta}x_1^{\beta}} \\ &= \frac{1}{1-\alpha-\beta}\frac{w}{k_0^{\alpha}l_1^{-\alpha}\left(\frac{x_1}{l_1}\right)^{\beta}}. \end{aligned}$$

We find $l_1$ as before, using the demand curve:

$$\begin{aligned} y_1 &= \left[\frac{\omega_1}{1-\tau}\right]^{-\sigma}, \\ k_0^{\alpha}l_1^{1-\alpha}\left(\frac{x_1}{l_1}\right)^{\beta} &= \left(1-\tau\right)^{\sigma}\left[\frac{1}{1-\alpha-\beta}\frac{w}{k_0^{\alpha}l_1^{-\alpha}\left(\frac{x_1}{l_1}\right)^{\beta}}\right]^{-\sigma}. \end{aligned}$$

Therefore,

$$\begin{aligned} l_1^{1-\alpha+\sigma\alpha} &= (1-\tau)^{\sigma}\left(\frac{w}{1-\alpha-\beta}\right)^{-\sigma} k_0^{\alpha(\sigma-1)}\left(\frac{x_1}{l_1}\right)^{\beta(\sigma-1)} \\ &= (1-\tau)^{\sigma}\left(\frac{w}{1-\alpha-\beta}\right)^{-\sigma} k_0^{\alpha(\sigma-1)}\left(\frac{\beta}{1-\alpha-\beta}\frac{w}{(1-\tau)\,z}\right)^{\beta(\sigma-1)} \\ &= (1-\tau)^{\sigma+\beta(1-\sigma)}\left(\frac{w}{1-\alpha-\beta}\right)^{-\sigma} k_0^{\alpha(\sigma-1)}\left(\frac{\beta}{1-\alpha-\beta}\frac{w}{z}\right)^{\beta(\sigma-1)}. \end{aligned}$$

This equation gives the following useful intermediate result.

**Lemma 6.** *Suppose* $\sigma > 1$. *Then*

1. $l_0 > l_1 > l_2$,

2. $y_0 > y_1 > y_2$,

3. $\omega_1 < \omega_2 < \omega_0$ *and* $\omega_0 < \frac{\omega_1}{1-\tau} < \frac{\omega_2}{1-\tau}$.

**Proof.** 1. The previous equation should also hold in period 2 when capital stock is set at its optimal value $k_2$, i.e.

$$l_2^{1-\alpha+\sigma\alpha} = (1-\tau)^{\sigma+\beta(1-\sigma)}\left(\frac{w}{1-\alpha-\beta}\right)^{-\sigma} k_2^{\alpha(\sigma-1)}\left(\frac{\beta}{1-\alpha-\beta}\frac{w}{z}\right)^{\beta(\sigma-1)}$$

which implies

$$\begin{aligned} \left(\frac{l_2}{l_1}\right)^{1+(\sigma-1)\alpha} &= \left(\frac{k_2}{k_0}\right)^{\alpha(\sigma-1)} \\ \frac{l_2}{l_1} &= \left(\frac{k_2}{k_0}\right)^{\frac{\alpha(\sigma-1)}{1+\alpha(\sigma-1)}}. \end{aligned}$$

Since $k_2 < k_0$, this implies $l_2 < l_1$.

Similarly, the analogous equation should hold in period 0 (when $\tau = 0$) so that

$$\begin{aligned}\left(\frac{l_1}{l_0}\right)^{1+(\sigma-1)\alpha} &= (1-\tau)^{\sigma+\beta(1-\sigma)} = (1-\tau)^{\sigma(1-\beta)+\beta} \\ \frac{l_1}{l_0} &= (1-\tau)^{\frac{\sigma(1-\beta)+\beta}{1+(\sigma-1)\alpha}} < 1.\end{aligned}$$

Therefore $l_1 < l_0$.

2. For output, we have

$$\begin{aligned}\frac{y_1}{y_0} &= \left(\frac{l_1}{l_0}\right)^{1-\alpha}\left(\frac{x_1/l_1}{x_0/l_0}\right)^{\beta} \\ &= (1-\tau)^{\frac{\sigma(1-\beta)+\beta}{1+(\sigma-1)\alpha}(1-\alpha)-\beta} \\ &= (1-\tau)^{\sigma\frac{1-\alpha-\beta}{1+(\sigma-1)\alpha}} < 1.\end{aligned}$$

Therefore, $y_1 < y_0$.

Using the fact that $\frac{x_1}{l_1} = \frac{x_2}{l_2}$, we have

$$\frac{y_2}{y_1} = \frac{k_2^{\alpha} l_2^{1-\alpha}}{k_0^{\alpha} l_1^{1-\alpha}}.$$

Since we showed already that $\frac{k_2}{k_0} < 1$ and $\frac{l_2}{l_1} < 1$, this implies that $y_2 < y_1$.

3. For marginal costs, we have

$$\begin{aligned}\frac{\omega_1}{\omega_2} &= \frac{\frac{1}{1-\alpha-\beta}\frac{w}{k_0^{\alpha} l_1^{-\alpha}\left(\frac{x_1}{l_1}\right)^{\beta}}}{\frac{w}{(1-\alpha-\beta)\left(\frac{k_2}{l_2}\right)^{\alpha}\left(\frac{x_2}{l_2}\right)^{\beta}}} = \left(\frac{k_2}{k_0}/\frac{l_2}{l_1}\right)^{\alpha} = \left(\frac{k_2}{k_0}\right)^{\alpha\left[1-\frac{\alpha(\sigma-1)}{1+(\sigma-1)\alpha}\right]} \\ &= \left(\frac{k_2}{k_0}\right)^{\frac{\alpha}{1+\alpha(\sigma-1)}} < 1.\end{aligned}$$

Thus, $\omega_1 < \omega_2$. We showed already that $\omega_2 < \omega_0$, which implies $\omega_1 < \omega_0$.

Moreover,

$$\frac{\omega_1}{\omega_0} = \frac{\frac{1}{1-\alpha-\beta}\frac{w}{k_0^{\alpha} l_1^{-\alpha-\beta} x_1^{\beta}}}{\frac{1}{1-\alpha-\beta}\frac{w}{k_0^{\alpha} l_0^{-\alpha-\beta} x_0^{\beta}}} = \frac{l_0^{-\alpha-\beta} x_0^{\beta}}{l_1^{-\alpha-\beta} x_1^{\beta}} = \left(\frac{l_1}{l_0}\right)^{\alpha}(1-\tau)^{\beta}$$

or

$$\frac{\omega_1/(1-\tau)}{\omega_0} = (1-\tau)^{\frac{\sigma(1-\beta)+\beta}{1+(\sigma-1)\alpha}\alpha-(1-\beta)} = (1-\tau)^{-\frac{1-\beta-\beta\alpha}{1+\alpha(\sigma-1)}},$$

which implies that $\frac{\omega_1}{1-\tau} > \omega_0$.

With this lemma, we can extend all the results of the simple model. ■

**Lemma 7.** *Suppose $\sigma > 1$. Then*

1. $TFPR_2 > TFPR_1 > TFPR_0$,
2. $sales_0 > sales_1 > sales_2$,
3. $0 = taxes_0 < taxes_2 < taxes_1$.

**Proof.** 1. Since $TFPR = q = \frac{\omega}{1-\tau}$, from the previous lemma we have

$$q_0 < q_1 < q_2.$$

2. Sales are $qy = q^{1-\sigma}$, so with $\sigma > 1$ we have, from the previous equation

$$sales_0 > sales_1 > sales_2.$$

3. Taxes revenues are $\tau(qy - zx)$. Since

$$\frac{zx_1}{q_1 y_1} = \frac{zx_2}{q_2 y_2} = \beta,$$

it becomes

$$taxes = (1-\beta)\tau \times sales.$$

Since $\tau_0 = 0$, and $sales_1 > sales_2$, we get

$$0 = taxes_0 < taxes_2 < taxes_1.$$

■

## D.3 Monopolistic competition

Here, we will extend the analysis to allow firms to have market power and set prices. We will focus on the benchmark economy without intermediate goods for simplicity.

Firms will be monopolistically-competitive, as in the Dixit-Stiglitz model. There is a continuum of firms and each firm produces a differentiated good.[46] Consumers buy all these goods, so their budget constraint is

$$\int_0^1 q(i)\, c(i)\, di = wl + m,$$

where $m$ is non-labor income.

Consumer preferences in each period are given by

$$\frac{Y^{1-1/\sigma}}{1-1/\sigma} - l,$$

where

$$Y = \left( \int_0^1 y(i)^{1-1/\varepsilon}\, di \right)^{\frac{\varepsilon}{\varepsilon-1}}.$$

Here, $\varepsilon > 1$ is the elasticity of substitution between goods.

Standard results imply that demand for good $i$ is determined by equation

$$y(i) = \left( \frac{q(i)}{Q} \right)^{-\varepsilon} Y,$$

where the aggregate price satisfies

$$Q = \left( \int_0^1 q(i)^{1-\varepsilon}\, di \right)^{\frac{1}{1-\varepsilon}}.$$

[46] We assume that the variety set is[0,1] because we assume that $y = Y$ and $q = Q$.

The aggregate demand can be found from

$$\max_{Y,l} \frac{Y^{1-1/\sigma}}{1-\sigma} - l,$$

$$YQ = wl + m$$

which gives

$$Y^{-1/\sigma} = Q/w.$$

Wage $w$ can be taken to be a numeraire, and it is without loss of generality to set $w = 1$.

### D.3.1 Firm's problem

We will do things in "partial" equilibrium so that the interest rate $r$ is fixed (equivalent to a GE model in which there are international capital markets with a rental rate of capital given by $r$). We will relax this assumption in another extension. In equilibrium, firm $i$ will take for now $Q$, $Y$, and $r$ as given ($w = 1$ always) and chooses $q(i)$ to maximize its profits, taking into account consumer demand. So the firm in period 0 solves

$$\max_{q,y,l,k} qy - wl - rk,$$

s.t.

$$\begin{aligned} y &= \left(\frac{q}{Q}\right)^{-\varepsilon} Y, \\ y &= k^{\alpha} l^{1-\alpha}. \end{aligned}$$

We have

$[l] : w = \omega (1-\alpha) k^{\alpha} l^{-\alpha},$

$[k] : r = \omega \alpha k^{\alpha-1} l^{1-\alpha},$

$[y] : q = \lambda + \omega,$

$[q] : qy = \lambda\varepsilon \left(\frac{q}{Q}\right)^{-\varepsilon} Y.$

The first two equations give us the usual conditions

$$\begin{aligned} \frac{k_0}{l_0} &= \frac{\alpha}{1-\alpha}\frac{w}{r,} \\ \omega_0 &= \frac{w}{(1-\alpha)\, k_0^{\alpha} l_0^{-\alpha}} = \frac{w}{(1-\alpha)\left(\frac{\alpha}{1-\alpha}\frac{w}{r}\right)^{\alpha}}. \end{aligned}$$

Note that $\omega_0$ has the same meaning as before: the marginal cost of producing an extra unit of a good.

In equilibrium, since all firms are identical, we have

$$q = Q, y = Y.$$

Therefore, the last two optimality conditions become

$$\begin{aligned} q_0 &= \lambda_0 + \omega_0, \\ q_0 &= \lambda_0 \varepsilon. \end{aligned}$$

This gives us

$$q_0 = = q_0\varepsilon - \omega_0\varepsilon = \frac{\varepsilon}{\varepsilon - 1}\omega_0.$$

This equation is the standard condition that the optimal price is equal to a markup $\frac{\varepsilon}{\varepsilon-1} > 1$ times the marginal cost, $\omega_0$. As $\varepsilon \to \infty$, goods become more and more substitutable and we converge to the perfect competition case considered in the benchmark model.

The consumer's optimality condition $Y^{-1/\sigma} = Q/w$ (together with normalization

$w = 1, y = Y, q = Q$) gives

$$y_0 = q_0^{-\sigma} = \left(\frac{\varepsilon}{\varepsilon - 1}\right)^{-\sigma} \omega_0^{-\sigma}.$$

So the analysis goes through the same way as before, except now everything is multiplied by a markup.

Given that, we will verify that markup is the same in periods 1 and 2. In that case, then all the analysis thus far goes through without any changes.

Period 2's problem is

$$\max_{q,y,l,k} (1 - \tau) qy - wl - rk,$$

s.t.

$$\begin{aligned} y &= \left(\frac{q}{Q}\right)^{-\varepsilon} Y, \\ y &= k^{\alpha} l^{1-\alpha}. \end{aligned}$$

These give the optimality conditions.

We have

$[l] : w = \omega (1 - \alpha) k^{\alpha} l^{-\alpha},$

$[k] : r = \omega \alpha k^{\alpha - 1} l^{1-\alpha},$

$[y] : (1 - \tau) q = \lambda + \omega,$

$[q] : (1 - \tau) qy = \lambda \varepsilon \left(\frac{q}{Q}\right)^{-\varepsilon} Y.$

So we have, as before, (the case $\beta = 0$) from the first two equations:

$$\omega_2 = \omega_0.$$

The last two give us

$$q_2 = \frac{\varepsilon}{\varepsilon - 1} \frac{\omega_2}{1 - \tau}.$$

This expression is the same as we had before, modulo a markup.

Finally, period 1 problem is

$$\max_{q,y,l} (1 - \tau) qy - wl - rk_0.$$

with

$[l] : w = \omega (1 - \alpha) k_0^{\alpha} l^{-\alpha}$,

$[y] : (1 - \tau) q = \lambda + \omega$,

$[q] : (1 - \tau) qy = \lambda \varepsilon \left( \frac{q}{Q} \right)^{-\varepsilon} Y$.

Note that again we have

$$q_1 = \frac{\varepsilon}{\varepsilon - 1} \frac{\omega_1}{1 - \tau}.$$

So the marginal costs are the same as in the baseline, and price is just a constant markup over those costs. Given that, all the steps in the proofs of the baseline economy should go through with minimal modifications.

## D.4 Multiple Sectors, Fixed Capital

Now, we will assume that there are 2 sectors, and that the capital stock is in fixed net supply. Other than that, we return to our baseline model of perfect competition. So

consumers will solve

$$\max \mu^{\frac{1}{\sigma}} \frac{y^{1-1/\sigma}}{1-1/\sigma} + (1-\mu)^{\frac{1}{\sigma}} \frac{Y^{1-1/\varepsilon}}{1-1/\sigma} - l,$$

s.t.

$$qy + QY = wl + r\bar{k} + \Pi,$$

where $\bar{k}$ is the total capital stock and capital letters denote "the other" sector, not affected by taxes. Here, $\mu \in (0,1)$. The case $\mu = 0$ corresponds to what we have done before: sector 1 is small, so nothing there affects taxes. Here, $\Pi$ denotes profits of the firms. For simplicity, we assume that the production function is the same in the two sectors.

The capital stock is in fixed supply and is rented out by consumers to the firms at a rate $r$. If the sector-level demands for capital are $k$ and $K$, then the market clearing condition for the capital stock is

$$k + K = \bar{k}.$$

Once again, everything will be in units of labor, so we normalize $w = 1$.

The two sectors are identical in period 0, but the VAT tax will be applied to the first sector in period 1.

Given our normalization, demand is again given by

$$y = \mu q^{-\sigma}, Y = (1-\mu) Q^{-\sigma}.$$

### D.4.1 Period 0

The analysis goes like before except now $l_0$ is not given by

$$\begin{aligned} \left(\frac{k_0}{l_0}\right)^{\alpha} l_0 &= \mu \left[\frac{w}{(1-\alpha)\left(\frac{k_0}{l_0}\right)^{\alpha}}\right]^{-\sigma}, \\ l_0 &= \mu \left(\frac{w}{1-\alpha}\right)^{-\sigma} \left(\frac{k_0}{l_0}\right)^{\alpha(\sigma-1)}, \end{aligned}$$

or

$$l_0 = \mu \left( \frac{w}{1-\alpha} \right)^{-\sigma} \left( \frac{\alpha}{1-\alpha} \frac{w}{r_0} \right)^{\alpha(\sigma-1)},$$

and

$$\begin{aligned} k_0 &= \frac{\alpha}{1-\alpha} \frac{w}{r_0} l_0 \\ &= \mu \left( \frac{w}{1-\alpha} \right)^{-\sigma} \left( \frac{\alpha}{1-\alpha} \frac{w}{r_0} \right)^{\alpha(\sigma-1)+1}. \end{aligned}$$

Demand in the other sector is

$$K_0 = (1-\mu) \left( \frac{w}{1-\alpha} \right)^{-\sigma} \left( \frac{\alpha}{1-\alpha} \frac{w}{r_0} \right)^{\alpha(\sigma-1)+1}.$$

This allows us to find the rental rate $r_0$ from

$$\begin{aligned} \mu \left( \frac{w}{1-\alpha} \right)^{-\sigma} \left( \frac{\alpha}{1-\alpha} \frac{w}{r_0} \right)^{\alpha(\sigma-1)+1} + (1-\mu) \left( \frac{w}{1-\alpha} \right)^{-\sigma} \left( \frac{\alpha}{1-\alpha} \frac{w}{r_0} \right)^{\alpha(\sigma-1)+1} &= \bar{k}, \\ \left( \frac{w}{1-\alpha} \right)^{-\sigma} \left( \frac{\alpha}{1-\alpha} \frac{w}{r_0} \right)^{\alpha(\sigma-1)+1} &= \bar{k}. \end{aligned}$$

### D.4.2 Period 1

In period 1, taxes are introduced but capital cannot be adjusted, so we simply assume that $r_1 = r_0$. Since capital stock cannot move, the rental rate is strictly-speaking indeterminate, but small refinements of this set up should give $r_1 = r_0$.

Since $(r, w)$ are the same in period 1 as in period 0, the problems of the two sectors are unchanged. The whole characterization of the period 1 problem of the sector affected by the VAT tax goes without any changes. The labor demand in sector 1 is given by

$$l_1^{1-\alpha+\sigma\alpha} = \mu (1-\tau)^{\sigma} \left( \frac{w}{1-\alpha} \right)^{-\sigma} k_0^{\alpha(\sigma-1)}.$$

### D.4.3 Period 2

We have, following the same steps as before

$$\begin{aligned} l_2 &= \mu\left(1-\tau\right)^{\sigma}\left(\frac{w}{1-\alpha}\right)^{-\sigma}\left(\frac{\alpha}{1-\alpha}\frac{w}{r_2}\right)^{\alpha(\sigma-1)} \\ &= \left(1-\tau\right)^{\sigma}\left(\frac{r_2}{r_0}\right)^{\alpha(\sigma-1)} l_0. \end{aligned}$$

and

$$\begin{aligned} k_2 &= \frac{\alpha}{1-\alpha}\frac{w}{r_2} l_2 \\ &= \mu\left(1-\tau\right)^{\sigma}\left(\frac{w}{1-\alpha}\right)^{-\sigma}\left(\frac{\alpha}{1-\alpha}\frac{w}{r_2}\right)^{\alpha(\sigma-1)+1} \\ &= \left[\left(1-\tau\right)^{\sigma}\left(\frac{r_0}{r_2}\right)^{\alpha(\sigma-1)+1}\right]\mu\left(\frac{w}{1-\alpha}\right)^{-\sigma}\left(\frac{\alpha}{1-\alpha}\frac{w}{r_0}\right)^{\alpha(\sigma-1)+1} \\ &= \left[\left(1-\tau\right)^{\sigma}\left(\frac{r_0}{r_2}\right)^{\alpha(\sigma-1)+1}\right] k_0. \end{aligned}$$

Capital in the other sector is

$$K_2 = \left(1-\mu\right)\left(\frac{w}{1-\alpha}\right)^{-\sigma}\left(\frac{\alpha}{1-\alpha}\frac{w}{r_2}\right)^{\alpha(\sigma-1)+1}.$$

So the market clearing condition is

$$\left[\mu\left(1-\tau\right)^{\sigma}+\left(1-\mu\right)\right]\left(\frac{w}{1-\alpha}\right)^{-\sigma}\left(\frac{\alpha}{1-\alpha}\frac{w}{r_2}\right)^{\alpha(\sigma-1)+1} = \bar{k}.$$

Equivalently

$$\begin{aligned} \left[\mu\left(1-\tau\right)^{\sigma}+\left(1-\mu\right)\right]\left(\frac{r_0}{r_2}\right)^{\alpha(\sigma-1)+1}\left(\frac{w}{1-\alpha}\right)^{-\sigma}\left(\frac{\alpha}{1-\alpha}\frac{w}{r_0}\right)^{\alpha(\sigma-1)+1} &= \bar{k}, \\ \left[\mu\left(1-\tau\right)^{\sigma}+\left(1-\mu\right)\right]\left(\frac{r_0}{r_2}\right)^{\alpha(\sigma-1)+1} &= 1, \end{aligned}$$

or

$$(1-\tau)^{\sigma}\left(\frac{r_0}{r_2}\right)^{\alpha(\sigma-1)+1} = \frac{(1-\tau)^{\sigma}}{\mu\,(1-\tau)^{\sigma}+(1-\mu)}.$$

Therefore we have

**Lemma 8.** *$(1-\tau)^{\sigma}\left(\frac{r_0}{r_2}\right)^{\alpha(\sigma-1)+1}$ is strictly increasing in $\mu$ with*

$$(1-\tau)^{\sigma} \leq (1-\tau)^{\sigma}\left(\frac{r_0}{r_2}\right)^{\alpha(\sigma-1)+1} \leq 1,$$

*with left and right inequalities holding as equality for $\mu = 0$ and $\mu = 1$ respectively.*

Therefore, we have

**Lemma 9.** *Suppose $\sigma > 1$. Then $k_2 \leq k_0, l_2 \leq l_1$, $sales_2 \leq sales_1, taxes_2 \leq taxes_1, TFPR_2 \geq TFPR_1$, where inequality holds as equality only if $\mu = 1$. The inequalities reverse for sector 2.*

**Proof.** The previous lemma and our equation for capital imply that $k_2 \leq k_0$. The labor supply $l_1$ and $l_2$ can be written (see Lemma 6) as

$$\begin{aligned} l_1^{1-\alpha+\sigma\alpha} &= \mu\,(1-\tau)^{\sigma}\left(\frac{w}{1-\alpha}\right)^{-\sigma} k_0^{\alpha(\sigma-1)}, \\ l_2^{1-\alpha+\sigma\alpha} &= \mu\,(1-\tau)^{\sigma}\left(\frac{w}{1-\alpha}\right)^{-\sigma} k_2^{\alpha(\sigma-1)}. \end{aligned}$$

Therefore, $l_2 \leq l_1$ with strict inequality if $\mu < 1$. Since $y_t = k_t^{\alpha} l_t^{1-\alpha}$, and both $k$ and $l$ decrease in period 2, $y_2 \leq y_1$. We have $sales_t = q_t y_t = \mu^{\frac{1}{\sigma}} y_t^{\frac{\sigma-1}{\sigma}}$, therefore $sales_2 \leq sales_1$. Taxes are gives by $taxes_t = \tau \times sales_t$, so we get the result on sales. Since we can also write $sales_t = \mu q_t^{1-\sigma}$ and $TFPR_t = q_t$, we get that $TFPR_2 \geq TFPR_1$ .

Since total capital is fixed, we must have $K_2 \geq K_0$ and the same steps prove reverse inequalities for sector 2 (which obviously does not have taxes). ■

This step completes the proof, since we already know what happens in period 1. Note that $\mu = 0$ is the same case as our baseline model (it is easier to see this if we redefine

all variables as ratios to $\mu$ and look at the limit as $\mu \to 0$). In this case, sector 1 is small, so that any reallocation of capital from sector 1 to sector 2 has no effect on price $r$. The lemma above shows that all the insights continue to generalize in the 2 sector GE model where interest rate $r$ is endogenously determined and is affected by the reallocation. The mechanism is the same as in the benchmark case: as long as there is some reallocation in period 2 of capital due to re-optimization, capital $k_2$ will decrease in period 2, further depressing labor demand $l_2$ and output $y_2$, leading to lower sales and tax revenues in sector 1. In the limit case, $\mu = 1$, sector 2 is negligibly small and cannot absorb any capital. As a result, with fixed capital stock, rental rates $r_2$ must fall sufficiently to prevent any re-allocation of capital from sector 1, in which case, period 1 and period 2 become identical.

## Table A.1: Sectors with Highest and Lowest Non-Deductible Shares

| Lowest Non-Deductible Share | | Highest Non-Deductible Share | |
|---|---|---|---|
| (1) | (2) | (3) | (4) |
| **Sector Name** | **Non-Deductible Share** | **Sector Name** | **Non-Deductible Share** |
| Beet Sugar | 0.24 | Tobacco Leaf Re - Baking | 0.60 |
| Cane Sugar | 0.24 | Other Tobacco Processing | 0.60 |
| Frozen Aquatic Products Processing | 0.25 | Cigarette Manufacturing | 0.60 |
| Dry Processing Of Aquatic Products | 0.25 | Caustic Soda Manufacturing | 0.56 |
| Electric Light Source Manufacturing | 0.27 | Inorganic Acid Manufacturing | 0.56 |
| Lamp Holder, Lampholders Manufacturing | 0.27 | Industrial Ceramics | 0.53 |
| Wire And Cable Manufacturing | 0.30 | Other Ceramics | 0.53 |
| Postal Machinery And Equipment Manufacturing | 0.30 | Other Stationery Manufacturing | 0.51 |
| Construction Machinery Manufacturing | 0.30 | Notebook Manufacturing | 0.51 |
| Sewing Machine Manufacturing | 0.30 | Stationery Manufacturing | 0.51 |
| Manufacture Of Special Equipment Not Included In Other Categories | 0.30 | Lime | 0.51 |
| Geological Special Equipment Manufacturing | 0.30 | Special Chemical Products Manufacturing | 0.50 |
| Commercial, Catering, Service Machinery Manufacturing | 0.30 | Manufacture Of Chemical Products In Forest Products | 0.50 |
| Petroleum Products | 0.31 | Explosives And Pyrotechnic Products Manufacturing | 0.50 |
| Viscose Fiber Manufacturing | 0.33 | Chemical Reagents, Additives Manufacturing | 0.50 |
| Acrylic Fiber Manufacturing | 0.33 | Chinese Herbal Medicine And Chinese Medicine Processing | 0.50 |
| Nylon Fiber Manufacturing | 0.33 | Biological Products | 0.50 |
| Polyester Fiber Manufacturing | 0.33 | Chemical Drug Manufacturing | 0.50 |
| Chemical Fiber Pulp Manufacturing | 0.33 | Manufacture Of Chemical Preparations | 0.50 |
| Other Synthetic Fiber Manufacturing | 0.33 | Books, Newspapers And Periodicals | 0.49 |
| Vinylon Fiber Manufacturing | 0.33 | Packaging And Decoration Printing | 0.49 |
| Motorcycle Manufacturing | 0.33 | Other Printing | 0.49 |
| Manufacturing Of Inland Waterways | 0.33 | Copying Of Recording Medium | 0.49 |
| Diving Equipment Manufacturing | 0.33 | Crude Oil Processing | 0.48 |
| Manufacture Of Aids To Navigation | 0.33 | Bearing Manufacturing | 0.48 |
| Motorcycle Parts And Accessories Manufacturing | 0.33 | Valve Manufacturing | 0.48 |
| Manufacture Of Marine Transport Ships | 0.33 | Casting Manufacturing | 0.48 |
| Luggage Manufacturing | 0.33 | Communication Terminal Equipment Manufacturing | 0.48 |
| Leather Leather Garment Manufacturing | 0.33 | Switching Equipment Manufacturing | 0.48 |
| Other Fur Products | 0.33 | Electronic Computer Manufacturing | 0.48 |
| Leather Shoes Manufacturing | 0.33 | Radar Special Equipment And Components | 0.48 |
| Fur Tanning | 0.33 | Other Electronic Equipment | 0.48 |
| Fur Clothing | 0.33 | Transmission Equipment Manufacturing | 0.48 |
| Wool | 0.34 | Radar Complete Machine Manufacturing | 0.48 |
| Top Processing | 0.34 | Other Communication Equipment Manufacturing | 0.48 |
| Wool | 0.34 | Radio And Television Equipment Manufacturing | 0.48 |
| Automotive Body Manufacturing | 0.34 | Asbestos Products | 0.48 |
| Special Vehicles And Modified Car Manufacturing | 0.34 | Other Refractory Products | 0.48 |
| Small Car Manufacturing | 0.34 | Concrete Structural Component Manufacturing | 0.48 |
| Passenger Car Manufacturing | 0.34 | Manufacture Of Waterproof Seal Building Materials | 0.48 |
| Heavy Truck Manufacturing | 0.34 | Building Stone Processing | 0.48 |
| Micro - Car | 0.34 | Asbestos Cement Products | 0.48 |
| Ink Manufacturing | 0.34 | Brick And Tile Manufacturing | 0.48 |
| Paint Manufacturing | 0.34 | Manufacture Of Lightweight Building Materials | 0.48 |
| Manufacture Of Organic Chemical Materials | 0.34 | Cement Products | 0.48 |
| Other Organic Chemical Products | 0.34 | Other Brick, Lime And Light Construction Materials | 0.48 |
| Foam And Synthetic Leather, Synthetic Leather Manufacturing | 0.34 | Other Cement Products | 0.48 |
| Other Plastic Products | 0.34 | Manufacture Of Other Basic Chemical Raw Materials | 0.48 |
| Manufacture Of Daily Plastic Sundry Goods | 0.34 | Optical Glass Manufacturing | 0.47 |
| Plastic Shoe Manufacturing | 0.34 | Other Glass And Glass Products | 0.47 |

*Notes:* Manufacturing sectors are defined by four-digit Chinese Industrial Codes. VAT share is calculated from 1997 Chinese Input Output Tables. See the text for a detailed description.

Table A.2: The Effect of Computerization on VAT: Robustness to Dropping U.S. Sectors Highly Exposed to Chinese Trade

| | Dependent Variable: VAT | |
|---|---|---|
| | (1) | (2) |
| | Drop Sectors with top 25% U.S. Exports from China / Total U.S. Exports | Drop Sectors with top 25% U.S. Exports to China / Total U.S. Exports |
| **Dep Var Mean** | **2,096** | **2,034** |
| Non-deductible share x Post-2002 | 1,130** | 958.7* |
| | (496.6) | (501.6) |
| Observations | 161,630 | 161,725 |

*Notes* : This sample is comprised of a balanced panel of firms during 1998-2007. All 2SLS regressions include year fixed effects and firm fixed effects. The instrument is U.S. non-deductible share x Post-2002. The standard errors are clustered at the sector level. *** p<0.01, ** p<0.05, * p<0.1

Table A.3: Correlations Between Non-Deductible Shares across Countries

| | Dependent Variable: Non-deductible Shares in Other Countries | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| | USA 2007 | Mexico 2000 | South Korea 2000 |
| Chinese Non-Deductible Share | 0.254*** | 0.366*** | 0.416*** |
| | (0.0714) | (0.0689) | (0.0698) |
| Constant | 0.563*** | 0.437*** | 0.327*** |
| | (0.0294) | (0.0284) | (0.0287) |
| Observations | 424 | 424 | 424 |
| R-squared | 0.029 | 0.063 | 0.078 |

*Notes:* This table presents the standardized bivariate correlation coefficients between the Chinese sectoral non-deductible share, calculated from the 1997 Chinese Input-Output Tables, and the sectoral non-deductible share from Mexico, South Korea, and the United States. For each of these countries, we compute the non-deductible share using input-output tables. For Mexico and South Korea, we use 2000 data from the World Input-Output Database. For the United States, we use 2007 data from the BEA. *** p<0.01, ** p<0.05, * p<0.1

Table A.4: The Effect of Computerization on VAT: Non-Deductible Shares from Mexico and South Korea

| | Dependent Variables | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| | VAT Gross | VAT Deductions | VAT | VAT/Sales |
| | A. Mexico: 2SLS | | | |
| Non-deductible share x Post-2002 | -6,291 | -12,405 | 4,859* | 0.0397 |
| | (8,733) | (7,764) | (2,689) | (0.0249) |
| Observations | 180,071 | 180,071 | 180,071 | 180,071 |
| Kleibergen-Paap F-statistic | 7.828 | 7.828 | 7.828 | 7.828 |
| | B. South Korea: 2SLS | | | |
| Non-deductible share x Post-2002 | -21,205*** | -23,429*** | 1,604 | 0.0492*** |
| | (7,640) | (6,925) | (1,752) | (0.0186) |
| Observations | 180,071 | 180,071 | 180,071 | 180,071 |
| Kleibergen-Paap F-statistic | 18.67 | 18.67 | 18.67 | 18.67 |
| | C. Mexico: Reduced Form | | | |
| Non-deductible share x Post-2002 | -1,124 | -2,217* | 868.4** | 0.00709* |
| | (1,507) | (1,203) | (401.9) | (0.00377) |
| Observations | 180,071 | 180,071 | 180,071 | 180,071 |
| R-squared | 0.626 | 0.500 | 0.692 | 0.560 |
| | D. South Korea: Reduced Form | | | |
| Non-deductible share x Post-2002 | -5,084*** | -5,618*** | 384.6 | 0.0118*** |
| | (1,344) | (1,100) | (428.9) | (0.00339) |
| Observations | 180,071 | 180,071 | 180,071 | 180,071 |
| R-squared | 0.627 | 0.500 | 0.692 | 0.560 |

*Notes:* The sample is a balanced panel of firms covering 1998-2007. All regressions include firm fixed effects, year fixed effects, and average 1998-2000 firm sales times year fixed effects. Standard errors are clustered at the sector level. *** p<0.01, ** p<0.05, * p<0.1

Table A.5: Descriptive Statistics – Balanced Panel, All Firms

| | Balanced Panel | | | All Firms | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| | N | Mean | Std. Dev. | N | Mean | Std. Dev. |
| Non-deductible share 1998-2000 Chinese Data | 180,148 | 0.404 | 0.067 | 1,268,574 | 0.397 | 0.067 |
| VAT (1000 RMB) | 180,148 | 2043 | 3085 | 1,268,574 | 1302 | 2568 |
| VAT/Sales | 180,148 | 0.042 | 0.033 | 1,268,574 | 0.035 | 0.032 |
| TFPR OLS | 180,148 | 4.618 | 0.532 | 1,268,574 | 4.611 | 0.543 |
| TFPR DLW | 180,148 | 0.278 | 1.540 | 1,268,574 | 0.175 | 1.366 |
| Sales (1000 RMB) | 180,148 | 58545 | 80044 | 1,268,574 | 42902 | 73267 |
| Employment (# workers) | 180,148 | 355 | 511 | 1,268,574 | 245 | 449 |
| Wage Bill (1000 RMB) | 180,148 | 3848 | 6053 | 1,268,574 | 2514 | 15610 |
| Deductible Input Share | 180,148 | 0.835 | 0.109 | 1,268,574 | 0.852 | 0.108 |
| Export Share | 166,076 | 0.134 | 0.276 | 1,136,055 | 0.093 | 0.238 |
| Imported Input Share | 180,138 | 0.300 | 3.136 | 1,268,504 | 0.305 | 4.408 |
| State-owned | 180,148 | 0.368 | 0.482 | 1,268,574 | 0.232 | 0.422 |
| Privately-owned | 180,148 | 0.363 | 0.481 | 1,268,574 | 0.552 | 0.497 |
| Foreign Owned | 180,148 | 0.268 | 0.443 | 1,268,574 | 0.214 | 0.410 |
| Corporate taxes | 180,148 | 604 | 1827 | 1,268,574 | 378 | 1606 |

Notes: Observations are at the firm and year level.

Table A.6: The Effect of Computerization on VAT and Firm Outcomes: Sample with All Firms

| | Dependent Variables | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | VAT | Sales | Employees | Intermediate Inputs | Intermediate Inputs as a Share of Total Input | | TFPR OLS | TFPR DLW | Export Share |
| | | | | | All | Deductible | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| **Dep Var Mean** | **1,253** | **41,518** | **238.3** | **28,142** | **0.852** | **0.807** | **117.3** | **25.6** | **0.202** |
| Non-deductible share x Post-2002 | 844.6*** | -19,300* | -144.8*** | -12,436* | -0.00723 | -0.188*** | 0.361*** | 0.366*** | -0.0693 |
| | (311.2) | (10,021) | (54.90) | (6,906) | (0.0230) | (0.0627) | (0.125) | (0.118) | (0.0509) |
| Observations | 1,268,574 | 1,268,574 | 1,268,574 | 1,268,574 | 1,268,574 | 1,268,574 | 1,268,574 | 1,268,574 | 1,268,574 |
| R-squared | 0.740 | 0.825 | 0.846 | 0.834 | 0.695 | 0.282 | 0.899 | 0.975 | 0.851 |

*Notes:* The sample is a balanced panel of firms covering 1998-2007. All regressions include firm fixed effects, year fixed effects, and average 1998-2000 firm sales times year fixed effects. Standard errors are clustered at the sector level. *** p<0.01, ** p<0.05, * p<0.1

Table A.7: The Effect of Computerization on VAT and Firm Outcomes: Dynamic Effects Using U.S. Non-Deductible Share × Post Periods as Instruments

| | Dependent Variables | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | VAT | VAT/Sales | TFPR OLS | TFPR DLW | Sales | Employees | Wage Bill | Intermediate Inputs | Intermediate Inputs as a Share of Total Input | | Export Share |
| | | | | | | | | | All | Deductible | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
| Non-deductible share x 2001-2002 ($\beta$1) | 1,255 | 0.0148* | 0.0998 | -0.0613 | -11,348 | -68.99 | 3,863** | -9,491 | -0.0119 | -0.593* | -0.00160 |
| | (1,006) | (0.00813) | (0.0913) | (0.114) | (12,835) | (146.0) | (1,539) | (9,517) | (0.0412) | (0.348) | (0.0592) |
| Non-deductible share x 2003-2005 ($\beta$2) | 2,423 | 0.0461*** | 0.823*** | 0.725*** | -51,999** | -28.67 | 5,805* | -42,442** | -0.105 | -1.154*** | 0.0510 |
| | (1,579) | (0.0160) | (0.276) | (0.274) | (26,265) | (237.1) | (3,035) | (19,127) | (0.0879) | (0.388) | (0.105) |
| Non-deductible share x 2006-2007 ($\beta$3) | 988.1 | 0.0328** | 1.714*** | 2.016*** | -94,546* | 2.605 | 6,276 | -53,383* | -0.249* | -1.536*** | 0.216 |
| | (1,658) | (0.0165) | (0.466) | (0.493) | (51,946) | (331.7) | (4,351) | (31,294) | (0.140) | (0.480) | (0.263) |
| Observations | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 | 180,148 |
| Kleibergen-Paap F-statistic | 8.908 | 8.908 | 8.908 | 8.908 | 8.908 | 8.908 | 8.908 | 8.908 | 8.908 | 8.908 | 8.908 |

Notes: The sample is a balanced panel of firms covering 1998-2007. All regressions are 2SLS (the instrumental variables are U.S. non-deductible share x the relevant post-period dummies) and include firm fixed effects, year fixed effects, and average 1998-2000 firm sales times year fixed effects. Standard errors are clustered at the sector level. *** p<0.01, ** p<0.05, * p<0.1

Table A.8: The Effect of Computerization on VAT: Robustness of Dynamic Effects to Export/Import Intensity, Province-Year-Specific Shocks, and Global Demand Shocks

| | Dependent Variable: VAT | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Controls: | Baseline | Export Rebates, Import and Export Duties | Export Growth 1998-2000 x Year FE | HHI 1998-2000 x Year FE | Province FE x Year FE | Agricultural Tax Share 2000 x Year FE | Sector-Year Imports and Exports | Omit Liaoning, Jiling and Heilongjiang 2004-2007 | Ownership Category x Year FE |
| Non-deductible share x 2001-2002 ($\beta$1) | 618.8* | 624.7 | 608.5* | 641.9* | 631.8* | 486.3 | 614.5* | 609.3* | 666.8* |
| | (364.2) | (385.0) | (361.9) | (360.8) | (364.1) | (370.2) | (362.0) | (364.5) | (370.0) |
| Non-deductible share x 2003-2005 ($\beta$2) | 1,667*** | 1,486** | 1,654*** | 1,700*** | 1,662*** | 1,668** | 1,644*** | 1,664*** | 1,654*** |
| | (599.9) | (586.5) | (599.9) | (597.8) | (596.8) | (645.2) | (587.7) | (610.5) | (588.0) |
| Non-deductible share x 2006-2007 ($\beta$3) | 1,100* | 871.5 | 1,088 | 1,112* | 1,008 | 1,275* | 1,035 | 1,122 | 1,063 |
| | (666.1) | (646.0) | (663.1) | (667.8) | (639.5) | (731.1) | (650.4) | (683.1) | (646.5) |
| Observations | 180,148 | 180,057 | 180,148 | 180,148 | 180,120 | 139,863 | 180,148 | 177,066 | 180,147 |
| R-squared | 0.692 | 0.693 | 0.692 | 0.692 | 0.697 | 0.700 | 0.692 | 0.694 | 0.693 |
| H0: $\beta$1=$\beta$2 (p-value) | 0.00400 | 0.0120 | 0.00400 | 0.00400 | 0.00300 | 0.00400 | 0.00400 | 0.00500 | 0.00400 |
| H0: $\beta$2=$\beta$3 (p-value) | 0.159 | 0.125 | 0.161 | 0.144 | 0.0970 | 0.353 | 0.137 | 0.176 | 0.140 |
| H0: $\beta$1=$\beta$3 (p-value) | 0.359 | 0.618 | 0.361 | 0.372 | 0.429 | 0.177 | 0.420 | 0.333 | 0.429 |

*Notes:* The sample is a balanced panel of firms covering 1998-2007. All regressions include firm fixed effects, year fixed effects, and average 1998-2000 firm sales times year fixed effects. Additional controls are stated in the column headings. Standard errors are clustered at the sector level. *** p<0.01, ** p<0.05, * p<0.1

Table A.9: The Effect of Computerization on VAT: Regression by Year

| Dependent Variable: VAT | |
|---|---|
| Non-deductible Share x 1998 | -68.46 |
| | (376.7) |
| Non-deductible Share x 1999 | 183.3 |
| | (280.6) |
| Non-deductible Share x 2000 | 252.6 |
| | (237.5) |
| Non-deductible Share x 2001 | - |
| | - |
| Non-deductible Share x 2002 | 729.4** |
| | (364.6) |
| Non-deductible Share x 2003 | 1,070** |
| | (524.1) |
| Non-deductible Share x 2004 | 1,564*** |
| | (528.6) |
| Non-deductible Share x 2005 | 1,621*** |
| | (455.5) |
| Non-deductible Share x 2006 | 1,209** |
| | (546.0) |
| Non-deductible Share x 2007 | 971.9* |
| | (578.6) |
| Observations | 180,148 |
| R-squared | 0.692 |
| 2002-2007 Joint p-value | 0.00963 |

*Notes:* This sample comprises of a balanced panel of firms during 1998-2007. All regressions include firm fixed effects, year fixed effects, and average 1998-2000 firm sales times year fixed effects. The standard errors are clustered at the sector level. *** p<0.01, ** p<0.05, * p<0.1

Figure A.1: VAT Deduction Invoice, Prior to Digital Encryption/Computerization

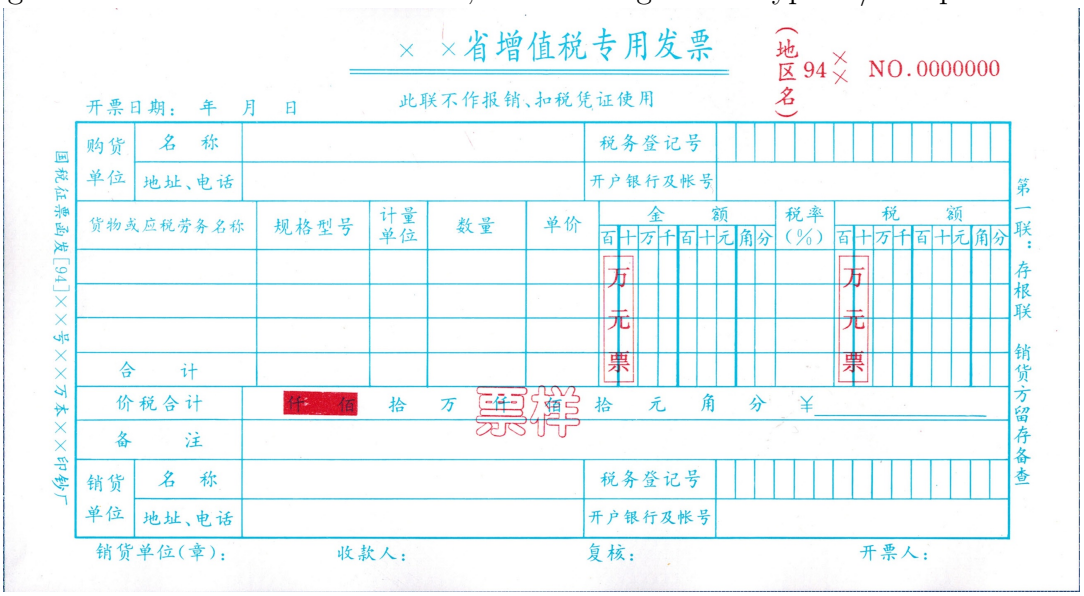



Figure A.2: VAT Deduction Invoice, After Digital Encryption/Computerization