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Three Essays at the Intersection of Public Finance and Environmental Economics

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by

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The dissertation of Antung Anthony Liu is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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DEDICATION

To my wife, Laura, for her love and faithful support while I completed this work.

To my daughters, Ailuen and Aili. I love you and cherish you both.

EPIGRAPH

I am the vine; you are the branches.
If you remain in me and I in you, you will bear much fruit;
apart from me you can do nothing.
—John 15:5

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ABSTRACT OF THE DISSERTATION

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This dissertation is comprised of three essays which explore environmental economics topics using public finance tools. The first and third essays are applied theory papers examining two overlooked factors – tax evasion and the shadow economy – which sharply alter the calculus of carbon tax reform. The basic finding is that carbon taxes are much less costly than has previously been found, particularly in developing countries. The second essay is an empirical paper studying how China's tax system has impacted its rollout of sewage treatment plants.

Chapter 1

Tax Evasion and Optimal Environmental Taxes

This paper introduces a new argument to the debate about the role of environmental taxes in modern tax systems. Some environmental taxes, particularly taxes on gasoline or electricity, are more difficult to evade than taxes on labor or income. When the tax base is shifted in a revenue-neutral manner toward these environmental taxes, the result is a net reduction in the amount of tax evasion. Using a carbon tax as a motivating example, the "tax evasion effect" is shown to sharply reduce the welfare cost of controlling emissions. A simple computable general equilibrium model suggests that the impact of considering tax evasion can be large: costs are lowered by 28% in the United States, by 89% in China, and by 97% in India. In countries with high levels of pre-existing tax evasion, a carbon tax will pay for itself through improvements in the efficiency of the tax system.

1.1 Introduction

> "Developing countries cannot and will not compromise on development."
>
> –Indian Prime Minister Manmohan Singh, at the 2009 United Nations Climate Change Conference in Copenhagen

Policy makers in developing countries have long opposed carbon taxes on the grounds that they are bad for economic growth. Arguing that carbon taxes will raise business costs, hurt profits, and diminish the competitiveness of exports, developing countries have refused to consider climate change agreements without substantial transfers from industrialized countries (Aldy et al 2010).

Views of these policy makers have been supported by previous work[1] examining the costs of environmental taxes. When considering a "green tax swap" or "double dividend" policy where pollution tax revenue is used to replace revenue from pre-existing taxes, these papers showed that concentrating the tax base on environmental goods hurts welfare by narrowing the tax base. Since, in the case of greenhouse gas emissions, estimates of the size of the negative externality vary widely, economists have separated the environmental benefits of a carbon tax from its other effects on the tax system. The literature has named the welfare gain associated with the recovery of deadweight loss from cutting pre-existing taxes the ***revenue-recycling effect***. It has named the welfare loss associated with exacerbating the distortion from pre-existing taxes through the new environmental tax the ***tax-interaction effect***.

Later papers[2] focused on real-world aspects of second-best tax systems which may decrease the costs of an environmental tax. Much of this work was developed for the industrialized country context, focusing on factors prominent in OECD tax systems. When a simulation is presented, only parameters from the United States are used.

This present paper suggests that tax evasion can play a potentially pivotal role in calculating the cost of reform. Certain environmental taxes, like carbon taxes and energy taxes, have unique properties which make them difficult to evade. When considering a green tax swap, shifting the tax base from easily-evaded taxes to a difficult-to-evade carbon tax can decrease the total amount of tax evasion in the system. This paper proposes two mechanisms by which decreasing tax evasion can produce social benefits. First, less real resources are spent on evading taxes.

[1]See Goulder (1995), Parry (1995), and Bovenberg and Goulder (1996).

[2]See Parry and Bento (2000), Williams (2002), Williams (2003), and Bento and Jacobsen (2007).

Second, taxpayers face effective tax rates which are closer together, improving the breadth of the tax base. The existence of tax evasion introduces wrinkles in the efficiency of the tax system which can be ironed out with a shift towards a less evadable environmental tax.

Through simple simulations, the paper finds that the effect of considering tax evasion is quantitatively large, even in OECD countries which have relatively low levels of tax evasion. In developing countries like China and India, where tax evasion is greater, the effect can serve to basically offset the entire cost of environmental tax reform.

The literature studying the double dividend is closely related to the optimal tax literature. The model presented here is similar in some respects to that of Cremer and Gahvari (1993), who point out that uniform commodity taxes are not appropriate in the presence of tax evasion. While Cremer and Gahvari focus on describing the optimal tax system, this paper's contribution is to analytically determine the welfare impact of plausible tax reform, and estimate its magnitude.

Tax evasion is a significant component of nearly all modern tax systems. The U.S. has an overall tax evasion rate of 16% (Slemrod 2007). Other countries can have even higher rates of tax evasion. One cross-country method of comparing how honestly countries pay their taxes is to compare estimates of the "shadow economy," the portion of goods in an economy that evades taxes and formal regulation. Schneider and Enste (2002) apply a variety of methodologies to estimate the size of the "shadow economy" within each country. These estimates range from 12% of GNP for OECD countries to 44% of GNP for Africa.

This paper is organized in sections. Section 2 presents an analytically tractable general-equilibrium model incorporating tax evasion behavior. Section 3 extends the model from section 2 to incorporate heterogeneity in tax evasion. Section 4 presents a computable general equilibrium (CGE) model which analyzes the magnitude of the impacts proposed here for parameters simulating the U.S. economy. Section 5 applies the methods from section 4 to the set of the 30 highest carbon emitting countries to estimate how each country's level of observed tax evasion and energy sector size will impact its welfare cost from environmental tax reform. The final section concludes.

1.2 A Two Good Model Incorporating Costly Tax Evasion

1.2.1 Assumptions

1.2.1.1 Households

Consider a representative household economy, where each household must divide their time endowment (T) between leisure (l) and labor (L). Households work to purchase two consumption goods: X and Y. Good X is a polluting good such as electricity or oil, producing emissions $\phi(X)$. Good Y represents non-polluting goods. Households maximize the utility function $U(l, X, Y) - \phi(X)$. Households supply labor L_X and L_Y to produce goods X and Y. The household time constraint is: $T = l + L = l + L_X + L_Y$.

Wages are normalized to 1. Along with wages, each household receives lump-sum transfers g from the government. The prices of the goods are p_X and p_Y. Although households also own firms, firms earn no profits. The household budget constraint is: $L_X + L_Y + g = p_X X + p_Y Y$.

1.2.1.2 Firms

The goods X and Y are produced with production functions $X = L_X$ and $Y = L_Y$. While all firms pay labor tax τ_L, only firms producing X pay pollution tax τ_p. The tax τ_L is meant to represent all pre-existing taxes, including sales taxes, labor taxes, and taxes on income.

Tax Evasion Firms can choose to evade taxes. A firm in sector i chooses its evasion rate E_i. For convenience of notation, the evasion rate E_p refers to the evasion rate of the pollution tax. An evasion rate of 0 means that all taxes owed are completely paid, while a rate of 1 means that no taxes are paid.

Under this model, firms must pay real costs to evade taxes. A firm producing good i pays $C_i(E_i)$ per unit produced for evading taxes. We assume that:

1. $C_i(0) = 0$, $C_i'(0) = 0$. When taxpayers are completely honest, there are no costs of evasion.

2. $\tau_i(1 - E_i(\tau_i))$ is increasing and concave. Although taxes are paid less honestly as the tax rate increases, the effective tax rate increases with respect to the tax rate levied.

3. $C_i(E_i(\tau_i))$ is increasing and convex in τ_i. While the initial marginal cost of hiding tax evasion is low, it increases as more of the tax base is hidden.

Under this setup, firms set the marginal cost of evading taxes equal to the marginal benefit of doing so in the form of taxes avoided. Since marginal costs are increasing under the third of these assumptions, there will be a unique point for each tax rate where firms are just indifferent to evading taxes and paying costs. Higher marginal tax rates result in higher tax evasion[3].

Firm Profits Firms producing good X maximize:

$$\pi_X = \max_{L_x, E_P, E_X} \{(p_X - (1 - E_p)\tau_p)X - (1 + (1 - E_X)\tau_L)L_X - C_p(E_p)X - C_X(E_X)L_X\} \tag{1.1}$$

The first term in this equation represents after-tax revenue, the second represents after-tax labor costs, and the third and fourth terms represent the costs paid by the firm to evade taxes.

Firms producing Y have profits:

$$\pi_Y = \max_{L_Y, E_Y} \{p_Y Y - (1 + (1 - E_Y)\tau_L)L_Y - C_Y(E_Y)L_Y\} \tag{1.2}$$

[3]While models such as that of Allingham and Sandmo (1972) predict an ambiguous impact of marginal tax rates on rates of evasion at the individual level, there is good evidence that tax evasion on aggregate responds to tax rates. Fisman and Wei (2004) documented how tax evasion of tariffs and VAT is directly related to the tax rate levied on a given product. Gorodnichenko et al (2009) showed how tax evasion in Russia responded strongly to the tax rate levied as a result of flat tax reform in Russia.

Although firms evade taxes, their profits are still driven down to zero by perfect factor mobility and perfect competition. To understand the inability of firms to make profits even when they evade taxes, imagine that the production processes of different types of goods yield different opportunities to evade taxes. With many firms in the market, each will choose the same optimal evasion rate, driving prices down and eliminating profits.

1.2.1.3 The Government

The government receives two forms of revenues: labor taxes and pollution taxes. Each stream of revenue is moderated by tax evasion. The government transfers all revenues G as lump sums g back to households. Supposing that there are N households, the government follows the constraint:

$$G = Ng = (1 - E_p)\,\tau_p X + (1 - E_X)\,\tau_L L_X + (1 - E_Y)\,\tau_L L_Y \tag{1.3}$$

1.2.2 Welfare Effects of a Pollution Tax

If W is the welfare of the household and λ is the marginal utility of income, the change in welfare from a double dividend style of tax reform is:

$$\frac{1}{\lambda}\frac{dW}{d\tau_p} = \underbrace{\left[\frac{1}{\lambda}\phi' - ((1 - E_p)\,\tau_p)\right]\left(-\frac{dX}{d\tau_p}\right)}_{Environmental\ Effect} + \underbrace{\sum_{i=X,Y}[(1 - E_i)\,\tau_L]\,\frac{dL_i}{d\tau_p}}_{Tax\ Base\ Effect} - \underbrace{\frac{dC_p\,(E_p)}{d\tau_p}X - \sum_{i=X,Y}\frac{dC_i\,(E_i)}{d\tau_p}L_i}_{Tax\ Evasion\ Effect} \tag{1.4}$$

Detail of this derivation is provided in Appendix A.

1.2.3 Relation to Prior Literature

In the absence of tax evasion, equation 1.4 can be re-written:

$$\frac{1}{\lambda}\frac{dW}{d\tau_p} = \left(\frac{1}{\lambda}\phi' - \tau_p\right)\left(-\frac{dX}{d\tau_p}\right) - \tau_L\frac{dl}{d\tau_p}$$

This result corresponds to that of Bento and Jacobsen (2007) and Williams

(2002):

$$\frac{1}{\lambda}\frac{dU}{d\tau_p} = \underbrace{\left(\frac{1}{\lambda}\phi' - \tau_p\right)\left(-\frac{dX}{d\tau_p}\right)}_{Environmental\ Effect} - \underbrace{\tau_L\frac{dl}{d\tau_p}}_{Tax\ Base\ Effect} \tag{1.5}$$

Bento and Jacobsen (2007) divide up the tax base effect into the *revenue-recycling effect* and the *tax-interaction effect*:

$$\frac{dL}{d\tau_p} = \underbrace{\frac{\partial L}{\partial \tau_L}\frac{d\tau_L}{d\tau_p}}_{Revenue-Recycling\ Effect} + \underbrace{\frac{\partial L}{\partial p_X}\frac{dp_X}{d\tau_p} + \frac{\partial L}{\partial p_Y}\frac{dp_Y}{d\tau_p}}_{Tax-Interaction\ Effect} \tag{1.6}$$

Equation 1.4 can now be separated into the various effects studied in the previous literature[4]:

$$\begin{aligned} \tfrac{1}{\lambda}\tfrac{dW}{d\tau_p} = & \underbrace{\left(\frac{1}{\lambda}\phi' - (1-E_p)\,\tau_p\right)\left(-\frac{dX}{d\tau_p}\right)}_{Environmental\ Effect} \\ & \underbrace{+\sum_{i=X,Y}\left[(1-E_i)\,\tau_L\right]\frac{\partial L_i}{\partial \tau_L}\frac{d\tau_L}{d\tau_p}}_{Revenue-Recycling\ Effect} \\ & \underbrace{+\sum_{i=X,Y}\left[(1-E_i)\,\tau_L\right]\left(\frac{\partial L_i}{\partial p_X}\frac{dp_X}{d\tau_p} + \frac{\partial L_i}{\partial p_Y}\frac{dp_Y}{d\tau_p}\right)}_{Tax-Interaction\ Effect} \\ & \underbrace{-\frac{dC_p\left(E_p\right)}{d\tau_p}X - \sum_{i=X,Y}\frac{dC_i\left(E_i\right)}{d\tau_p}L_i}_{Tax\ Evasion\ Effect} \end{aligned} \tag{1.7}$$

[4]Note that the revenue recycling effect can be re-written:

$$\begin{aligned} R.R.E. &= \sum_{i=X,Y}\left[(1-E_i)\,\tau_L\right]\frac{\partial L_i}{\partial \tau_L}\frac{d\tau_L}{d\tau_p} \\ &= Z_L\frac{dG}{d\tau_p} \end{aligned}$$

where Z_L is the marginal excess burden of labor,

$$Z_L = \frac{\sum_{i=X,Y}\left[(1-E_i)\,\tau_L\right]\frac{\partial L_i}{\partial \tau_L}}{\partial G/\partial \tau_L}$$

This is the form used in Parry and Bento (2000) and Williams (2002).

1.2.4 Welfare Analysis

Comparing equation 1.7 with equations 1.5 and 1.6 from the prior literature yields three observations.

First, the environmental effect may be diluted to the extent to which the environmental tax is evaded, diminishing the pollution cutting impact of the environmental tax. This is an important point which has been overlooked in the previous literature.

Second, the tax base effect, which combines the revenue-recycling effect and the tax-interaction effect, is impacted by the respective tax evasion rates of the clean and dirty sectors. This is discussed in section 2.6.

Third, the presence of real costs in evading taxes suggests a new effect: the "tax evasion effect." Under the assumptions from section 2.1.2 and the assumption that the environmental tax is more difficult to evade than the pre-existing tax, the tax evasion effect boosts welfare while the new environmental tax rate is less than that of the tax that is replaced.

At the margin, as taxes are cut, taxpayers no longer find it profitable to pay high costs to evade taxes. Savings are realized through lower spending on tax evasion of the pre-existing tax. As the environmental tax is phased in, new real costs are generated on evasion of the environmental tax. Since it is harder to evade the environmental tax, and the statutory environmental tax rate is less than the rate of the pre-existing tax[5], new real costs generated will always be less than cost savings realized, decreasing total spending on tax evasion on net.

Intuitively, there is a reduction in costly evasion stemming from the substitution of a hard-to-evade environmental tax for an easy-to-evade labor tax. This is the first mechanism by which benefits can be realized. The second mechanism, a broadening of the tax base when pre-existing tax evasion is heterogenous, is presented in section 3.

[5]For reference, some analysts have suggested a carbon tax of around $25 per short ton. This represents a 12% tax on a $100 barrel of crude oil.

1.2.5 Key Assumptions

The model depends on two key assumptions:

1. Tax evasion behavior incurs real costs.
2. Environmental taxes are more difficult to evade than pre-existing taxes.

1.2.5.1 Tax evasion behavior incurs real costs.

One key assumption of this model is that there are real costs of tax evasion. Real costs here include both direct and indirect actions which consume real resources and drive up the prices of goods. Both tax avoidance and tax evasion behaviors should be included.

Legal means of minimizing tax burden may include structuring production between international divisions of a conglomerate to take advantage of disparities in tax rates. Production might be structured in more efficient ways if taxes were not a driving consideration. Headquartering in remote locations such as Bermuda, the Cayman Islands, or certain municipalities in Switzerland is another costly form of tax avoidance. Another example is the employment of tax lawyers and tax consultants, a multibillion dollar industry whose primary purpose is the minimization of tax burden.

Strictly illegal forms of costly tax evasion may include the employment of migrant laborers who do not face payroll taxes. These labor decisions are distortionary, and are directly related to tax rates. Another illegal and costly form of tax evasion is the use of corporate tax shelters, defined by the Department of the Treasury (1999) as transactions which are costly and minimize tax burden but without economic substance.

One possible cost of tax evasion that is not explicitly modeled here is the cost of monitoring: governments may have to spend more to audit taxpayers in high evasion contexts. If governments respond to higher tax evasion with higher monitoring, or if monitoring environmental tax compliance is less costly than monitoring labor tax compliance, an additional benefit will be realized when tax evasion is cut.

1.2.5.2 Environmental taxes are more difficult to evade than pre-existing taxes.

Certain forms of environmental taxes, such as a carbon tax or a tax on energy, are difficult to evade. Since relatively few mechanisms are available, avoiding taxes is difficult and expensive. As a result, taxes levied on upstream suppliers of energy will provoke a limited tax evasion response. There are several major reasons why carbon taxes and energy taxes have beneficial tax monitoring properties:

First, it is easy to measure and monitor physical units of energy at the supplier level: megawatt hours of electricity, barrels of oil, gallons of gasoline, and tons of coal. Most forms of energy must pass through centralized points of infrastructure, like oil or natural gas pipelines, coal grading facilities, or the electricity grid. Compared to other tax bases, such as hours worked, profits earned, or personal income, energy consumed and carbon emitted are easy-to-monitor.

Second, it is easy to check at the consumer level how much is consumed through existing infrastructure: meters, bills, and storage tanks. Commercial users will have powerful incentives to deduct their expenditures in this area. This setup makes it easy to catch cheating suppliers.

Third, it is usually easier to assess the price of energy than other goods. It is difficult to determine the price of goods sold at wholesale when transactions are not at arm's length. When goods are sold at retail, there is the possibility of discounts or co-products which blur revenues received and profits. For energy sources like oil, gasoline, electricity, and natural gas, there are well-established prices occurring in transparent marketplaces. This also eliminates a key pathway for tax evasion.

Fourth, many of the largest forms of energy produce a variety of air pollutants that have a known relationship to the quantity of primary energy consumed. This provides an independent way to verify how much oil or coal is being consumed. Each of these has a particular fingerprint. Indeed, coal or oil from different sources leave air pollution signatures which can be traced.

Metcalf and Weisbach (2009) study design issues in implementing a carbon tax for the United States. They conclude that tax collection covering 80% of

US greenhouse gas emissions, and nearly all carbon dioxide emissions, can be accomplished by monitoring fewer than 3,000 points. These 3,000 points include 146 oil refineries, 1,438 coal mines, and 500 natural gas fields. Close monitoring of these relatively few sources would lead to very accurate assessment of the tax base.

Moreover, both the government and other natural resource owners already have very strong incentives to carefully monitor these sources. Because of the fixed chemical relationships which govern the composition of energy, taxes on carbon or on energy can be precisely assessed and avoided only with extreme difficulty.

Some pollution taxes in developing countries, like wastewater fines in China, have been observed to have high incidences of evasion. While the welfare formulas 1.4 and 1.7 still still apply if the environmental tax is easy-to-evade, the effects described here may not be welfare-enhancing.

1.2.6 Industry Tax Evasion and its Welfare Impacts

Differences in tax evasion between the energy sector and non-energy sectors can play a significant role in the suitability of environmental taxes. If the energy industry pays its taxes more honestly than other sectors pay theirs, the initial effective tax burden on the energy industry will be higher, resulting in a higher marginal excess burden on the energy industry and a more negative tax interaction effect. The converse is also true: if the energy industry pays its taxes less honestly, its initial tax burden is lower, and an energy tax will be more welfare enhancing.

While there are studies of the tax burden across industries (e.g. Nicodeme 2001), no study has been published with rates of tax evasion across industrial sectors. In this absence of empirical data, this paper briefly discusses two arguments evaluating how asymmetries in tax evasion between the energy and non-energy sectors will affect the change in welfare from a double dividend reform.

The first set of arguments deals with the evasion rate of the energy industry relative to other sectors. The energy industry generally has larger, more well-organized firms than sectors representing other goods. According to the U.S. BEA National Income and Product Accounts, there are negligible numbers of the self-employed in the energy sector. Additionally, energy companies are usually involved in resource extraction, a politically sensitive activity which requires good governmental relationships. On the other hand, energy companies are also large and have cross-country operations, increasing their opportunities to hide profitable activity and avoid taxes. On balance, one might think that energy companies tend to be evade labor taxes at a lower rate than companies in other industries, and have less tax evasion.

A second line of argument is whether a Pigouvian tax is deemed necessary on energy sectors at all. If the energy industry pays its taxes more honestly than non-energy sectors, an implicit tax on the polluting good is already in place in the form of higher effective tax rates. Since most studies have generally found positive primary net benefits from a tax on carbon, it is sensible to assume that the tax evasion rates, even if lower in the energy sector, have not eliminated the "environmental effect" component of welfare change.

1.3 A Three Good Model Incorporating Clean Sector Heterogeneity

This section diversifies the model presented in section 2 by incorporating the possibility that the clean sector is composed of multiple goods, and that the firms producing these goods have different inherent abilities to evade taxes. Heterogeneity in the clean sector leads to a less negative tax base effect.

To streamline the text, the full three goods model is relegated to Appendix B. In brief, this model assumes that the clean good is divided into two types: one where tax evasion is easy, and one where tax evasion is difficult. For intuition's sake, the difficult-to-evade good might be produced by a large corporation, while the easy-to-evade good might be produced by a small business or by the self-employed. Self-employment has been widely linked to higher tax evasion opportunities (Engstrom and Holmlund 2006, Torrini 2005).

When there is asymmetric tax evasion, the tax base effect is less negative, further reducing the cost of the green tax swap. The ability of some taxpayers to evade places the burden of payment on those who do not evade: low evasion sectors start with high effective tax rates, and high evasion sectors start with low effective tax rates. When the policy is implemented, statutory tax cuts lower taxes most for industries with high effective rates; they lower taxes least for industries with low effective rates. This spreads the burden of taxation more evenly and results in welfare gains relative to the situation where tax evasion is not considered.

This result is similar in some respects to that of Parry and Bento (2000). They argue that the presence of legislated exemptions in the tax code, like employer-provided health care and mortgage interest, create inefficiencies in the tax code. A uniformly-applied environmental tax can reduce pre-existing tax shelters and distribute the tax burden more evenly. In the same manner, this present paper argues that the presence of tax evasion, and the presence of asymmetries in opportunities to evade taxes, creates inefficiencies which can be smoothed over with the revenues from a less-evadable environmental tax.

A less negative tax base effect lowers the overall cost of reform. This finding complements that of section 2.4, which also showed that the presence of tax evasion lowered the costs of reform.

1.4 Simulation Model

Sections 2 and 3 showed theoretically that the welfare cost of double dividend reform is less when pre-existing tax evasion is present. This section estimates the magnitudes of those cuts in the context of the U.S. economy.

1.4.1 Structural Model

1.4.1.1 Households

The representative household has nested constant elasticity of substitution (CES) utility:

$$U = \left(\alpha_{UG} C^{\frac{\sigma_U - 1}{\sigma_U}} + \alpha_{Ul} l^{\frac{\sigma_U - 1}{\sigma_U}}\right)^{\frac{\sigma_U}{\sigma_U - 1}} \tag{1.8}$$

$$C = \left(\alpha_{CX} X^{\frac{\sigma_G - 1}{\sigma_G}} + \alpha_{CY} Y^{\frac{\sigma_G - 1}{\sigma_G}} + \alpha_{CZ} Z^{\frac{\sigma_G - 1}{\sigma_G}} \right)^{\frac{\sigma_G}{\sigma_G - 1}} \tag{1.9}$$

where l is leisure, and C is the utility derived from consuming goods. Good X is the polluting good consumed by households, Y is a clean good that is difficult to evade, and Z is a clean good that is easier to evade. The parameter σ_U represents the elasticity of substitution between goods and leisure. σ_G represents the elasticity of substitution between X, Y, and Z goods. The α parameters are calibrated to control for the share of income spent on each good.

Since the object of this CGE simulation is to study the impact of tax evasion on welfare related to the tax base effect, there is no disutility caused by emissions from the environment. Although pollution is not included in utility, the same results apply in the case of separable environmental damages or an emissions target. Williams (2002) examines the case of non-separable environmental damages.

Households are constrained by their budgets:

$$p_X X + p_Y Y + p_Z Z = L + g \tag{1.10}$$

where p_i is the price of good i, L is the hours worked at a wage normalized to 1, and g is the per-household government transfer. Household transfers are held constant under this policy.

The welfare cost of tax reform is calculated using **equivalent variation**. A policy's equivalent variation is how much households are willing to pay to avoid reform.

1.4.1.2 Firms

There are three kinds of firms, each producing a different kind of good: X, Y, and Z. Production is given by $X = L_X$, $Y = L_Y$, and $Z = L_Z$, where L_i is the labor used in good i. Production is constant returns to scale.

Firms of type i can evade labor taxes at a rate E_i by paying a per-unit cost and marginal cost:

$$C_i\left(E_i\right) = \frac{A_i}{N_i + 1} E_i^{N_i + 1} \tag{1.11}$$

$$MC_i\left(E_i\right) = A_i E_i^{N_i} \tag{1.12}$$

where A_i and N_i are parameters that will be chosen during calibration. This functional form satisfies the assumptions laid out in section 2.1.2.

1.4.1.3 Government

The government taxes labor and may tax emissions. The government uses all revenues to provide lump sum transfers to households. Transfers are held fixed during the tax reform.

$$\tau_L\left(\left(1-E_X\right)L_X + \left(1-E_Y\right)L_Y + \left(1-E_Z\right)L_Z\right) + \tau_E\left(1-E_p\right)X = G = gN \tag{1.13}$$

where X is the emissions level, with each unit of the polluting good producing one unit of emissions, G is total government transfers, g is per-household transfers, and N is the number of households.

1.4.1.4 Model Solution

When an emissions target is chosen, the government holds G fixed and adjusts the emissions tax and the labor tax until emissions levels are brought down to their target. The numerical model is solved by setting taxes and prices such that the household budget balances, the government budget balances, and the factor market for labor clears. Note that households receive an income of $L_X+L_Y+L_Z+g$ while the total cost of goods produced is $L_X + L_Y + L_Z + g + \sum_{i=X,Y,Z} C_i L_i + C_p X$, due to wasteful tax evasion activities.

1.4.2 Model Calibration

The baseline for these simulations is intended to reproduce a very simplified version of the U.S. economy.

The elasticities of substitution σ_U and σ_G are set at $\sigma_U = 0.9$ and $\sigma_G = 1.01$. A benchmark labor tax rate of 40% is chosen, common in the previous literature.

Changes in these parameters have a minimal effect on the results[6].

Slemrod (2007) records that the overall rate of tax evasion in the U.S. is 16.3%. The parameters A_i and N_i can be calibrated using this fact and the estimate that about \$50 billion[7] is spent annually in tax evasion activity. Since information on environmental tax evasion is not available, we assume that, at every tax rate, environmental tax evasion is half that of labor tax evasion[8].

Equations 1.11 and 1.12 result in an elasticity of tax evasion with respect to the tax rate of $\frac{1}{N_i}$. For these simulations, the calibrated parameters result in elasticities between 0.08 and 0.16. Gorodnichenko et al (2009), in a unique study of the response to tax evasion to flat-tax reform in Russia, report an elasticity of 0.376.

The baseline size of the polluting sector is 2.7% of the economy, following Bento and Jacobsen (2007). This simulation uses the size of the self-employed sector as an identifying characteristic which determines the size of the high evasion and low evasion sectors of the economy. Slemrod (2007) states that FICA is evaded at the rate of 2% while the self-employment tax, the equivalent of FICA for the self-employed, is evaded at the rate of 52%. According to the 2007 U.S. BEA National Income and Product Accounts, 7.4% of employees in the U.S. are self-employed.

1.4.3 Simulation Results

In the following sections, we test the magnitudes of the tax evasion effect and of the asymmetric tax evasion effect. In each case, the reform being considered

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[6] One of the key results in this paper is that the welfare cost of environmental tax reform in the U.S. is 28% less when asymmetric tax evasion is considered. When σ_U is increased or decreased by 10%, this result changes by 0.2%. When σ_G is increased or decreased by 10%, this result changes less than 3%. Variations in the initial tax rate are discussed in footnote 12.

[7] The tax burden of the U.S. was \$2.5 trillion in 2008 (OMB 2009). Using the figure from Slemrod (2007) that 16.3% of all taxes were evaded in 2001, this implies that \$491.5 billion in taxes were evaded in 2008. With the conservative assumption that evaders spent 10% of taxes evaded on non-productive evasion activities, we estimate that \$50 billion was spent on tax evasion activity. The costs spent on tax evasion can be considerably higher. A study of corporate tax shelters by the Department of the Treasury (1999) found that these shelters cost between 25% and 50% of taxes evaded.

[8] Recall that the labor tax is a representative tax. Different pre-existing taxes have different rates of evasion. The actual variation between the environmental tax and the pre-existing tax depends on which tax is actually cut with the recycled revenue.

is a new pollution tax which cuts baseline pollution by 10% coupled with a revenue-neutral reduction in labor taxes.

1.4.3.1 The Tax Evasion Effect

Calibrated marginal cost curves of tax evasion are illustrated in figure 1.1. At each tax rate, evasion in pollution taxes is exactly half of that for labor taxes.

The labor tax and pollution tax rates required to cut emissions 10% are shown in figure 1.2. Each point along the horizontal access represents a separate simulation. In these simulations, the starting fraction of the economy taken up by the polluting good is varied between 1% and 40%. The double bar across the top of the graph represents the initial labor tax rate in each of these simulations. The dashed line shows that, as the share of the polluting good increases, larger pollution taxes are necessary. As the polluting good takes on a more important role in a given economy, a bigger price distortion is necessary to cut emissions by 10%. With larger pollution taxes and a larger polluting good, more revenue recycling is enabled, as reflected by the downward sloping solid line.

Figure 1.3 illustrates how the total cost of evasion has been affected by double dividend reform. As the pollution tax increases in size, the amount spent on environmental tax evasion increases, as illustrated by the bottom line marked with squares. However, as more revenue recycling is enabled, the amount of real resources spent on labor tax evasion falls. The solid green line, reflecting the total amount spent on tax evasion in the economy, falls gradually. As the total amount of real resources spent on tax evasion falls, society realizes real welfare benefits.

Figure 1.4 shows the total welfare cost of the green tax swap. The solid line shows that the welfare cost increases as the size of the polluting sector increases, since greater distortions in price are necessary to achieve cuts in emissions. For each simulation, the tax evasion effect significantly reduces this welfare cost. For the simulations considered here, calibrated to the U.S., between 23% and 27% of the welfare cost of the policy is offset by the reduction in the costs of tax evasion.

1.4.3.2 The Effect of Asymmetric Tax Evasion

In this section, we quantify the impact of asymmetric tax evasion. The general strategy is to use the simulations with symmetric evasion as a baseline; the counterfactual considered is one where individual sectors have asymmetric evasion but the overall evasion levels are the same.

The impact of narrowing the gap in tax burden in the clean sector is illustrated in figure 1.5. Each point on the horizontal axis on each line represents a separate simulation. The solid line shows that the cost of double dividend tax reform is constant in a system with no tax evasion. The solid line with square markers represents the cost of tax reform when there is tax evasion, but the clean good has symmetric tax evasion properties. The dashed line with triangle markers shows the cost of tax reform when the clean good is asymmetric in tax evasion. As can be seen by the gap between this line and the line marked with squares, there can be significant value attached to narrowing the gap in tax burden between high evasion and low evasion goods. This value increases as the size of the high evasion sector increases.

The savings in welfare costs from this set of simulations is summarized in figure 1.6. As this diagram shows, the total reduction in welfare cost from a double dividend reform increases when the asymmetry being reduced is more bigger. Cost savings range between 30% and 60% for these simulations.

In the U.S., where the self-employment sector makes up 7.4% of the clean sector (NIPA 2007), these simulations suggest that a double dividend tax reform will be 32% cheaper when the costs of evasion and the presence of asymmetric evasion are considered.

1.5 Cross Country Comparisons

This section applies the methods developed in section 4 to the set of the top 30 carbon emitting countries. Since no consistent cross-country estimates of tax evasion are available, the self-employment rate is used as the identifying characteristic for how much tax evasion occurs in each economy. Countries differ from each other only in the composition of self-employment in their economies.

This method is likely to result in a lower bound estimate since it represents just one route by which taxpayers evade taxes. While applying this method to the U.S. yields a tax evasion rate of just 8.3%, the U.S. has a reported evasion rate of 16.3% (Slemrod 2007). Moreover, this method assumes that the self-employed in each country evade taxes at a similar rate as the self-employed in the U.S., and that the employees of others evade taxes at a similar rate as those in the U.S.

1.5.1 Calibrating the Model

The countries selected for this section are the top 30 carbon dioxide emitters, as reported by the Millenium Development Group. Self-employment rates in each country are obtained from the International Labour Organization's Labour Statistics Database. If a country's self-employment rate in 2005 was not available, the latest year of data available for each country was used. When the self-employment data were not available from the ILO, the data were obtained from OECD's online statistical abstracts database.[9]

The total size of each country's economy was computed using nominal GDP in current dollars in 2005 , obtained from the IMF World Economic Outlook database. Each country's tax burden in 2005 was obtained first from the OECD Tax Database. When a country's tax burden was not in the OECD Tax Database, it was located in the Heritage Foundation's 2010 Index of Economic Freedom.

The value of fossil fuel consumption in 2005 is used as the polluting sector. Data from the U.S. Energy Information AdministrationInternational Energy Statistics were used, which give the amount of natural gas, coal, and oil consumed by each country. The online EIA dataset also includes prices for natural gas and for coal. For the price of crude oil, OECD statistical abstract data were used.[10] When a country's price for a given natural resource was not available, the average

[9]Three countries – Saudi Arabia, Ukraine, and Iran – were excluded because they had no self-employment data. India's self-employment rate was obtained from a June 24, 2011 press release by the Indian government's Ministry of Statistics and Programme Implementation.

[10]For natural gas, the "Natural Gas Prices for Households" data were used. For coal, the "Steam Coal Prices for Electricity Generation" data were used. For oil, the "Crude Oil Import Prices" were used.

world price for that resource was used.

These datasets were combined to divide each country's GDP into an energy sector X[11], a low evasion clean sector Y, and a high evasion clean sector Z, with the assumption that self-employed workers evade taxes at a 50% rate while other employees evade taxes at at 5% rate. Each country's initial tax level was set to their tax burden. Data are summarized in table 1.1.

Each country's initial spending on tax evasion was calculated in the same manner as in footnote 7. Other parameters, such as elasticities of substitution, are assumed to be the same as were used in section 4.2.

1.5.2 Results

Table 1.2 summarizes these results[12]. Several observations are apparent by comparing the inputs from table 1.1 and the results in table 1.2. First, the cost of a double dividend reform, as a percentage of GDP, increases with the relative share of the energy sector in a country. When the energy sector in a country is a large share of its economy, a relatively higher energy tax must be levied to make up for energy sector labor tax cuts. Second, the welfare impacts of including tax evasion are larger as tax evasion increases. Since, in this model, tax evasion wastes resources and creates price distortions, higher levels of tax evasion create greater opportunities for benefits with tax reform. Third, the cost of evasion represents a bigger portion of the welfare benefits than asymmetric evasion. In countries with high evasion, spending on evasion is likely to be big, the cost of evasion can

[11] Under some forms of carbon tax proposals, "carbon tariffs" are levied on imported forms of energy; exported energy is excluded from taxation. Under proposals of this type, a more appropriate measurement for the energy sector X would be the value of energy consumption, not energy production.

[12] One area of heterogeneity between countries that is not explored in section 5 is the differences in tax rates between countries. Some countries have low tax burdens, while others have high tax burdens. The impact of the size of the tax burden on the cost of a green tax swap was studied in a series of simulations calibrated to the U.S. similar to the ones from section 4.

The results basically line up with intuition. First, the cost of double dividend reform rises with the tax rate, reflecting the greater tax interaction effect. When the cost of tax evasion is added to the model, the cost savings from reform increase with the tax rate. Higher tax rates incentives taxpayers to incur higher marginal costs. Double dividend reform allows cost savings from cutting the highest marginal cost labor tax evasion. On net, tax evasion tends to produce greater cost savings in percentage terms when the pre-existing tax rate rises.

even overwhelm the welfare cost of double dividend reform. Asymmetric evasion is important when high amounts of evasion are present, and the size of the energy sector is small.

The cuts in the welfare cost of double dividend reform reported here are large. The U.S. receives a 28% cut in the welfare cost of its carbon emissions reform. China's welfare cost would be decreased by 89%, and India's by 97%. In these countries, already among the world leaders in greenhouse gas emissions, benefits from a green tax swap are close to the costs of reform. In many of the countries who emit the most carbon now or are projected to be the most important carbon emitters – South Korea, the United Kingdom, Brazil, Mexico, and Indonesia – the cost of a carbon tax is less than half of what it would be when tax evasion is considered.

1.6 Conclusion

Many of the countries which are the most significant greenhouse gas emitters, like China, India, Brazil, and Indonesia, are also the countries with the highest levels of tax evasion. These are precisely the countries that might benefit the most by shifting their tax bases towards taxes which are difficult-to-evade. This paper has argued that, for many of these countries, the benefits of low evasion carbon taxes can be so significant that they should be considered even with no policy interest in improved environmental quality or reduced emissions.

Would developing countries really set up their tax structure in order to minimize tax evasion, as suggested by this paper? There is growing evidence that they already do[13]. For developing countries, with institutional barriers to collecting taxes and monitoring taxable activity, carbon taxes could represent an efficient way to raise tax revenues.

There is a large and growing economics literature focused on the distribution of costs and benefits of climate change. Much of this literature treats international climate change agreements as a prisoner's dilemma, where the dominant strategy

[13]Gordon and Li (2009) and Gordon (2010)

is to avoid cutting emissions (Helm 2008). The findings of this paper can have a potentially large impact on this literature with its finding that revenue-neutral shifts towards environmental taxes can have extremely low or negative costs, even when carbon taxes are implemented unilaterally.

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Chapter 1, in part, is currently being prepared for submission for publication of the material.

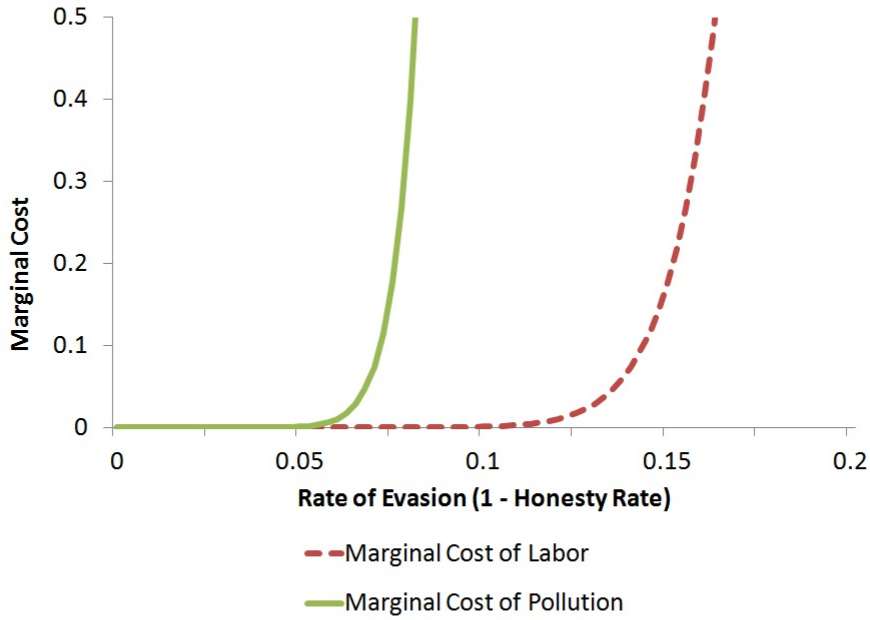

Figure 1.1: The marginal cost curves of labor tax and pollution tax evasion. Curves are calibrated to honesty rates and costs in the 2-good model.

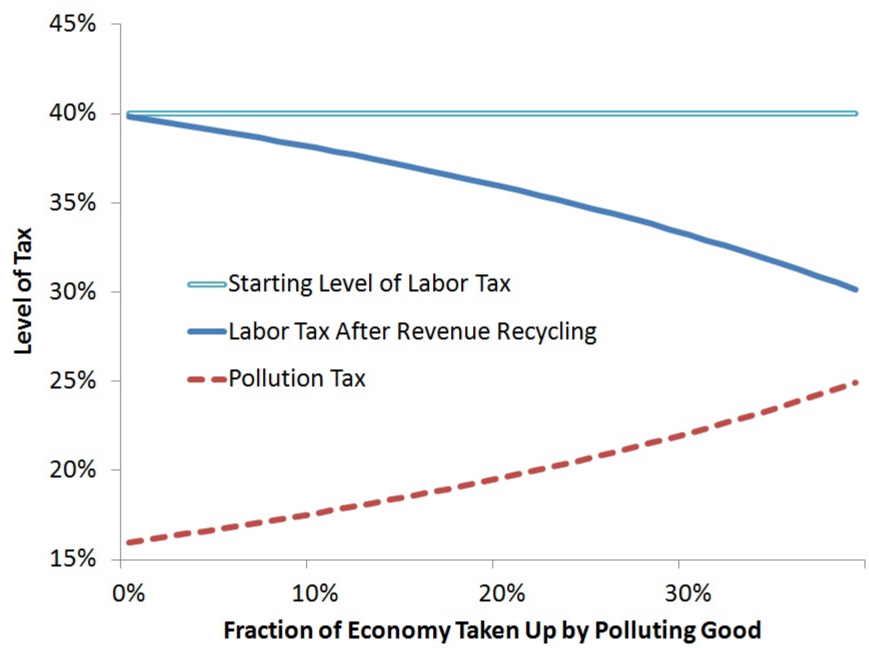

Figure 1.2: Labor tax and pollution tax rates necessary to cut emissions 10% while maintaining the same level of government spending.

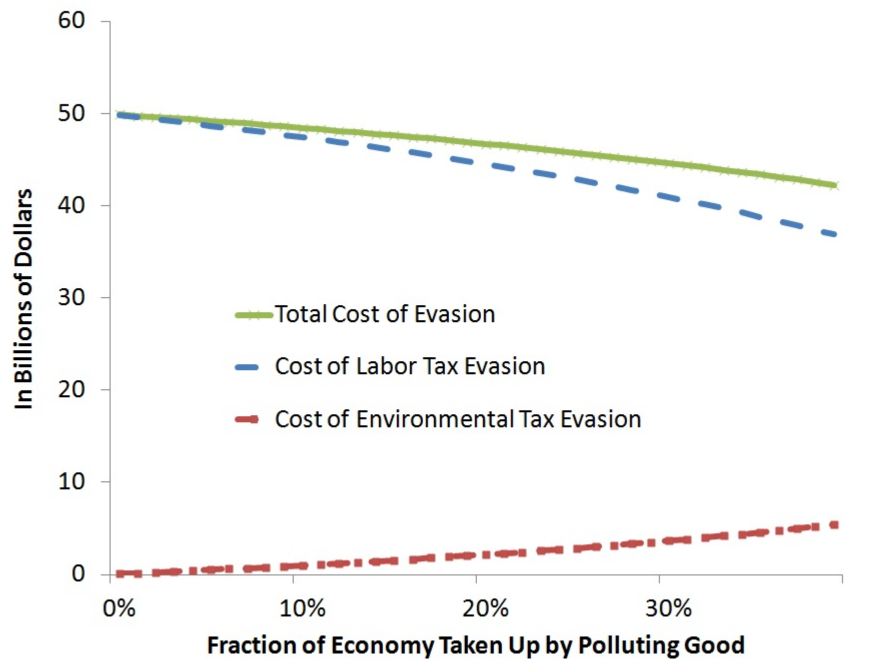

Figure 1.3: Decomposition of total costs spent on evasion after a double dividend reform.

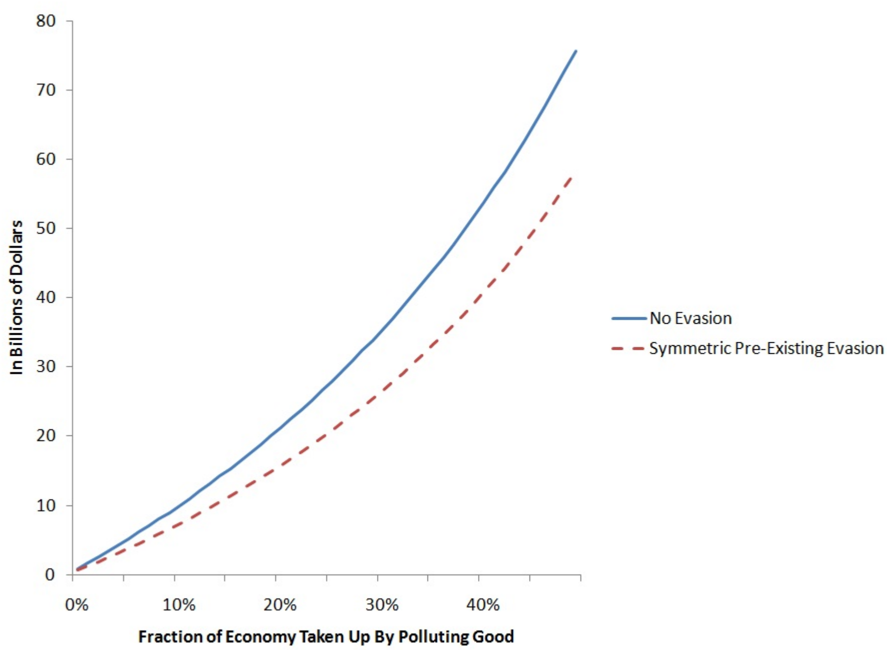

Figure 1.4: Total welfare cost of double dividend tax reform (10% cut in emissions.)

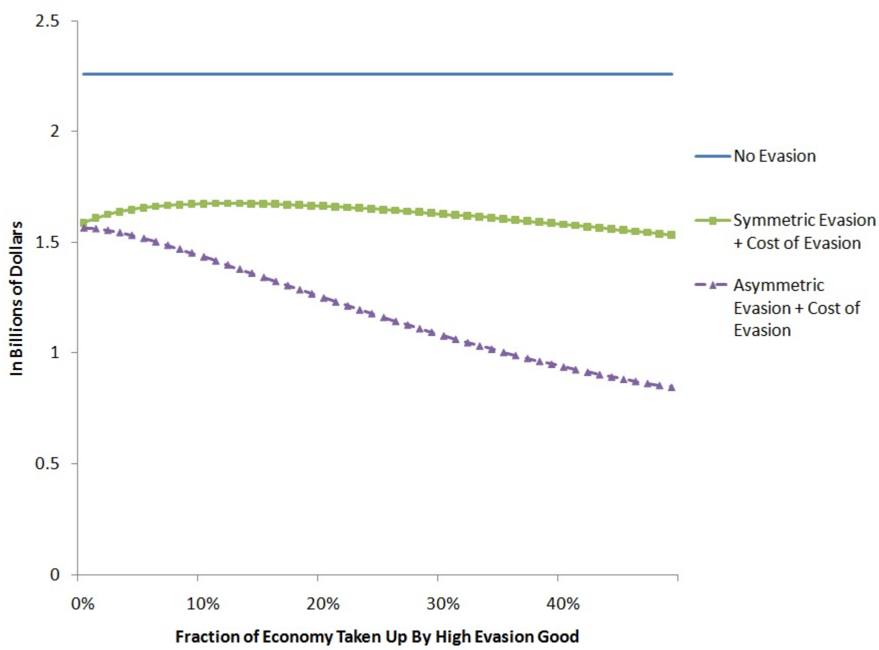

Figure 1.5: The total welfare cost of double dividend reform with a 10% cut in emissions. Two cases are presented here. The first assumes that the clean goods evade labor taxes at the same rate; the second has different levels of evasion between sectors of clean goods.

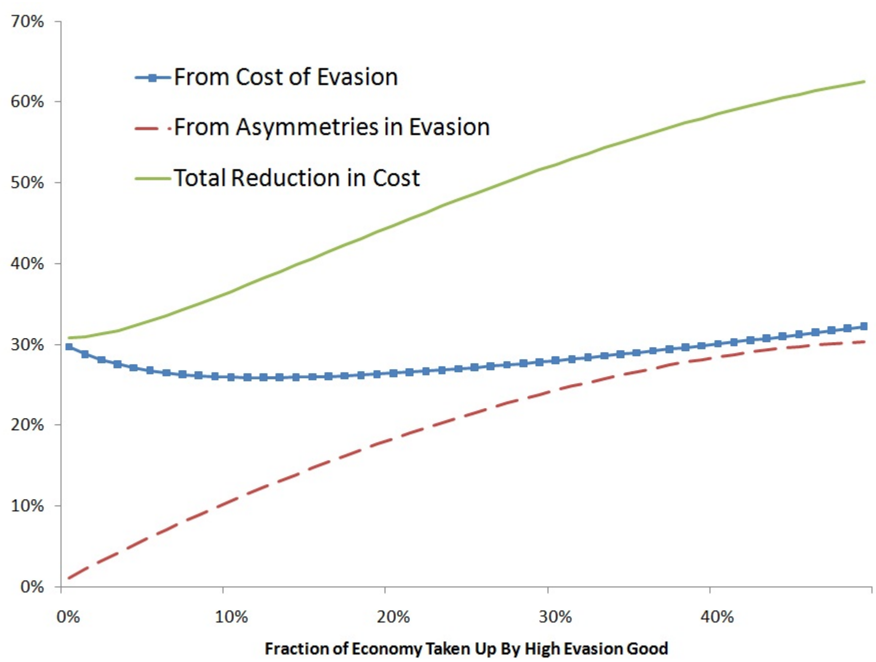

Figure 1.6: Percentage of welfare costs cut as a result of the existence of costly evasion, and as a result of the existence of asymmetric tax evasion.

Table 1.1: Calibration parameters used in international version of model.

Country	Coal	Oil	Natural Gas	Self-Employment	Tax Burden	GDP
China	114.1	127.8	25.7	48.2%	18.3%	2235.8
U.S.	36.1	370.7	280.0	7.5%	27.3%	12638.4
Russia	11.1	53.2	214.7	6.1%	34.6%	764.3
India	9.8	48.0	20.1	51.0%	18.8%	784.3
Japan	9.3	100.3	103.2	7.7%	27.4%	4552.2
Germany	19.6	50.0	51.0	5.0%	34.8%	2793.2
Canada	1.5	44.3	37.9	9.4%	33.4%	1133.8
U.K.	4.1	35.8	43.8	13.4%	36.3%	2282.9
Italy	1.3	33.4	64.7	20.9%	40.9%	1780.8
S. Korea	4.4	40.1	16.0	21.9%	28.7%	844.9
Mexico	0.8	40.4	27.1	26.4%	19.9%	849.0
S. Africa	1.8	10.2	1.2	9.2%	26.6%	242.7
France	1.6	38.3	28.0	5.6%	43.9%	2147.8
Australia	7.0	19.3	16.0	9.5%	30.8%	713.2
Spain	2.3	29.6	22.2	10.9%	35.8%	1132.1
Brazil	1.1	42.1	10.1	23.5%	35.3%	881.8
Indonesia	1.1	24.4	11.6	45.3%	11.3%	285.9
Poland	6.5	9.0	6.0	15.9%	32.9%	304.0
Thailand	1.5	17.8	16.7	31.5%	16.2%	176.4
Turkey	2.0	12.2	9.2	20.5%	24.3%	482.7
Malaysia	0.6	10.0	14.3	16.6%	15.7%	138.0
Kazakhstan	3.4	4.4	0.7	33.4%	26.7%	57.1
Egypt	0.1	11.9	18.8	12.3%	15.3%	89.8
Netherlands	0.7	18.6	31.4	12.4%	38.8%	639.6
Venezuela	0.0	11.1	14.6	28.9%	17.0%	144.1
Argentina	0.0	9.2	22.2	20.2%	24.5%	181.5
Pakistan	0.4	6.4	14.0	37.1%	10.2%	109.6

Notes: The countries are listed in descending order of carbon dioxide emissions, according to their ranking by the Millenium Development Group. See footnote 9 for countries excluded as a result of data issues. GDP is given for each country in 2005 measured in billions of US dollars, current prices. The size of each country's fossil fuel energy sectors are given in billions of dollars, current prices.

Table 1.2: Results from CGE simulations of the impact of tax evasion on the cost of double dividend reform.

Country	Cost of Reform, No Evasion	% Reduction, Cost of Evasion	% Reduction, Asymmetric Evasion	Total % Reduction from Evasion
China	1.90	72%	17%	89%
U.S.	4.95	23%	5%	28%
Russia	3.07	23%	3%	26%
India	0.54	79%	18%	97%
Japan	1.52	23%	6%	28%
Germany	0.92	24%	4%	28%
Canada	0.65	30%	8%	37%
U.K.	0.64	40%	12%	52%
Italy	0.81	63%	20%	82%
S. Korea	0.45	45%	15%	60%
Mexico	0.47	41%	13%	54%
S. Africa	0.09	24%	7%	31%
France	0.56	33%	6%	39%
Australia	0.32	28%	7%	35%
Spain	0.42	35%	10%	45%
Brazil	0.42	58%	19%	77%
Indonesia	0.25	54%	10%	64%
Poland	0.17	40%	13%	53%
Thailand	0.27	42%	10%	51%
Turkey	0.16	38%	13%	51%
Malaysia	0.18	24%	6%	30%
Kazakhstan	0.07	60%	18%	78%
Egypt	0.28	18%	3%	21%
Netherlands	0.42	41%	11%	52%
Venezuela	0.19	40%	10%	50%
Argentina	0.25	36%	10%	47%
Pakistan	0.15	41%	7%	48%

Notes: This table represents the results of 3 CGE simulations. The first column is the cost of welfare reform when emissions are cut 10% through double dividend reform when no tax evasion is possible, expressed in billions of current dollars. The second column is the reduction in welfare cost when the costs of tax evasion are considered. The third column is the additional reduction in welfare cost when the costs of tax evasion and the presence of a high evasion sector and low evasion sector are considered.

Appendix A: Welfare Effects of a Pollution Tax

This section provides derivations behind equations 1.4 and 1.20.

For the two good model of equation 1.4, the constrained maximization problem for the household is:

$$W = U\left(X, Y, l\right) - \phi\left(X\right) - \lambda\left[p_X X + p_Y Y - T + l - g\right]$$

The impact on household welfare from a marginal pollution tax is then:

$$\frac{dW}{d\tau_p} = \frac{dU}{d\tau_p} - \phi^{'}\left(X\right) - \lambda\left[\frac{dp_X}{d\tau_p}X + p_X\frac{dX}{d\tau_p} + \frac{dp_Y}{d\tau_p}Y + p_Y\frac{dY}{d\tau_p} + \frac{dl}{d\tau_p}\right]$$

After totally differentiating $\frac{dU}{d\tau_p}$ and applying the envelope conditions, we find:

$$\frac{1}{\lambda}\frac{dW}{d\tau_p} = -\frac{dp_X}{d\tau_p}X - \frac{dp_Y}{d\tau_P}Y - \frac{1}{\lambda}\phi^{'}\left(X\right) \tag{1.14}$$

Since markets are competitive and profits are zero, the unit prices of the goods are set to unit costs:

$$p_X = 1 + H_X\tau_L + H_p\tau_p + C_X\left(H_X\right) + C_p\left(H_p\right) \tag{1.15}$$

$$p_Y = 1 + H_Y\tau_L + C_Y\left(H_Y\right) \tag{1.16}$$

We take the derivatives of these functions with respect to τ_p and plug them into equation 1.14.

Next we observe that the derivative of government spending G from equation 1.3 with respect to τ_p must be 0 in the presence of a revenue-neutral tax reform. Hence,

$$-\frac{d\left(H_p\tau_p\right)}{d\tau_p}X - \frac{d\left(H_X\tau_L\right)}{d\tau_p}L_X - \frac{d\left(H_Y\tau_L\right)}{d\tau_p}L_Y = H_p\tau_p\frac{dX}{d\tau_p} + H_X\tau_L\frac{dL_X}{d\tau_p} + H_Y\tau_L\frac{dL_Y}{d\tau_p}$$

Plugging this into the result from the above work, we derive equation 1.4.

Appendix B: Full Version of the Three Goods Model

Assumptions

To make it easier for the reader to compare this model with the model from section 3.1, we follow the same organization in this section. Assumptions stated here are in addition to those in section 3.1.

Households

Now households consume three goods: X, Y, and Z. As before, X represents the polluting good, but clean goods are divided into two types that are similar but not perfectly substitutable. Labor taxes on producers of good Y are hard to evade; labor taxes on producers of good Z are easy to evade. For intuition's sake, we might think of good Y as goods produced by large corporations, while Z represents goods produced by small businesses and the self-employed.[14]

The household utility function, the household time constraint, and the household budget constraint, are all the same as in section 3.1.1 except there are now three goods.

Firms

Firms producing Z produce in the same manner as the other sectors:

$$Z = L_Z \tag{1.17}$$

Tax Evasion

Firms in sector Z evade taxes at a rate H_Z, and pay cost $C_Z(H_Z)$ per unit to evade.

In addition to assumptions 1-3 from section 3.1.2, we further assume:

[14]Self-employment has been widely linked to higher tax evasion opportunities. See, for example Engstrom and Holmlund (2006) or Torrini (2004).

4. $\frac{d(\tau_i H_i(\tau_i))}{d\tau_i} > \frac{d(\tau_j H_j(\tau_j))}{d\tau_j}$ if $H_i(\tau) > H_j(\tau)$ for all τ.

Sector Y, which pays taxes more honestly than sector Z for all tax rates, also receives the biggest adjustment in its effective tax rate when the labor tax rate is cut.

Firm Profits Firms producing Z have profits:

$$\pi_Z = \max_{L_Z, H_Z} \{p_Z Z - (1 + H_Z \tau_L) L_Z - C_Z(H_Z) L_Z\} \tag{1.18}$$

The Government

The government now receives tax revenue from all three sectors:

$$G = Ng = H_p \tau_p X + H_X \tau_L L_X + H_Y \tau_L L_Y + H_Z \tau_L L_Z \tag{1.19}$$

Welfare Effects of a Pollution Tax

The change in welfare from a double dividend style of reform is:

$$\frac{1}{\lambda}\frac{dU}{d\tau_p} = \underbrace{\left[\frac{1}{\lambda}\phi' - (H_p \tau_p)\right]\left(-\frac{dX}{d\tau_p}\right)}_{Environmental\ Effect} + \underbrace{\sum_{i=X,Y,Z} [H_i \tau_L] \frac{dL_i}{d\tau_p}}_{Tax\ Base\ Effect} - \underbrace{\frac{dC_p(H_p)}{d\tau_p} X - \sum_{i=X,Y,Z} \frac{dC_i(H_i)}{d\tau_p} L_i}_{Tax\ Evasion\ Effect} \tag{1.20}$$

The derivation of this equation is step-by-step identical to that in Appendix A with the exception that there are three goods instead of two.

For good Z, the first order condition on welfare is $U_Z = \lambda p_Z$. The price of good Z is $p_Z = 1 + H_Z \tau_L + C_Z(H_Z)$ Following the steps outlined above using the government spending constraint embodied in equation 1.19, the derivation for equation 1.20 is now straightforward.

Chapter 2

Fiscal Incentives and Infrastructure: the Case of Sewage Treatment in China

This paper provides evidence that China's system of tax revenue sharing is an important explanation for differences in the rate of sewage treatment construction among its cities. Exploiting the history and political economy of China's 1994 tax reform, we use the share of VAT retained by each city in 1995 as an instrument for its fiscal incentives. The construction of sewage treatment capacity between 2002 and 2008 is regressed on this measure of fiscal incentives. After controlling for other factors, we find that a 10 percentage point increase in the VAT sharing rate results in a 13.8% increase in the construction of sewage treatment capacity, suggesting that fiscal incentives can play an important role in the provision of pollution-reducing infrastructure.

2.1 Introduction

Sewage treatment in China is important because of its linkages with two important issues in China: water pollution and public health. Water pollution in China is extensive and serious. Scholars have documented that 54% of China's rivers are not fit for consumption, and water pollution-related damages to health alone cost China 9.47 billion yuan in 2003[1]. The ability to return treated water into the environment is important because China leans heavily on surface sources of water. Between 300 and 500 million Chinese lack access to piped water, and only 28% of rural households have access to improved sanitation[2].

Against this backdrop, China has embarked on an aggressive campaign of wastewater treatment plant construction. It invested $29 billion of public funds between 1991 and 2005[3] and $58 billion between 2006 and 2010[4]. While this has accelerated construction of sewage treatment facilities, progress between cities has been uneven[5].

Intuition would suggest that factors like population, wealth, and preferences drive the provision of sewage treatment. These explanations are significant and do seem to play an important role. The purpose of this paper is to argue that China's system of tax sharing is a potentially significant factor in explaining the different levels of provision of environmental public infrastructure.

We focus on China's system of sharing the value added tax (VAT). Some cities were able to keep the entire local share of the VAT, while others kept relatively small shares. We hypothesize that cities which received relatively high shares were incentivized to direct financial resources toward activities that directly boosted the tax base. One attractive form of investment is to build more infrastructure in the form of sewage treatment capacity. Cities in China widely believe that providing infrastructure is the best way to attract new industrial businesses and expand their tax base.

To study the impact of fiscal incentives on a long-lived, lumpy type of infrastructure such as sewage treatment, we use an empirical specification where the observable growth in sewage treatment, that occurring between 2002 and 2008, is regressed on a measure of city-level fiscal incentives. However, there are several endogeneity problems with using the most direct candidate: a city's share of VAT retained in 2001.

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[1] World Bank (2007)
[2] Vennemo et al (2009)
[3] Browder (2007)
[4] Lee (2009)
[5] See figure 2.1.

For example, provinces had the right to change or re-assign city tax shares. If a city had a budget surplus, its VAT share might be decreased. If a city had a change of leadership, that leader might plausibly negotiate a larger VAT share, or a smaller decrease in share than would otherwise be expected. While most cities had fixed VAT shares, many had shares that moved up-and-down each year[6].

As a result, we employ an instrumental variables strategy where we use the share of VAT retained in 1995 to proxy for a city's fiscal incentives. The use of this instrument restricts the number of endogenous pathways which can affect both VAT share and the construction of sewage treatment facilities to one: the method by which provinces initially assigned fiscal incentives.

The historical origins of China's current tax system suggest that this instrument is both relevant and valid. China's 1994 tax reform installed an entirely new structure for the VAT, but did not address how revenues should be allocated to cities. The authority to allocate fiscal incentives was given to provinces, and each province installed its own system of allocating pools of VAT revenue. Provincial tax-sharing systems installed in 1994 have persisted until the time period of our sewage data.

We provide evidence in this paper that cities react to higher sharing ratios by expanding their sewage treatment capacity. Under our central specification, a 10 percentage point increase in the 1995 VAT sharing ratio (i.e. from 60% to 70%) resulted in 13.8% more growth in sewage treatment facilities during the 2002-2008 period for which sewage treatment outcomes are observable. Since fiscal incentives are the result of provincial decisions exogenous to cities, we believe that city managers reacted to their incentives by investing more in sewage treatment infrastructure.

We closely study the the methods by which provincial authorities assigned fiscal incentives, and control for the most likely avenues through a number of robustness checks. We look at which provinces chose to pass through all revenues and which chose to withhold revenues. We study the empirical patterns by which provinces initially deployed fiscal incentives for cities within their domain, and find

[6]See figure 2.4.

that the most important explanation is "equalization," where poorer cities received higher shares of VAT revenues. We investigate the possibility that negotiation or favoritism were likely to affect the VAT sharing ratio in a manner significant to the growth of sewage treatment capacity.

Our results are consistent over a wide set of sensible covariates. A number of alternative explanations are ruled out through tests demonstrating how these results hold for subgroupings of cities in China, such as provincial capitals and coastal cities. Finally, we show that transfer payments, which should be independent of fiscal incentives, are uncorrelated with VAT sharing ratios.

China's disaggregated economic system, termed "market-preserving federalism," has been credited with helping to explain its economic success (Montinola et. al 1995, Qian and Weingast 1996). Province-level and city-level governments in China have the primary authority for implementing economic policy within their domains.

Other papers have used different contexts to connect local fiscal incentives and spending on public goods. Zhuravskaya (2000) argued that local governments with low fiscal incentives have no incentives to increase the tax base or provide public goods. After showing that some cities in Russia must share almost all additional revenues they generate, she connected the absence of fiscal incentives among these cities with inefficient public service provision, in the forms of higher infant mortality and decreased availability of regular schooling. Jin, Qian, and Weingast (2005) tied fiscal incentives to government performance in China at the provincial level, showing how provinces with higher marginal revenue retention rates develop the private sector more and encourage incentive-based compensation.

This strand of literature is most related to the "second generation" branch of fiscal federalism (Oates 2005). Rather than presenting local officials as benign decision makers focused entirely on social welfare, this strain of literature models them as revenue-maximizing opportunists who channel effort into functions which reap financial reward. The possible inefficiencies in decentralized government were derived analytically by Gordon (1983), in an elegant optimal tax model of fiscal federalism.

This paper offers several contributions to this strand of literature. First, we explore econometrically the drivers of an important policy topic. Water pollution in China affects hundreds of millions of people; sewage treatment must be a key part of any wide-scale water treatment plan. Second, very few economics papers have focused on the behavior of political entities at the city level in China. We provide a new method of observing city-level fiscal incentives, and tie these incentives to city-level outcomes.

This paper is organized as follows. Section 2 lays out the history of the 1994 tax reform in China and discusses the history and political economy of VAT sharing. The importance of sewage treatment is also discussed. Section 3 describes the data. Section 4 explains the measure of fiscal incentives used, and describes the empirical methodology and identification strategy of the paper. Section 5 contains empirical results. Section 6 discusses the significance of our findings to environmental policy in China.

2.2 Institutional Background

2.2.1 Federalism and the Tax System in China

2.2.1.1 The 1994 Tax Reform

The 1994 Tax Reform represented a watershed change of China's fiscal system. It was aimed at three goals (World Bank 2002). First, it was intended to reverse a longstanding downward trend of central government revenues. Second, it was intended to reduce the distortionary elements of the existing tax structure. Third, it was intended to move China away from a system where negotiation played an important role in central and local government relations, and move it toward a fixed, stable, and transparent tax system.

To accomplish its first goal, it sharply changed the tax administration system. Rather than relying on local tax authorities to collect taxes and share them with the central government, the 1994 reform gave tax collection responsibilities of central taxes and shared taxes to the central government. From that point forward, the central government controlled revenues and shared them downwards, rather than relying on upwards sharing from local governments.

To accomplish its second goal, the tax reform replaced the prior turnover tax system, which consisted of as many as 37 overlapping and contradictory taxes and applied different rates to different products (Ma 1997). The new system applied the Value-Added Tax (VAT) to a much broader tax base, and set a uniform rate of 17%. It set a turnover tax on services of between 3% and 5%. Finally, it set new corporate income tax rates and personal income tax rates while eliminating many forms of special treatment, like lower rates for foreign enterprises and individuals.

To accomplish its third goal, it codified a new system of tax sharing which applied a uniform set of rules to local governments. In the previous system, provinces held one of six forms of revenue-sharing contracts (Agarwala 1992), which resulted in sharply different marginal revenue retention rates. After the reform, each tax was designated as either a central tax, a shared tax, or a local tax, depending on who would receive revenues from that tax. Shared taxes had fixed, statutory sharing rules set between the central government and provincial governments. The VAT, designated a shared tax, was split with 75% of VAT revenues accruing to the central government and 25% to the province in which revenues were generated.

2.2.1.2 The VAT Share as a Measure of Fiscal Incentives

The VAT is the tax at the center of our analysis. The VAT is the most important tax in China in terms of revenue collected, accounting for over 40% of all central government tax revenues. This paper focuses on how fiscal incentives led cities to attract industry through building sewage treatment.

Among the streams of revenues received by cities, there are other options which might be potential candidates for our study. For example, cities receive annual rebates from higher levels of government. The amount of these rebates is determined through a formula which grows a base amount according to the combined growth rates of the VAT and the consumption tax (Shah Shen 2006). The consumption tax in China is a turnover tax, paid by consumers, and is focused on particular types of goods such as tobacco, alcohol, and fireworks. In the formula determining these rebates, the year-over-year growth rates of VAT and of the consumption tax are mixed, making it difficult to extract meaningful information about city incentives.

Another possible candidate might be the corporate income tax, which is also shared between the levels of Chinese government hierarchy. However, the corporate income tax is levied on all corporations, including firms in the services and agricultural industries that would not be attracted to sewage treatment infrastructure. Hence, this paper focuses on the VAT, the only tax focused on firms in the industrial sector[7], as the most appropriate subject for our study. The VAT is also attractive because the data give clean measures which allow direct observation of VAT sharing rates.

2.2.1.3 VAT Sharing Between Provinces and Cities

The 1994 Tax Reform, while eliminating many avenues of negotiation between the central government and the provinces, did not specify patterns of tax sharing between provinces and cities. Provinces decided on the allocation of revenues among its subordinate units. Since the central government did not require submission of final accounts for individual local governments (Bahl 1999), provinces had largely unchecked discretion in determining the distribution of revenue between layers of government. The local governments' right to appeal its tax sharing agreement was limited only to egregious cases (World Bank 2002).

Although the central government took the same, fixed 75% share out of each province's VAT collections, provinces were able to determine themselves how to apportion the remaining 25%. As a result, a variety of systems proliferated.

An example will facilitate understanding of these systems. Suppose a firm within the city of Zunyi, in the province of Guizhou, pays 100 RMB of VAT. The central government collects this tax and keeps 75 RMB. It passes 25 RMB to Guizhou, the province where Zunyi is located. Guizhou has an agreement with Zunyi where Zunyi retains 60% of VAT revenues generated in its domain. Hence,

[7]The "business tax" is a turnover tax, levied only on services firms.

out of the 100 RMB in tax revenue that was initially collected from Zunyi, Zunyi keeps 15%.

Although the city share of its VAT could seem small, that share is important to the city. Each city's share of VAT revenues represent an important component of their budget. On median, cities derived 15.9% of their total tax base from their share of VAT, and 7.5% of total spending in 2001. For many cities, VAT is the biggest single source of tax revenue.

Table 2.1 illustrates how VAT were actually shared between provinces and cities in 1995 and in 2001[8]. We draw two conclusions from this table. First, it is clear that provinces make decisions on VAT sharing rates. All cities within a province follow the same basic pattern. 16 province-level entities, representing 145 of the 285 cities in our public finance dataset, chose to pass through 100% of local VAT revenues to their cities. The other provinces chose to pass through some smaller share of revenues. For most of the cities in this dataset, their sharing rates were fixed with no regard to factors such as their role within the government hierarchy or the ability of city managers to negotiate.

The second conclusion that can be drawn is that each province's system of VAT sharing in 2001 remained basically constant with the system of sharing established in 1995. At the time of the 1994 reform, each province selected a system of VAT sharing for all cities in their domain. Once a province decided on a method, it generally retained that method through the relevant time period of our analysis.

Nine of the thirty-one provinces examined here passed less than 100% of VAT revenues, and did so in a manner which assigned different VAT sharing rates to different cities. Among these provinces, the VAT share retained by cities often fluctuates between 1995 and 2001. However, the VAT rate was restricted to the

[8]For much of our analysis, we use the 1995 VAT sharing rate, although the tax reform in China was initiated in 1994. Wong (1997) writes that the 1994 tax reform was implemented only a few months after it was approved. She documents that neither taxpayers nor local tax officials were "prepared" for the transition. Moreover, through 1994, cities and counties were in doubt as to whether the rules of the contract system (the pre-1994 system) would govern the new tax sharing system.

We conclude from this reading that 1994 VAT sharing rates may be unreliable, since they involved a period of transition and, at best, reflect a system in place for only part of the year.

domain of possibilities allowed by the province. These data suggest that provinces changed some city rates in the middle of this time period. Data in these provinces are marked by a period of steady VAT shares, a sudden decline or rise, followed finally by another steady period of VAT shares.

However, for many cities, the VAT shares they receive between 1995 and 2001 seem almost random. For these cities, it is possible that VAT sharing contracts take a different form than a fixed percentage type of contract. For example, Bahl (1999), who documents a few case studies of revenue-sharing agreements between provinces and cities, found a complex system of sharing between Beijing and its subordinate districts. Beijing receives 25% of initial collections of its districts, where initial collections are defined according to a base year. It then divides incremental revenues (those beyond the base-year level) in an entirely different fashion, splitting a portion with both the central government, the districts, and the city itself. For sharing arrangements like that of Beijing, the VAT sharing data are unlikely to reveal a consistent share.

Why did different provinces decide on different patterns of VAT sharing? Bahl (1999), p. 150, writes:

> With so much discretion, it is not surprising that provincial governments have developed many different systems of revenue sharing. Some provinces seem to stress equalization, others seem to promote regions with greater economic development potential, others seem to emphasize incentives for resource mobilization, and in a few instances, the division of revenues seems almost random.

In summary, VAT sharing systems were determined immediately after the 1994 tax reform. Provinces made decisions on the VAT shares of cities in their domain. They made decisions individually, each selecting a different set of reasons. The VAT sharing systems set up in 1994 were strongly related to the shares eventually observed in 2001, the beginning of the period where we can observe cities building up their sewage treatment.

Our identification strategy depends importantly on the historical basis and political economy of city revenue sharing agreements. Our hypothesis is that, as a consequence of early provincial decisions, cities had strongly different incentives to provide sewage treatment infrastructure, helping to explain the patterns of sewage treatment in evidence today.

2.2.2 Sewage Treatment in China

2.2.2.1 Central Government Policy on Sewage

The Chinese central government established the "three synchronizations policy" (*san tongshi zhengce*) in the 1989 PRC Environmental Protection Law. This policy is described in detail in Ma and Ortolano (2000). Under this policy, the design, construction and operation of a new factory or other industrial facility must be accompanied by the design, construction, and operation of appropriate waste treatment facilities. The official data suggest that this policy was followed: the industrial sewage treatment rate was 92.9% in 2006 (China Environment Yearbook 2007).

Sewage treatment is funded in part out of a set of fees included in the price of water. The level of the water consumption fee varies with each city. One of the fees within the water consumption fee is split between the operation of wastewater treatment facilities and the construction of new wastewater treatment plants. This fee is collected by government billing agencies and distributed to wastewater treatment plant operators.

The price of water is considered a sensitive political subject in China. Cities cannot arbitrarily raise the price of water to fund the construction of new sewage treatment plants; price rises in cities are usually carefully coordinated with the central government and phased in over an extended period of time.

2.2.2.2 Local Government Implementation of Sewage Treatment

Local governments have widely adopted the strategy of building sewage treatment facilities to attract industry. One saying, "*qitong yiping*", states that, in order to attract investment, local governments must build seven forms of infrastructure: electricity, roads, water, telecommunications, cable, leveled ground, and waste treatment.

Companies considering a choice of location know that, under the three synchronizations policy, they must provide a means of treating their wastewater when they build new industrial facilities. However, instead of constructing their own sewage treatment plants, they can take advantage of city-provided sewage treatment plants, providing the benefit of economies of scale and lower costs.

The central government and the provincial governments also have the ability to earmark funds for the construction of sewage treatment plants. More generally, the assignment of responsibilities to different levels of government is vague in China (World Bank 2002). Shah and Shen (2006) analyzed earmarks and found that they are generally regressive; more earmarks are dedicated to richer and more populated areas.

Sewage treatment facilities operated at near-capacity in most cities during the entire period of our sample, 2002-2008. This period represented a building-out stage for sewage treatment facilities; all plants, once built, had demonstrated demand in place.

A second form of local government incentives to build sewage treatment plants is to prevent environmental disasters for which they can be blamed. When the media reports widely on an environmental disaster, government officials in charge of the environment, such as the head of the local environmental protection agency, can be disciplined or fired.

2.3 Description of Data

Our sewage panel is comprised of 111 cities for the period 2002-2008. These cities and years are the sample of sewage treatment outcomes published by the China Environment Yearbooks, a joint publication of the Chinese National Bureau of Statistics and the State Environmental Protection Agency. In general, the CEY report only large cities and "important" cities such as provincial capitals, a subset of all cities in China as reported in the China City Statistical Yearbook. Hence, the results of this study apply only to major cities, all those for which sewage data are reported.

Figure 2.1 plots populations and sewage treatment capacity per capita in 2007. There are clear differences in both the sizes and treatment levels of the different types of cities. Municipalities are the clearest outliers; Shanghai, Beijing, and Chongqing have far higher populations than other cities. Shenzhen and Xiamen have very high sewage treatment capacity per capita, although their actual treatment capacity is not out of line with other cities.

City public finance revenues are compiled from the Sub-Provincial Public Finance Statistics (*Quanguo Dishixian Caizheng Tongji Ziliao*), an annual publication of China's Ministry of Finance. These publications contain detailed statistics of city tax revenues, transfers, and expenditures.

Figures 2.2 and 2.3 illustrate the geographic distributions of fiscal incentives and sewage treatment capacity growth during our time period. As described earlier, fiscal incentives are strongly correlated within a province. with high fiscal incentives apparently concentrated along the eastern and southern coasts, and in the middle of the country. Sewage treatment growth appears to be more concentrated in the east, and along the major Yellow river and Yangtze river systems.

Other city-level characteristics such as the industrial output, population, and tax revenue are obtained from the China City Statistical Yearbooks, another official publication of the Chinese government. Summary statistics of key variables are presented in table 2.2.

2.4 Methodology

2.4.1 Empirical Specification

In appendix A, we lay out a brief model of the choice of public spending under a system of revenue sharing. The intuition behind this model is that cities with higher shares of revenue retained have higher marginal benefit from directing funds towards activities generating more taxes. As a result, they expand infrastructure more relative to cities with low fiscal incentives.

Our base empirical specification for this model is:

$$log\,(y_{i,2008} - y_{i,2002}) = \beta_1 FI_i + \beta_2 x_{i,2001} + \epsilon_i \tag{2.1}$$

Here, the term $y_{i,2008} - y_{i,2002}$ is the growth in sewage treatment capacity over our sample period for city i. We use the difference between the years 2008 and 2002 as the entire period where sewage treatment data are available. Over this period, total sewage treatment capacity increased more than 200%. $x_{i,2001}$ represents a vector of control variables for city i in the year 2001, obtained from the China City Statistical Yearbooks.

We think that using a cross-section empirical specification involving the growth in sewage treatment capacity is appropriate for several reasons. First, sewage treatment facilities are long-lived; sewage plants may have been built for other reasons outside the years which our data cover. We have data that provides details of some sewage plants. Some of these plants were built before the 1994 fiscal reform, implying that they could not be affected by city fiscal incentives. Second, investment in sewage treatment is lumpy. In some cities, constructing even one plant can double or triple a city's treatment capacity. Hence, measuring the change in facilities over a period of time is appropriate. Third, sewage treatment facilities are strongly serially correlated across time. The use of a panel dataset rather than a cross-section would tend to underestimate standard errors. Finally, for 60% of cities, their fiscal incentives are virtually constant over the entire period we can observe. Using a panel dataset rather than a cross-section would eliminate the use of these cities.

Our hypothesis is that fiscal incentives are positively related to measures of public spending which expand the city tax base, including sewage treatment infrastructure:β_1 is positive and significant. In addition, fiscal incentives are unrelated to forms of public spending which do not expand public infrastructure, such as transfers.

FI_i is city i's share of VAT retained. The Sub-provincial Public Finance Statistics reports the amount of VAT retained by the city (*gongshang shuishou zengzhishui*) and the figure representing 75% of all VAT collected, which is turned over to the central government (*yiban yusuanshouru zongji zengzhishui* 75%). We can therefore compute the city share of local VAT taxes as:

$$FI_i = \frac{VAT\ Retained_i}{Central\ Government\ Share_i/3} \tag{2.2}$$

Cities which retain 25% of VAT generated, the entire local share, will have $FI_i = 1$; cities which retain none of its VAT will have $FI_i = 0$. We test our hypothesis for city fiscal incentives in the year 2001 and the average incentive in the years 2001-2003. In our instrumental variables approach, to be discussed in the following section, we use a city's VAT share in 1995.

2.4.2 Identification Strategy

Our identification strategy relies on the history and political economy of China's system of prefecture-level fiscal incentives. Between the time a city's VAT share was established, after the 1994 reform, and the time that the city was making visible decisions to build sewage treatment, in 2002, many endogenous circumstances could have caused provinces to adjust a city's VAT share.

We use a city's 1995 VAT share as an instrument for its 2001 VAT share. This restricts the endogeneity in determination of VAT share only to the set of reasons by which provinces decided to initially allocate VAT shares in 1994. Provinces adopted a variety of systems, with some provinces designating a complete pass-through while other provinces decided to keep much of revenues generated.

While a city's share of VAT retained may have changed between 1994 and 2001, the data suggest that the system of assigning incentives remained essentially constant (See table 2.1.) A city's VAT share in 1995 is *relevant* because provincial systems remained constant over our sample period. We examine the *validity* of our instrument in section 5.2, where we analyze why cities chose 1995 VAT shares and whether they were chosen in a manner independent from sewage treatment capacity.

2.4.3 Potential Threats to Identification

2.4.3.1 Equalization and the Mobilization of Economic Development

The primary threat to identification is whether the method by which provinces allocated fiscal incentives is correlated with their sewage treatment. As recounted in section 2.1.3, Bahl (1999) states that provinces did not give out fiscal incentives randomly, but instead had underlying motives. Some provinces stressed equalization (giving higher control of revenues to poorer cities), while others stressed the mobilization of economic development potential (giving higher control of revenues to richer cities).

To test the contrasting hypotheses of equalization and economic mobilization, we analyze the patterns of distributing fiscal incentives. While individual provinces may have had a plan for individual cities in their domain, the most important fact for the purposes of this study is what evidence can be found about fiscal incentives among cities in China as a whole. We then test whether the patterns that can be observed would be likely to influence the development of sewage treatment.

In addition, we utilize China's unique pattern of development, which emphasized the development of some areas, such as coastal cities, over inland cities. These types of cities, which are more similar, are likely be benefited or harmed in the same way by equalization or mobilization. We examine whether the impacts of fiscal incentives can be seen within these subgroups of cities.

2.4.3.2 Negotiation and Favoritism

One possible consideration is whether cities were able to negotiate their fiscal shares. If a city had an unobservable characteristic, such as a more competent city manager, it might be able to negotiate a higher fiscal share. Simultaneously, this competence would allow them to build higher amounts of sewage treatment. Closely related to this is the concern that some cities are favored by being targeted for development over others. They would then receive both higher fiscal shares and higher development of sewage treatment in the form of infrastructure earmarks.

We address this concern through our study of who tends to get higher levels of VAT shares. What patterns of negotiation or favoritism can be observed from the data? Do VAT shares look like they were negotiated or more like they were assigned?

2.4.3.3 Other Forms of Fiscal Incentives

The VAT share is just one part of a broader revenue-sharing arrangement between provinces and cities. If other parts of these contracts, such as corporate income tax sharing, or transfers, are correlated, these could also drive city incentives to build infrastructure.

To address this concern, we argue that other parts of revenue-sharing agreements between provinces and cities are less likely to serve as incentives to build sewage treatment. Other taxes, like the corporate income tax or the business sales tax, include in large part non-industrial sectors that are unlikely to be interested in sewage treatment. Transfers between provinces and cities are tied to both the growth rate of VAT and of the consumption tax, making the marginal incentive to grow the industrial base unclear.

2.4.3.4 Province-Level Variation in Needs

Since the VAT share is driven strongly by province-level choices, do more needy provinces keep higher shares of VAT revenues for themselves? These poorer and more needy provinces would then be unable or unwilling to supply sewage treatment infrastructure.

To address this concern, we looked closely at which provinces allowed their cities high levels of fiscal incentives, and which provinces kept high shares for themselves. We examined the possibility that the motive driving provinces to assign low VAT shares was based on their own needs.

2.5 Evidence and Results

2.5.1 Description of Fiscal Incentives

Our measure of fiscal incentives is the share of local VAT revenues retained by the city. We use equation 2.2 to calculate the sharing rate for each city in each year. Figure 2.4 shows the raw data, limiting the sample of cities to the 111 for which sewage treatment outcomes are available.

Significant variation between cities exists. Most cities retain between 50% and 100% of local VAT revenues, with a concentration of cities at 100%. A very small number of cities have VAT sharing ratios in individual years above 1. We do not understand why cities would be able to retain more than the local share of VAT. It is possible that temporary special deals were negotiated with the government; alternatively, data entry errors are known to be present in China's official yearbooks. Since over 99% of these data show a sharing ratio at or below 1, the VAT shares data appear to reflect our expectations well.

Figure 2.5 graphs the relationship between population and fiscal incentive by province[9]. This graph suggests that province-level variation is not a particular driver of our results. We would be concerned if any one province had both particularly low fiscal incentives and low growth in sewage treatment capacity, indicating that it was an outlier. However, a variety of provinces have cities that are low in fiscal incentives and low in sewage treatment.

2.5.2 The Assignment of Fiscal Incentives

We are most concerned about the methods by which provinces assigned fiscal incentives to cities as a result of the 1994 tax reform. Our strategy is to identify these methods and then to account for them in our instrumental variables

[9]There are 4 Directly Controlled Municipalities (DCM): Beijing, Shanghai, Chongqing, and Tianjin. These cities have been given province-level tax and political authority. DCM do not have fiscal incentive ratios at 1 as would be expected since they do not belong to a province.

We believe that DCM use a different method to report budgetary statistics to the Sub-provincial Finance Statistics than other cities. Data from the China City Statistical Yearbook of 2002 match the budgetary information provided in the Sub-provincial Finance Statistics of 2002 for all cities except DCM.

regressions. The possible methods can be classified into two broad areas. The first is whether the provinces which assigned complete pass-through differed systematically from those which required sharing from their cities. The second is whether the assignment of fiscal incentives within provinces was endogenous in some way to sewage treatment infrastructure.

We tested for endogeneity using the Durban-Wu-Hausman test. Neither VAT sharing ratios in 1995 nor those in 2001 show endogeneity under this test.

We studied the methods by which provinces chose their method of assignment. Table 2.3 divides the provinces by whether they allowed a 100% pass through of VAT revenues and illustrates their key characteristics. This table excludes direct-controlled municipalities. We see in this table that provinces which allowed high fiscal incentives are moderately more populous, richer, and have higher spending overall.

However, these means mask the high level of variation within each category. For each set of provinces, there are some provinces which are relatively rich and populous, and some which are poorer and smaller. This helps alleviate the fourth of our threats to identification: that poorer provinces kept higher shares of VAT for themselves and also did not fund sewage treatment.

With the possible exception of the VAT dependence variable, the two groups cannot be distinguished with any significant level of statistical confidence, as reflected by the P-values in the righthand column of this table. Regressions support these general findings, as shown in table 2.4. The only variable that is statistically significant in some functional forms is the VAT dependence variable. In provinces which were more dependent on industrial productivity for their taxes, lower shares of VAT revenue were assigned to cities in their domain.

A second area of concern is the methods by which each province assigns fiscal incentives to its cities. We studied within-province variation in the assignment of VAT shares to cities by using a city-level regression which includes province-level fixed effects. These regressions are presented in table 2.5. These regressions support the hypothesis that "equalization," rather than "economic mobilization," seemed to play a role in within-province assignment of VAT shares; poorer cities receive higher shares of VAT.

These findings are contrary to the second of our threats to identification: that negotiation and favoritism played a significant role. For the large number of cities located in provinces which assigned constant fiscal incentives to all cities in their domain, negotiation and favoritism cannot possibly play a role. For the cities that offered heterogenous fiscal incentives, cities that were poorer tended to receive higher fiscal incentives, rather than cities which are richer. This finding suggests that VAT shares were assigned as part of a provincial plan to provide more financial resources to less well-off cities, rather than well-off cities being able to negotiate good deals for themselves.

To account for possibility that equalization played an important role in both the assignment of fiscal incentives and the growth of sewage treatment, we include variables controlling for the different starting positions of cities: their wealth, their initial existing levels of industrial activity, their initial level of sewage treatment, and their spending levels.

2.5.3 Results on the Relationship Between Fiscal Incentives and Sewage Treatment Capacity

Ordinary least-squares regressions of the impact of fiscal incentives in 2001 on sewage treatment capacity are presented in table 2.8. We see that fiscal incentives have a significant and positive impact on the development of sewage treatment infrastructure over the 2002-2008 period.

Our instrumental variables specification requires the inclusion of variables that might influence both our instrument, the share of VAT retained by the city in 1995, and the dependent variable of growth in sewage treatment capacity. Since we found that dependence on VAT influences the assignment of fiscal incentives, we include that variable. Since we would like to assure ourselves that the equalization motive of provinces does not drive our results, we include the initial level of sewage treatment capacity, a city's ability to spend as defined by total expenditures divided by GDP, and each city's absolute level of expenses. To address the possibility that sewage treatment fees are tied to both fiscal incentives and sewage treatment capacity, we include each city's water consumption per capita[10].

First-stage regression results of fiscal incentives in 2001 and fiscal incentives in 1995 are displayed in table 2.6. The large f-statistic in column 1 suggests that fiscal incentives in 1995 are not a weak instrument.

We display the relationship between fiscal incentives and growth in sewage treatment capacity in figure 2.6. There are no obvious outliers overall. Results from our instrumental variables regressions of equation 2.1 are presented in table 2.7. We find a positive relationship of the effect of fiscal incentives on sewage treatment construction for all samples of cities tested. For the full sample, in columns 1-3 a statistically significant result at the 10% confidence interval is found.

Our preferred specification is presented in column 3. In this specification, we use the extended set of covariates as discussed in section 4.2, and exclude province-level municipalities, which have different properties than other cities. Our central estimate suggests that a 10 percentage point increase in a city's share of VAT retained (e.g. from 0.6 to 0.7) resulted in an increase in sewage treatment capacity of 13.8% over the sample period.

The ideal natural experiment would be to have two identical bins of cities separated only by their exogenously-imparted fiscal incentives. By placing cities within subgroups and then controlling for important differentiating factors like population and wealth, we attempt to econometrically construct these bins. Cities within the same bin are likely to experience similar degrees of favoritism, isolating the impact of fiscal incentives.

Depending on the subsample of cities chosen, a 10% higher fiscal incentive results in a similar percentage growth in sewage treatment capacity. With smaller numbers of cities, the results are naturally more noisy. Since our regressions control for the level of city expenses, the positive relationship between fiscal incentives and sewage treatment capacity suggests that, even among cities with the same financial capacities, fiscal incentives promote the construction of sewage treatment capacity.

[10]Sewage treatment fees are collected as a portion of the water consumption fee. These fees fund the construction and operation of treatment plants. Sewage treatment fees are widely regarded as inadequate to pay for the operating costs of sewage treatment. They fall far short of paying for the construction of sewage treatment plants. (Lee 2009)

2.5.3.1 Other Significant Covariates

All control variables in table 2.8 are the level of that variable in 2001. As expected, cities that were larger in population and richer also grew their sewage treatment capacity more. These cities may have higher needs for wastewater treatment and greater ability to build infrastructure.

Also, the initial level of sewage treatment capacity provided in 2002 appeared to negatively related to growth over the time period examined. As noted before, sewage treatment investment is lumpy, with some cities constructing only 1 or 2 plants. Having high capacity at the beginning of the sample may indicate some slack in capacity, with relatively less need required in the future.

2.5.4 Results on the Relationship Between Fiscal Incentives and Transfers

Our regressions using transfer payments of cities act as a placebo test, ensuring that our methods do not produce a false positive result against forms of spending that should be unrelated to fiscal incentives. Since spending on transfers is generally a function of underlying demographic characteristics, cities can exercise only limited discretionary control. Moreover, increases in spending on transfers do not build the tax base. We expected a null result.

Our testing, displayed in table 2.9, shows a moderately positive relationship between fiscal incentives and spending on education and science. It finds statistically insignificant relationships for spending on pensions. It finds a statistically negative relationship between spending on social security and fiscal incentives. Most tests actually have a moderately negative result for these coefficients.

These results suggest that the relationships between spending and fiscal incentives that we have found are not purely income effects caused by increased levels of spending. Cities appear to substitute between different types of spending as their incentives go up. They spend more on types of spending that may be attractive to expanding their tax base, like infrastructure and education, and less on types of spending that have no impact on tax base, like transfers.

2.6 Conclusion

China's need for a systematic water treatment plan is enormous and growing. China has over 300 cities with more than 1 million people; its industry shows no signs of slowing down. Sewage treatment plants must play a key role in any coordinated response to these needs.

This paper has demonstrated that cities in China respond to higher fiscal incentives by building more sewage treatment infrastructure. This suggests that financial incentives might be part of the solution to pressing water pollution treatment issues. While city-level fiscal incentives are too broad a weapon to levy at these problems, targeted financial incentives might be provided to cities in key geographic areas, such as those upstream from large populations, or to cities sharing a common-pool water resource.

More broadly, China has seen an increasing devolution of expenditures to local authorities, coupled with an increasing centralization of revenues to the central government. If fiscal incentives are an important driver of local government behavior, decreasing the local share of revenues may have significant unintended consequences. Since, on the margin, local governments will participate less in the gains of their investments, they may choose to invest less of their scarce resources in important infrastructure projects.

Acknowledgements

Chapter 2, in part, is currently being prepared for submission for publication of the material. Zhang, Junjie. The dissertation author was the primary investigator and author of this material.

Appendix A: A Model of Revenue Sharing and Infrastructure

We use a simple model similar to that of Zhuravskaya (2000) to demonstrate our points.

Consider a city manager deciding where to spend public funds. Spending on public infrastructure, S, expands the tax revenues of the city according to the function $g(S)$; the city retaining only a share α of these revenues. It also increases city welfare by aS, where a is an exogenous constant. The cost of purchasing and operating the public infrastructure is a convex function $I(S)$.

Cities can also choose to spend public funds through other means, such as transfers. Transferring an amount E provides non-financial benefits to the city E.

The city manager's problem is then:

$$\max_{S,E} aS + E \; s.t. \; I(S) + E \leq \alpha g(S) \quad (2.3)$$

We prove that $\frac{dS^*}{d\alpha} > 0$ using the following assumptions:

1. $I(S) > 0$, $I'(S) > 0$, $I''(S) > 0$

2. $g'(S) > 0$, $g''(S) < 0$

Proofs: The first-order condition with respect to S yields:

$$a + \alpha g'(S) = I'(S)$$

Differentiating this equation with respect to α, we find $g'(S) + \alpha g''(S) \frac{dS}{d\alpha} = I'(S) \frac{dS}{d\alpha}$.

Solving for $\frac{dS}{d\alpha}$:

$$\frac{dS}{d\alpha} = \frac{g'(S)}{-\alpha g''(S) + I'(S)}$$

Under assumptions 1 and 2 above, $\frac{dS}{d\alpha} > 0$.$\square$

The city manager receives a positive net benefit from spending on E. Any funds that are not spent on S are spent on E. However, the change in the amount of funds spent on E as a result of changes in fiscal incentives α is ambiguous. On one hand, a higher sharing increases the financial resources of the city $\alpha g(S)$. On the other hand, higher sharing rates also increase subsitution towards S away from E.

We see from this simple model that increasing the share of revenue retained should increase spending on revenue-producing forms of spending, with an ambiguous relationship between fiscal incentives and other forms of spending.

Data Appendix

- There appear to be several typos in the 2008 China Environment Yearbooks, where a figure for the same city drops 90% between years. The most obvious error relating to sewage treatment capacity is in Shanghai, where the sewage capacity reported in CEY 2008 is 539,100, an inexplicable drop from CEY 2007's figure of 4,704,105. In CEY 2009, Shanghai reports 6,488,400. The most reasonable explanation is that a "0" has been omitted from the 2008 figure. Results are largely robust to either a correction of the CEY 2008 figure to "5,391,000" or dropping the observation altogether.

- Some cities shrank sewage treatment capacity or did not change over the 2002-2008 sample time frame. To incorporate this into our analysis, we took the biggest drop in sewage treatment capacity within a city, and added this figure to the sewage capacity increase in each city. With this correction, all cities receive positive numbers for $log\left(y_{i,2008} - y_{i,2002}\right)$, except the city with the largest drop in sewage treatment capacity, which is excluded from the results presented. Our results are robust to this correction or to simply dropping cities which did not increase sewage treatment capacity.

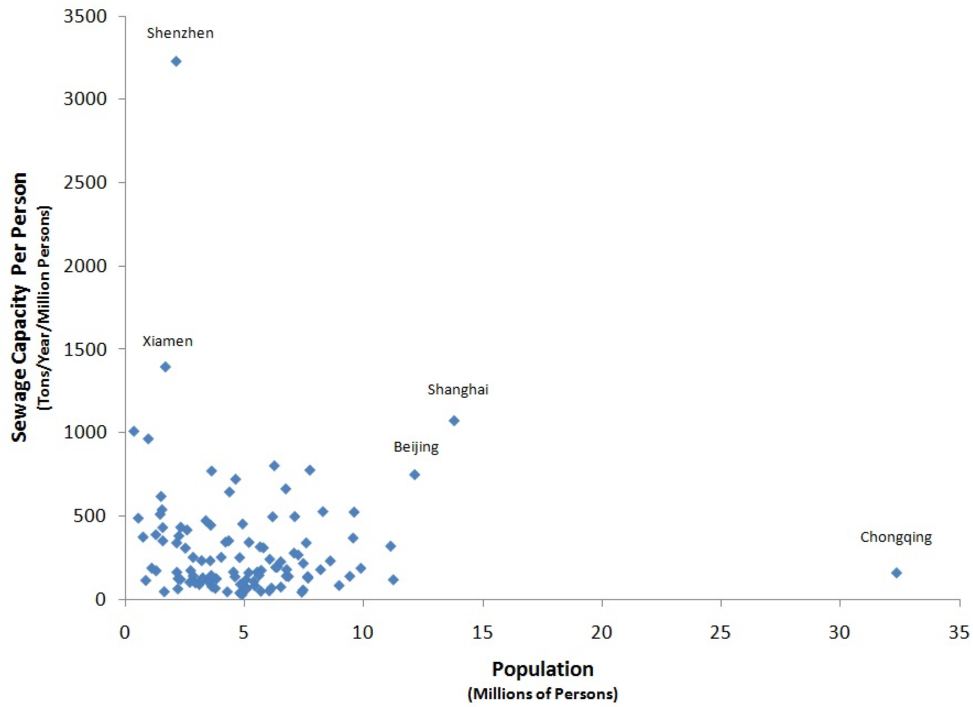

Figure 2.1: Population and Sewage Treatment Capacity per Person, plotted by City, in 2007. Source: China Environmental Statistical Yearbook 2008.

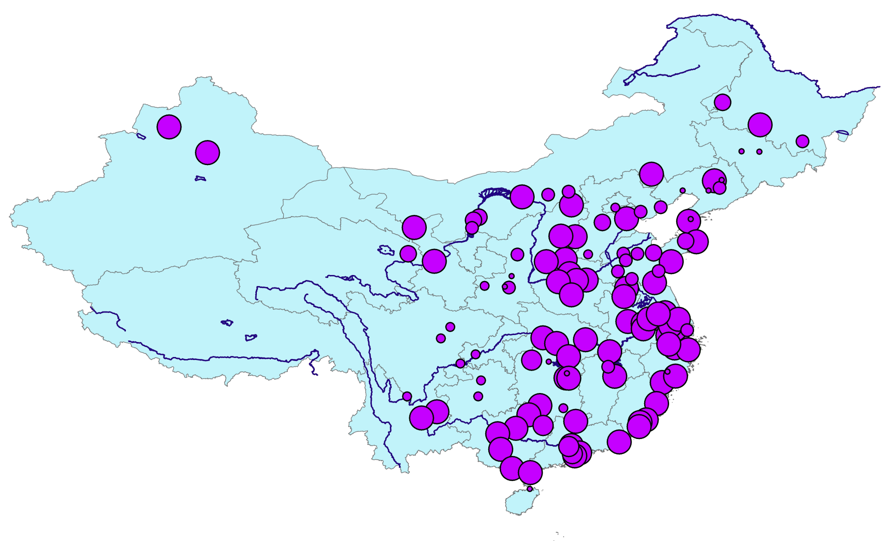

Figure 2.2: The Geographic Distribution of Fiscal Incentives. Source: China Sub-Provincial Public Finance Statistics.

Table 2.1: Patterns of Fiscal Incentives by Province

Province	Number of Cities	VAT Share Retained by City	
		In 1995	In 2001
Beijing	1	Not reported	61%
Tianjin	1	100%	100%
Hebei	11	Range: from 61% to 94%	Range: from 53% to 93%
Shanxi	11	All 100%	All 100%
Neimenggu	8	Huhehaote: 80%; all others 100%	Huhehaote: 79%; all others 100%
Liaoning	14	Range: from 23% to 100%	Range: from 17% to 100%
Jilin	8	All cities 40%	Range: from 41% to 100%
Heilongjiang	12	Range: from 82% to 100%	Range: from 83% to 100%
Shanghai	1	87%	75%
Jiangsu	13	All 100%	All 100%
Zhejiang	11	All 100%	All 100%
Anhui	17	All 100%	All 100%
Fujian	9	All 100%	All 100%
Jiangxi	11	Range: from 73% to 100%	Range: from 42% to 100%
Shandong	17	Range: from 12% to 100%	Range: from 14% to 100%
Henan	17	All 100%	All 100%
Hubei	12	All 100%	All 100%
Hunan	13	Range: from 54% to 91%	Range: from 44% to 100%
Guangdong	21	Range: from 90% to 100%	Range: from 95% to 100%
Guangxi	14	All 100%	All 100%
Hainan	2	Both 100%	One 24%, one 70%
Chongqing	1	100%	62%
Sichuan	18	All 100%	All 65%
Guizhou	4	All 60%	All 60%
Yunnan	8	All 100%	All 100%
Tibet	1	100%	100%
Shanxi	10	Range: from 46% to 100%	Range: from 36% to 100%
Gansu	12	Range: from 37% to 100%	Range: from 42% to 100%
Qinghai	1	45%	93%
Ningxia	5	Not reported	Range: from 78% to 100%
Xinjiang	2	Both 100%	Both 100%

Table 2.2: Summary Statistics of Important City Variables

	2001	2002	2003	2004	2005	2006	2007	2008
Treatment Capacity	N/A	240,166	281,793	336,130	394,019	464,087	531,273	613,270
(tons/day)	N/A	(262,074)	(323,225)	(542,111)	(614,309)	(658,926)	(727,291)	(831,768)
Population	4.7	4.8	4.9	4.9	5.0	5.0	5.1	5.1
(millions)	(3.6)	(3.6)	(3.6)	(3.7)	(3.7)	(3.7)	(3.8)	(3.8)
GDP/Capita	14,973	15,103	17,082	20,765	22,959	26,544	31,260	36,397
(yuan)	(16,510)	(10,740)	(11,979)	(14,329)	(14,887)	(16,946)	(19,117)	(21,089)
City Expenditures	4,095	5,173	7,851	9,447	11,621	13,901	12,640	22,076
(millions of yuan)	(9,320)	(11,042)	(13,450)	(16,576)	(19,816)	(22,317)	(26,650)	(33,187)
Secondary Share	0.475	0.480	0.500	0.518	0.504	0.516	0.523	0.531
	(0.101)	(0.100)	(0.102)	(0.106)	(0.114)	(0.110)	(0.110)	(0.111)
Tertiary Share	0.393	0.395	0.384	0.370	0.390	0.387	0.384	0.380
	(0.085)	(0.085)	(0.082)	(0.084)	(0.098)	(0.099)	(0.101)	(0.103)
Water Consumption	75.5	62.4	58.0	58.8	58.7	54.1	49.1	N/A
(Tons/Household)	(36.5)	(34.5)	(31.5)	(33.6)	(38.0)	(37.1)	(27.1)	N/A
City Expenditure Ratio	0.053	0.059	0.091	0.090	0.093	0.098	0.065	0.114
	(0.035)	(0.035)	(0.032)	(0.033)	(0.028)	(0.030)	(0.033)	(0.047)

Note: Unweighted means are reported for each category. Standard deviations for each item are reported in parentheses below the mean of that item. Only cities for which sewage treatment data reported in the China Environmental Statistical Yearbook are included here; the averages for all cities in China may be different.

Table 2.3: Key Co-variates of Provinces that Passed Through VAT Shares Against Provinces which Retained Shares

	Provinces with 100% VAT Sharing	Provinces with <100% VAT Sharing	P-value of Difference
Number of Provinces	15	12	
Population (thousands)	45,629	39,882	0.6964
GDP/Capita (RMB)	3,689	3,227	0.7968
Total City Income (millions of RMB)	20,505	15,818	0.7790
Total City Expenditures (millions of RMB)	19,658	15,214	0.7852
Secondary Share	42.8%	43.3%	0.4442
Tertiary Share	32.5%	31.8%	0.7028
VAT Dependence (VAT Generated/GDP)	4.84%	5.39%	0.1761
Sewage Treatment Capacity (tons/day, in 2001)	759,006	640,065	0.6484

Note: Unweighted means are reported for each category.

Table 2.4: The Determinants of Province-level Fiscal Incentives

	(1)	(2)	(3)	(4)	(5)	(6)
log(Population)	0.0400	0.0403	0.00977	0.0277	0.185	0.0303
	(0.0382)	(0.0449)	(0.0425)	(0.0410)	(0.150)	(0.177)
GDP/capita	0.193	0.0218	0.0993	0.171	0.660	-0.667
	(0.242)	(0.448)	(0.276)	(0.394)	(0.465)	(1.065)
VAT/GDP	-4.320*					-6.691*
	(2.273)					(3.738)
Expenditures/GDP		1.979				6.158
		(3.354)				(4.776)
City Deficit/GDP			6.910			-2.236
			(5.701)			(7.388)
Coastal (0/1)				0.0262		0.0208
				(0.116)		(0.118)
log(Ind. Output)					-0.0919	0.0334
					(0.0850)	(0.112)
Constant	0.336	0.0888	0.659	0.329	-1.050	0.111
	(0.648)	(0.778)	(0.740)	(0.714)	(1.419)	(1.628)
r2	0.199	0.0814	0.125	0.0691	0.114	0.282
F	1.816	0.650	1.051	0.544	0.944	1.009
N	26	26	26	26	26	26

Standard errors in parentheses
All variables are measured in the year 1995. Our measure of fiscal incentives is the dependent variable.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.5: The Determinants of City-level Fiscal Incentives

	(1)	(2)	(3)	(4)	(5)	(6)
log(Population)	0.00774	0.00708	0.00774	0.00684	0.00294	0.00712
	(0.0122)	(0.0122)	(0.0122)	(0.0123)	(0.0175)	(0.0177)
GDP/capita	-0.0390**	-0.0685**	-0.0313*	-0.0323*	-0.0382	-0.0875***
	(0.0188)	(0.0270)	(0.0184)	(0.0188)	(0.0239)	(0.0306)
VAT/GDP	-0.200					-0.292*
	(0.149)					(0.154)
Expenditures/GDP		0.474*				0.639**
		(0.269)				(0.286)
City Deficit/GDP			-0.335			-0.374
			(0.237)			(0.240)
Coastal (0/1)				-0.00779		-0.0135
				(0.0245)		(0.0246)
log(Ind. Output)					0.00386	0.00270
					(0.0125)	(0.0131)
r2	0.636	0.638	0.636	0.633	0.633	0.648
F	13.84	13.96	13.86	13.67	13.67	12.54
N	251	251	251	251	251	251

Standard errors in parentheses
All variables are measured in the year 1995. Our measure of fiscal incentives is the dependent variable. Regressions include province-level fixed effects.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.6: First-stage Instrumental Variables Results: The Relationship between VAT Share in 2001 and VAT Share in 1995.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VAT Share (1995)	0.462***	0.449***	0.537***	0.543***	0.782***	0.570*	1.272
	(0.116)	(0.118)	(0.119)	(0.119)	(0.217)	(0.278)	(1.708)
Log(Population)		-0.0688	-0.200**	-0.162*	-0.142	-0.187	0.0538
		(0.0541)	(0.0918)	(0.0940)	(0.130)	(0.165)	(0.148)
Log(GDP/Capita)		-0.0690	-0.158	-0.153	-0.131	-0.456*	-0.0526
		(0.0783)	(0.105)	(0.105)	(0.167)	(0.239)	(0.191)
Log(Ind. Output)		0.0738	0.180***	0.197***	0.164	0.259	0.0895
		(0.0529)	(0.0583)	(0.0594)	(0.112)	(0.154)	(0.124)
All VAT Revenues/GDP			-0.0434***	-0.0442***			
			(0.0113)	(0.0114)			
log(Capacity 2002)			-0.0232	-0.0293			
			(0.0212)	(0.0213)			
Water Consump./Capita			0.470	0.413			
			(0.616)	(0.619)			
City Expend / GDP			-0.325	0.753			
			(1.804)	(1.984)			
Log(City Expenses)			0.0116	-0.00956			
			(0.0847)	(0.0871)			
Constant	0.417***	0.901	1.828***	1.859***	0.928	3.954**	-0.236
	(0.107)	(0.616)	(0.680)	(0.677)	(1.447)	(1.859)	(2.223)
r2	0.132	0.158	0.286	0.302	0.669	0.251	0.379
F	15.78	4.725	4.224	4.413	5.064	1.590	1.830
N	106	106	105	102	15	24	17

Standard errors in parentheses
The dependent variable is the log of the growth in sewage treatment capacity between the years 2002 and 2008. Each independent variable is the level of that variable in 2001. Each column represents a different sample for testing. Columns 1 and 2 include the full sample. Column 3 excludes DCM. Column 4 includes only subprovincial cities. Column 5 includes only provincial capitals. Column 6 includes only coastal cities.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.7: Instrumental Variables Results: The Relationship between VAT Share in 1995 and Growth in Sewage Treatment Capacity.

	(1)	(2)	(3)	(4)	(5)	(6)
VAT Share (2001)	1.732**	1.372**	1.378**	5.071***	2.720*	1.738
	(0.849)	(0.679)	(0.671)	(1.706)	(1.543)	(3.006)
Log(Population)	0.748***	0.864***	0.804**	1.369*	0.939*	0.198
	(0.180)	(0.322)	(0.318)	(0.809)	(0.503)	(0.370)
Log(GDP/Capita)	0.609**	0.542	0.559	1.437	0.719	0.483
	(0.252)	(0.341)	(0.342)	(1.012)	(0.715)	(0.445)
Log(Ind. Output)	0.140	0.215	0.195	-0.636	-0.183	0.266
	(0.179)	(0.201)	(0.207)	(0.711)	(0.511)	(0.377)
All VAT Revenues/GDP		0.0296	0.0269			
		(0.0395)	(0.0397)			
log(Capacity 2002)		-0.171**	-0.158**			
		(0.0676)	(0.0690)			
Water Consumption/Capita		-0.583	-0.647			
		(1.881)	(1.897)			
City Expend / GDP		6.047	4.981			
		(5.582)	(6.006)			
Log(City Expenses)		0.0600	0.0640			
		(0.261)	(0.266)			
Constant	3.832*	5.454**	5.320**	-4.858	3.113	5.065
	(2.156)	(2.475)	(2.472)	(8.950)	(6.308)	(4.511)
r2	0.590	0.671	0.627	0.197	0.467	0.784
F	38.51	22.03	17.45	2.512	4.979	9.985
N	106	105	102	15	24	17

Standard errors in parentheses
The dependent variable is the log of the growth in sewage treatment capacity between the years 2002 and 2008. Each independent variable is the level of that variable in 2001. Each column represents a different sample for testing. Columns 1 and 2 include the full sample. Column 3 excludes DCM. Column 4 includes only subprovincial cities. Column 5 includes only provincial capitals. Column 6 includes only coastal cities.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.8: Ordinary Least-Squares Regressions: The Relationship Between VAT Share in 2001 and Sewage Treatment Capacity.

	(1)	(2)	(3)	(4)	(5)	(6)
VAT Share (2001)	0.712**	0.675**	0.751**	2.121	1.285*	1.486*
	(0.294)	(0.295)	(0.301)	(1.264)	(0.681)	(0.749)
Log(Population)	0.633***	0.663**	0.717**	1.124	0.658	0.212
	(0.170)	(0.276)	(0.305)	(0.792)	(0.496)	(0.395)
Log(GDP/Capita)	0.549**	0.418	0.505	1.393	0.325	0.472
	(0.247)	(0.326)	(0.340)	(0.997)	(0.679)	(0.507)
Log(Ind. Output)	0.216	0.319*	0.304	-0.289	0.0714	0.288
	(0.169)	(0.187)	(0.193)	(0.688)	(0.484)	(0.334)
All VAT Revenues/GDP		0.00290	0.00149			
		(0.0358)	(0.0365)			
log(Capacity 2002)		-0.183***	-0.172**			
		(0.0677)	(0.0690)			
Water Consumption/Capita		-0.623	-0.745			
		(1.931)	(1.965)			
City Expend / GDP		5.608	7.277			
		(4.729)	(6.066)			
Log(City Expenses)		0.100	0.0180			
		(0.241)	(0.269)			
Constant	5.152**	7.108***	6.623***	-3.036	7.540	5.297
	(1.972)	(2.200)	(2.245)	(8.792)	(5.613)	(4.277)
r2	0.620	0.682	0.626	0.480	0.526	0.786
F	42.41	23.40	17.45	2.308	5.557	11.00
N	109	108	104	15	25	17

Standard errors in parentheses
The dependent variable is the log of the growth in sewage treatment capacity between the years 2002 and 2008. Each independent variable is the level of that variable in 2001. Each column represents a different sample for testing. Columns 1 and 2 include the full sample. Column 3 excludes DCM. Column 4 includes only subprovincial cities. Column 5 includes only provincial capitals. Column 6 includes only coastal cities.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.9: The Relationship Between Fiscal Incentives and Other Forms of Public Spending.

	(1) Education	(2) Education	(3) Science	(4) Science
VAT Share (2001)	0.644**	0.784*	-0.348	-2.274**
	(0.298)	(0.458)	(0.351)	(0.958)
Log(Population)	0.814***	0.328	0.495***	-0.103
	(0.140)	(0.215)	(0.165)	(0.450)
Log(GDP/Capita)	0.478***	0.256	-0.243	-0.947*
	(0.150)	(0.231)	(0.177)	(0.483)
Log(Ind. Output)	0.0185	0.386***	0.162	0.351
	(0.0917)	(0.141)	(0.108)	(0.295)
All VAT Revenues/GDP	0.0496***	0.0533**	-0.00296	-0.0497
	(0.0176)	(0.0270)	(0.0207)	(0.0565)
log(Capacity 2002)	0.0713**	0.0420	0.0705*	0.0320
	(0.0306)	(0.0471)	(0.0360)	(0.0984)
Water Consump./Capita	0.559	1.401	0.808	-0.262
	(0.833)	(1.281)	(0.981)	(2.678)
City Expend / GDP	2.688	0.291	1.274	-3.192
	(2.607)	(4.010)	(3.070)	(8.385)
Log(City Expenses)	-0.0350	0.375**	0.301**	0.920**
	(0.117)	(0.180)	(0.138)	(0.377)
Constant	6.455***	2.105	9.457***	14.47***
	(1.091)	(1.679)	(1.285)	(3.511)
r2	0.858	0.874	0.806	0.326
F	62.73	69.60	43.49	7.975
N	103	103	103	103

Standard errors in parentheses
In each column, the dependent variable is obtained by adding spending between 2002 and 2008. Each independent variable is the level of that variable in 2001.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

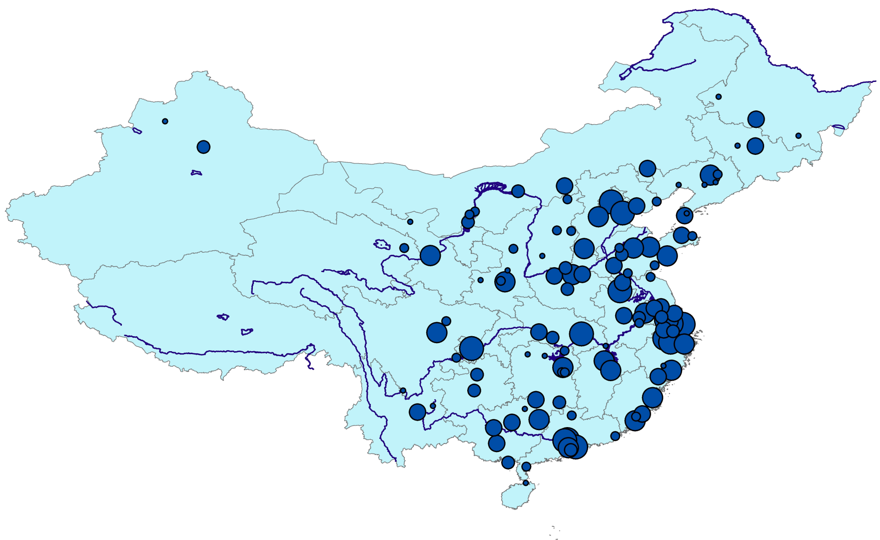

Figure 2.3: The Geographic Distribution of Growth in Sewage Treatment. Source: China Environment Yearbooks.

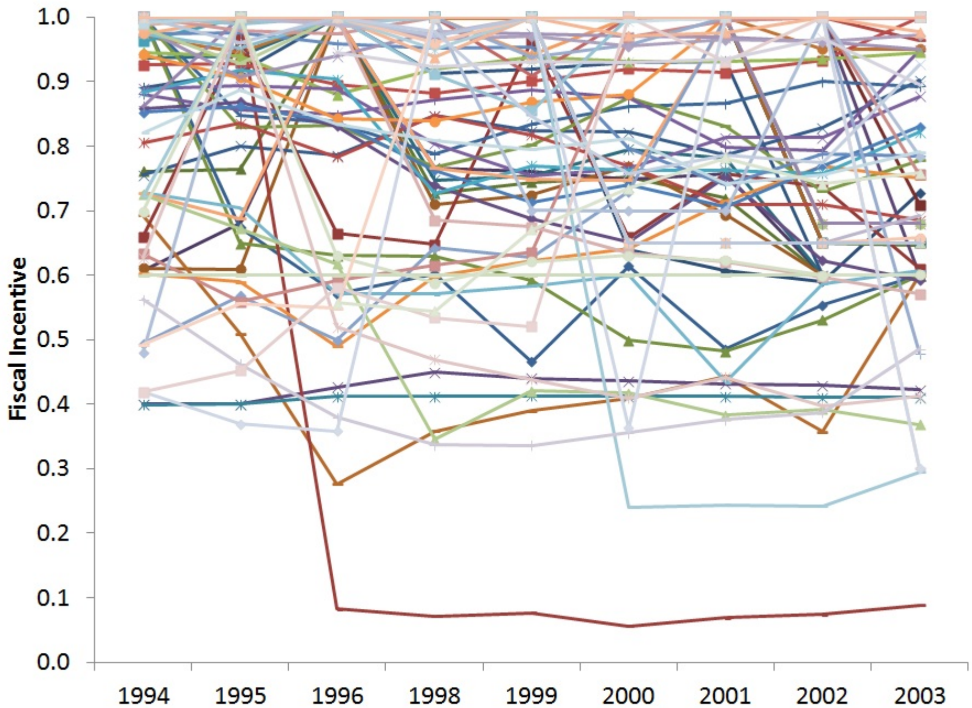

Figure 2.4: Raw Data for Fiscal Incentives, plotted by City. See equation 2.2 in section 4.1 for more details of how the fiscal incentive for each city is derived. Many cities had values marginally higher than 1. These usually fell within the rounding error of the original source. One city in 2002 and one city in 2003, of the 113 cities presented here, had a fiscal incentive value substantially higher than 1. We adjusted the fiscal incentive value to 1 when equation 2.2 resulted in a ratio higher than 1. Source: Sub-Provincial Public Finance Statistics.

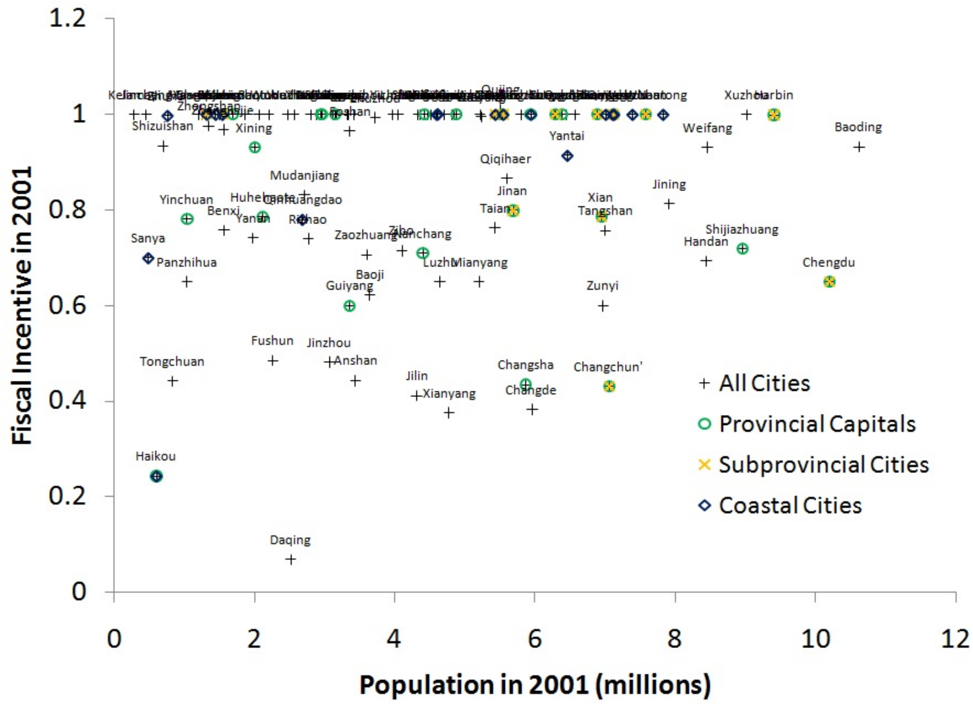

Figure 2.5: Fiscal Incentive and Population, plotted by Province, in 2002. Population figures are drawn from the 2002 China City Statistical Yearbook. Fiscal incentive figures are calculated using equation 2.2 using data from the 2002 Sub-Provincial Finance Statistics.

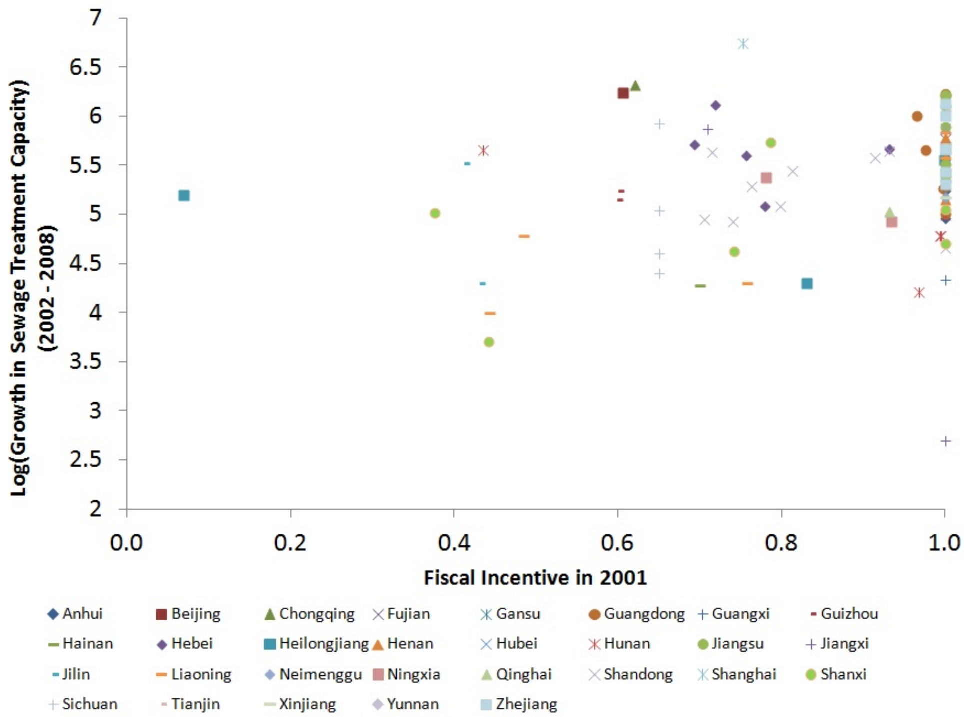

Figure 2.6: Fiscal Incentive and Growth in Sewage Treatment Capacity, plotted by Province. Fiscal incentive figures are calculated using equation 2.2 using data from the 2002 Sub-Provincial Finance Statistics. Sewage treatment capacity figures are obtained using China Environment Yearbooks.

Chapter 3

Environmental Policy in the Presence of an Informal Sector

This paper demonstrates how the presence of an untaxed informal sector can sharply lower the cost of energy tax reforms through an expansion of the tax base. The effect occurs when energy tax revenue is used to lower labor tax rates, which on the margin will draw informal labor into the formal sector. While the energy tax itself is a narrow tax (and interactions with the rest of the tax system increase the distortionary cost even further) the expansion of the formal sector can more than offset the cost of the energy tax. We prove the result in a general framework and then use a simple computable general-equilibrium simulation to investigate its magnitude. Under our central set of parameters the cost of environmental tax reform is reduced by 65% in the U.S., implying an optimal tax well above the Pigouvian level. This result is even stronger at levels of informal production typical in developing economies.

3.1 Introduction

The size of the tax base plays a central role in the debate over environmental taxes in modern tax systems. Environmental economists have broadly supported environmental taxes or tradable permits as market-based mechanisms to internalize environmental externalities such as pollution. The revenue-raising potential of these taxes has also been emphasized, though the relatively narrow base on which energy taxes fall can make them costly sources of revenue. We investigate how these tax base effects enter, and in particular extend previous work to allow an informal sector in production.

The prior literature on energy tax reform generally separates the welfare effects into two parts: a "first" dividend from correcting an environmental externality, and a second or "double" dividend from using the revenue raised to offset other taxes. The swapping of environmental taxes for taxes on other goods has therefore offered policy makers the tantalizing prospect of two sources of welfare improvement simultaneously. However, a series of papers (Bovenberg and de Mooij 1994, Goulder 1995, and Bovenberg 1999) showed that the welfare benefits resulting from the broad-based tax cut are outweighed by the new distortion resulting from the narrowly based tax increase. This finding relates closely to work by public finance economists on optimal taxes and we draw heavily from each of these literatures in our results here.

We begin by observing that even the broadest taxes in any economy fail to cover a collection of sectors collectively labeled the "informal economy." These sectors escape government scrutiny for a range of reasons: The activity may be illegal, as in the case of certain narcotics, or it may be too costly to track effectively, as in the case of migrant labor or some domestic employment. The informal sectors compose a substantial portion of all modern economies. Using a variety of measurement methods, Schneider (2011) reports that the informal economy was 8.4% of GDP in the U.S. and averaged 16.1% of GDP in 21 OECD countries in 2004. Even larger values are reported in developing economies, with 30.4% of GDP in Asia and 43.2% of GDP in Africa categorized as informal.

Our contribution investigates the interaction between this informal activity and energy taxes. In particular, and contrary to previous work, we show that an energy tax can actually broaden the tax base via changes in the size of the informal sector. Our paper is most closely related in the literature to Pigott and Whalley

(2001). Pigott and Whalley overturn conventional prescriptions recommending broad-based taxes by showing how certain tax reforms fail to account for the role of the informal sector. They argue that the extension of some taxes to include services results in higher prices in the formal sector, creating additional demand for informal production. A tax reform meant to broaden the tax base instead narrows it by causing substitution into untaxed sectors.

We show, using very similar logic, that the reverse holds in the case of energy taxes: the narrowing pointed out by Pigott and Whalley runs the opposite direction under a very simple set of assumptions about energy input shares in the economy. As long as energy taxes fall more heavily on formal manufactured goods than on services the tax cuts associated with the reform will draw a larger share of the service sector into the formal economy. In spite of the apparent narrowness of the energy tax, it actually serves to broaden the total base over which taxes are collected. In the context of the environmental economics literature and the double dividend, this creates two sets of welfare benefits: it enhances environmental quality and it improves the efficiency of the tax system at its core by expanding the tax base.

Our result is in contrast to earlier work on the double dividend in that we do not begin in a setting with uneven or inefficient tax collection over the existing tax base. (The literature identifies a number of important inefficiencies of this type, including the use of taxes to favor certain classes of consumption in Parry and Bento (2000), the failure to fully tax fixed factors in Bento and Jacobsen (2007), and the existence of costly, uneven tax evasion in Liu (2011).) Instead of correcting inefficient use of the existing tax base, we consider ways that an energy tax can change the size of the taxable part of the economy overall. The welfare improvement available here requires the ability of a relatively narrow tax on energy to increase total demand in the formal parts of the economy through substitution in consumption.

We first offer an analytical proof in a general model and then impose specific functional forms in a set of simulations testing the magnitude of the effect. Our simulation model mirrors the analytical setup but allows calibration of energy shares and sector sizes to the U.S. economy. The distortionary cost of an energy tax is reduced by 65% when considering the existence of an informal sector that is only 8.4% of the overall economy. In settings with larger informal sectors the effect grows even stronger, completely offsetting the welfare cost (offering a strong form of the double dividend) in many developing economies.

Section 2 provides our general analytical model and derivations relating the energy tax to the size of the tax base. We describe the simulation model calibration and results in Section 3 and conclude in Section 4.

3.2 A Model of the Informal Sector

Pigott and Whalley (2001) introduce a model to capture substitution between the formal and informal sectors of an economy. We follow their three-good formulation throughout, considering manufactured goods (G), market-traded services $\left(S^M\right)$, and non-market services $\left(S^N\right)$. They show that a revenue-neutral tax reform which extends one tax from covering only G to including both G and S^M can actually narrow the tax base and worsen welfare as a result of substitution across the formal and informal sectors.

Our model introduces an energy input to the manufacturing sector and provides a simple illustration of the contrapositive of Pigott and Whalley's result. Initially, a labor tax in our model falls both on G and S^M. We impose a narrow environmental tax that falls only on G (via the energy input) and use the revenue to reduce the labor tax. The reduction of tax on S^M in particular causes substitution from S^N to S^M, increasing the size of the tax base and improving welfare.

3.2.1 Model Structure

3.2.1.1 Firms

There are four kinds of firms: energy producers E, manufactured goods firms G, market-traded services S^M and non-market services S^N.

Energy firms are part of the formal sector and create damages as a result of pollution in the amount $\phi\left(E\right)$. Labor is the only underlying factor of production and production is constant returns to scale:

$$E = L_E \tag{3.1}$$

Energy firms are taxed in two ways. First, they must pay labor taxes on the labor used τ_L. They must also pay an environmental tax proportional to production τ_E. Workers receive an after tax wage normalized to 1, pre-tax wages are $1+\tau_L$. Hence, the price of energy is:

$$p_E = 1 + \tau_L + \tau_E \tag{3.2}$$

Firms which produce manufactured goods G use labor L_g and energy E_g as inputs. Production is increasing in inputs and constant returns to scale:

$$G = G\left(L_g, E_g\right)$$

Defining energy intensity at the optimal mix of energy and labor as I_g we have:

$$E_g = I_g G$$

$$L_g = \left(1 - I_g\right) G$$

Energy intensity is a function of the prices of labor and energy: $I_g\left(\tau_L, \tau_E\right)$ making the price of G:

$$p_G = 1 + \tau_L + I_g \tau_E \tag{3.3}$$

Firms which produce formal sector services S^M produce using only labor and again have constant returns to scale:

$$S^M = L_M$$

The price of formal sector services is:

$$p_{SM} = 1 + \tau_L \tag{3.4}$$

Finally, we have production of informal sector services S^N. This again uses only labor, but we will now assume rising marginal costs of production and consequently an upward sloping supply curve. Early informal sector firms are efficient and can produce cheaply but as they proliferate it becomes more difficult to escape attention, resulting in rising marginal costs. We assume informal sector production follows:

$$S^N = (L_N)^{\theta_L} \tag{3.5}$$

where θ_L is between 0 and 1 and controls the degree to which marginal cost rises as production increases.

We assume that formal sector services S^M and informal sector services S^N are perfect substitutes in consumption, a common mechanism used in the literature to model the co-existence of both formal and informal sectors[1]. Hence, informal sector firms will produce along their supply curve until marginal cost (and therefore price) equals that in the formal sector:

$$p_{SN} = 1 + \tau_L \tag{3.6}$$

As a result of rising marginal cost informal firms accumulate rents on inframarginal production.[2] We assume these accrue to the representative household. If informal firms have a marginal cost of labor given by the function $MC(L)$, the rents are in the amount of:

$$\pi_{SN} = \int_0^{MC^{-1}(p_{SN})} \left[p_{SN} - MC(L)\right] dL \tag{3.7}$$

3.2.1.2 Households

The representative consumer enjoys utility from manufactured goods G, service goods S, and leisure (l). Service goods are a combination of market-traded

[1]See Keen (2008), Koreshkoba (2006), and Pigott and Whalley (2001)

[2]We include the equation for completeness, but note that the rents will not influence welfare consequences at the margin.

services and non-market, informal services:

$$S = S^M + S^N \tag{3.8}$$

Leisure is equal to the consumer time endowment $\left(\overline{L}\right)$ less the labor supply (L). Emissions from using energy (E) cause environmental damages in the form of reduced consumer utility. The household utility function is given by:

$$U = u\left(G, S, \overline{L} - L\right) - \phi\left(E\right) \tag{3.9}$$

$u(.)$ is the utility from non-environmental goods and is quasi-concave. $\phi\left(.\right)$ is the disutility from emissions and is weakly convex. The separability restriction in (3.9) implies that the demands for G, S, and labor supply do not vary with changes in E. In turn, emissions are generated by the energy inputs used in the production of these goods.

The individual budget constraint is:

$$p_G G + p_S S = L + h + \pi \tag{3.10}$$

where h is a per-household lump-sum government transfer and π are the rents from the informal sector, also accumulating to households.

3.2.1.3 Government

The government collects taxes on formal sector labor supply and on energy taxes, when levied.

$$hN = \tau_L\left(L - L_N\right) + \tau_E E \tag{3.11}$$

where N is the number of households in the economy.

3.2.2 Welfare Analysis

Using equations 3.9 and 3.10, the household optimization problem is given by:

$$W = u\left(G, S, \overline{L} - L\right) - \phi\left(E\right) - \lambda\left[p_G G + p_S S - L - h - \pi\right] \tag{3.12}$$

Totally differentiating this equation with respect to τ_E and substituting in the envelope conditions yields the equation:

$$\frac{1}{\lambda}\frac{dW}{d\tau_E} = -\frac{1}{\lambda}\phi'\left(E\right)\frac{dE}{d\tau_E} - \frac{dp_G}{d\tau_E}G - \frac{dp_{SM}}{d\tau_E}S + \frac{d\pi}{d\tau_E} \tag{3.13}$$

Our proposed tax reform involves the revenue neutral substitution of energy taxes for labor taxes. Totally differentiating equation 3.11 with respect to τ_E yields:

$$\frac{dhN}{d\tau_E} = \tau_L\frac{d\left(L - L_N\right)}{d\tau_E} + \frac{d\tau_L}{d\tau_E}\left(L - L_N\right) + E_g + \tau_E\frac{dE_g}{d\tau_E} = 0 \tag{3.14}$$

We know that $\frac{dp_G}{d\tau_E} = \frac{d\tau_L}{d\tau_E} + \frac{d(I_G\tau_E)}{d\tau_E}$ and $\frac{dp_{SM}}{d\tau_E} = \frac{d\tau_L}{d\tau_E}$ from equations 3.3 and 3.4.

We re-state profits, from equation 3.7, as $\pi = \int_0^{p_{SN}} L_N\left(\tau\right)d\tau$, where $L_N\left(\tau\right)$ is the demand for informal labor as a function of the labor tax rate. Since $p_{SN} = 1 + \tau_L$, this implies:

$$\frac{d\pi}{d\tau_E} = L_N\frac{d\tau_L}{d\tau_E} \tag{3.15}$$

Plugging in each of these parts, we can simplify equation 3.13 to:

$$\frac{1}{\lambda}\frac{dW}{d\tau_E} = \left[-\tau_E I_g\left(-\frac{dG}{d\tau_E}\right) - \frac{1}{\lambda}\phi'\left(E\right)\frac{dE}{d\tau_E}\right] + \left[\tau_L\frac{d\left(L - L_N\right)}{d\tau_E}\right] \tag{3.16}$$

Term 1 The first term in square brackets identifies the distortionary cost of the policy in the final goods markets balanced against the gain in utility from environmental quality improvements. The first part of the term is the tax distortion introduced directly in the manufacturing sector G. The second part of the term describes benefits in utility accruing from the change in environmental quality via ϕ. The net effect is identical to the prior literature (e.g. Bento and Jacobsen 2007, Parry and Bento 2000) and is sometimes referred to as the “first” or “environmental" dividend from the policy.

Term 2 The second bracketed term in (3.16) is the combined revenue recycling effect and tax interaction effect, which as decomposed here comprise the core argument of our paper.

In prior work, where all production occurs formally, this term incorporates the entire labor supply L in the numerator. Goulder (1995) and other authors show conclusively in their models that the effect on L is negative due to interactions between the energy tax and a pre-existing labor tax.

In contrast, our model yields an effect that includes in the numerator only the portion of labor supply that is taxable: $L - L_N$. When labor supply moves out of the informal sector the untaxed labor L_N will shrink, at least partially offsetting the decrease in overall labor supply L.

In sum, the presence of an informal sector makes the second bracketed term less negative indicating smaller welfare losses:

Proof:

$$\begin{aligned}
\pi_{SN} &= p_{SN} S^N - p_{LN} L_N \\
&= L_N^{\theta_L} - (1 - \tau_L) L_N \\
\frac{d\pi_{SN}}{dL_N} &= \theta_L L_N^{\theta_L - 1} - (1 - \tau_L) = 0 \\
L_N^{1-\theta_L} &= \frac{\theta_L}{1 - \tau_L} \\
\frac{d\left(L_N^{1-\theta_L}\right)}{d\tau_E} &= \frac{\theta_L}{(1 - \tau_L)^2} \frac{d\tau_L}{d\tau_E}
\end{aligned}$$

Since the first part of the right-hand side of the last line is positive, and the second part is negative, the informal labor supply L_N shrinks with the energy tax swap. Intuitively, the environmental tax has been levied on the manufacturing sector which has relatively few informal substitutes. The revenue is used to lower the labor tax, which lowers the tax rate on the formal services sector. In turn, labor shifts away from the informal sector creating a beneficial effect as the tax base is broadened.

3.2.3 Energy Intensity in the Formal and Informal Sectors

We have extended the model above to include energy consumption in the services sector, but have omitted this derivation for brevity. The basic insight of this extension is that the direction of the result above depends on the relative energy intensities of the manufacturing sector and the services sector. If the manufacturing sector is more energy intensive, taxes on energy fall more heavily on manufacturing. Energy tax revenues are then used to lower the price of formal sector services via the tax swap, generating the base-broadening effect. Conversely, if the services sector bears the intial burden of the energy tax through a higher relative energy intensity, the green tax swap will have the opposite effect: it will raise the price of formal services and cause tax-induced substitution away from the formal sector. Therefore, the energy intensities of the manufacturing sector and the services sector are pivotal factors in this analysis.

The empirical evidence strongly supports the idea that the manufacturing sector is more energy intensive than the services sector. For the United States, we calculate that the energy intensity of the manufacturing sector is 3.1 times higher than that of the services sector[3].

Throughout this paper we assume that the services sector has been used as the sector interchangeable with the informal sector. The validity of this assumption depends substantially on the composition of the informal sector. While empirical evidence on the composition of the informal sector is understandably limited, an important piece of evidence comes from a survey of informal workers conducted in Lemieux et. al (1994). The authors conduct a statistically representative survey of informal sector activity in Quebec City, Canada. They find a total informal market participation rate of 8.5%: 2.8% of workers were employed in informal construction,

[3]We define energy intensity as the value of energy used divided by the value of output. The US Energy Information Administration reports in its estimates of consumer expenditure by end-use sector that the "commercial" sector, composed of services, spent $155 billion on energy, while the "industrial" sector, composed of agriculture and industry, spent $209 billion on energy. Using the US Bureau of Economic Analysis data of gross output by industry for these sectors, we calculate that the energy intensity for services is 0.96%, and the energy intensity for industry is 3.00%.

2.7% in informal services, and the remainder mainly in transportation, trade, and finance. This evidence is strongly consistent with the claim that the informal sector provides a close substitute for economic activity that is both service-oriented and on average less energy-intense than manufacturing.

3.3 Simulation

In this section we conduct a simple simulation to demonstrate the magnitude of tax-induced base broadening under a variety of settings. The version of the simulation here includes the energy intensities of the services and manufacturing sectors as described above for the U.S. We are currently extending the simulation to include the possibility of informal energy use.

3.3.1 Households

For the numerical simulation we employ a nested constant elasticity of substitution (CES) functional form for utility:

$$U = \left(\alpha_{UG} C^{\frac{\sigma_U - 1}{\sigma_U}} + \alpha_{Ul} l^{\frac{\sigma_U - 1}{\sigma_U}}\right)^{\frac{\sigma_U}{\sigma_U - 1}} \tag{3.17}$$

$$C = \left(\alpha_{CG} G^{\frac{\sigma_C - 1}{\sigma_C}} + \alpha_{CS} S^{\frac{\sigma_C - 1}{\sigma_C}}\right)^{\frac{\sigma_C}{\sigma_C - 1}} \tag{3.18}$$

where l is leisure and C is the utility derived from consuming goods. G represents the manufactured good and S services. σ_U, σ_C, α_{UG}, and α_{CG} are calibrated and control the substitution elasticities and sizes of the various sectors.

Market-traded services $\left(S^M\right)$ and informal sector services $\left(S^N\right)$ are perfect substitutes:

$$S = S^M + S^N \tag{3.19}$$

The household budget constraint is:

$$p_G G + p_S S = L + h + \pi \tag{3.20}$$

where p_i is the price of good i, L is the hours worked at an after-tax wage normalized to 1, h is the per-household government transfer, and π are rents from the upward-sloping supply of informal goods. Since S^N and S^M are perfect substitutes, the price of each is p_S.

3.3.2 Firms

There are four types of firms as before: one producing energy (E), one producing manufactured goods (G), one producing formal sector services $\left(S^M\right)$, and one producing informal sector services $\left(S^N\right)$.

Production is given by:

$$E = L_E \tag{3.21}$$

$$G = \gamma_G \left(\alpha_{LG}^{1/\sigma_G} L_G^{\frac{\sigma_G - 1}{\sigma_G}} + \alpha_{EG}^{1/\sigma_G} E_G^{\frac{\sigma_G - 1}{\sigma_G}} \right)^{\frac{\sigma_G}{\sigma_G - 1}} \tag{3.22}$$

$$S^M = \gamma_{SM} \left(L_{SM}\right)^{\theta_{LM}} \left(E_{SM}\right)^{\theta_{EM}} \tag{3.23}$$

$$S^N = \gamma_{SN} \left(L_{SN}\right)^{\theta_{LN}} \left(E_{SN}\right)^{\theta_{EN}} \tag{3.24}$$

In this equation, L_i and E_i represent the amounts of labor and energy used to make good i. The parameter σ_G represents the elasticity of substitution of good G, while the parameters α_{LG} and α_{EG} govern input shares. In the production of services, the parameters γ_{SM}, γ_{SN}, θ_{LM}, θ_{EM}, θ_{LN}, and θ_{EN} govern the productivity of inputs to S_M and S_N. We choose Cobb-Douglas functional forms for the services production functions to follow the prior literature, most directly Piggott and Whalley (2001) and Koreshkova (2006).

L_E, L_G, L_M, and L_N comprise total labor supply (L):

$$L = L_E + L_G + L_M + L_N \tag{3.25}$$

Total energy (E) is represented by the equation:

$$E = E_G + E_{SM} + E_{SN} \tag{3.26}$$

3.3.2.1 Informal Firms

The parameters γ_{SN}, θ_{LN}, and θ_{EN} control the relationship between informal sector labor L_N and informal sector production S^N. As in the analytical model, informal sector services are produced with increasing marginal cost, so $\theta_{LN} + \theta_{EN} < 1$. Informal services are produced up to the point where their marginal cost equals that of formal sector services. Formal sector services meet remaining demand.

The upward sloping supply curve in the informal sector results in inframarginal rents that accrue back to the household:

$$\pi_N = p_S S^N - L_N - p_E E_{SN} \tag{3.27}$$

3.3.2.2 Government

The government receives taxes from labor and from the pollution tax when levied. It transfers all funds received back to households in a lump-sum fashion. The tax reform we consider holds the size of government transfers fixed, recycling revenue from the energy tax to lower the labor tax:

$$\tau_L L + \tau_E E = H = hN \tag{3.28}$$

Here, τ_L and τ_E are the tax rates on labor and energy, respectively. H is all government revenues, h are per-household transfers, and N is the number of households.

3.3.3 Model Solution

When an emissions target is chosen, the government holds H fixed and adjusts the emissions tax and the labor tax until emissions levels are brought down to their target. The numerical model is solved by setting taxes and prices such that consumers make decisions about leisure and goods purchases, the government budget balances, and the factor market for labor clears. Government transfers are held constant in real terms.

3.3.4 Model Calibration

The baseline for these simulations is a simplified version of the U.S. economy with just three sectors (manufactured goods, formal services, and informal services), and taxes on labor and energy inputs. We begin with the result from Schneider (2005) that the shadow economy makes up 8.4% of the U.S. economy. We vary this value between zero and 40% in alternative simulations.

One of the more important choices in calibration surrounds the parameters that govern production in the informal sector, specifically the elasticity of substitution between formal and informal production. This is determined in the model via the parameters θ_{LN} and θ_{EN}. In our central case we follow Pigott and Whalley, using a baseline specification of $\theta_{LN} + \theta_{EN} = 0.4$, corresponding to an elasticity between the tax rate and the size of the informal sector of about 0.2. By contrast, Peter (2009) uses a global panel of tax rates and informal sector activity and estimates a much larger elasticity of between 0.7 and 0.9. This implies that our estimate of the welfare gain from changes in the informal sector is quite conservative. We again employ a variety of sensitivity analyses, with our most elastic case ($\theta_{LN} + \theta_{EN} = 0.67$) being closest to the Peter (2009) result.

Finally, the baseline size of the polluting sector is 2.7% of the economy, consistent with the size of the energy sector according to BEA statistics. The elasticities of substitution σ_U and σ_G are set at $\sigma_U = 0.9$ and $\sigma_G = 1.01$, implying close to average substitution and similar to prior work. We assume a benchmark labor tax of $\tau_L = 0.4$, also following the previous literature (for example Bento and Jacobsen [2007]) . Following these baseline tax and substitution rates makes the magnitude of our welfare estimates here more easily comparable with the literature.

3.3.5 Simulation Results

3.3.5.1 Tax Induced Substitution out of the Informal Sector

We begin by illustrating the proposed mechanism. The government introduces a pollution tax and recycles revenue to cut the labor tax. Since the services sector is less energy-intense the relative tax on formal services is reduced. This in turn diminishes the demand for informal services, drawing labor out of the informal sector.

Figure 3.1 illustrates the impact of the tax reform on informal labor supply. Each of the points on the horizontal axis should be interpreted as a separate simulation with different initial conditions. Under our central set of parameters, an emissions tax of 16% cuts emissions 10%. These revenues cut the labor tax by 0.4% and result in a roughly 0.5% decrease in informal labor. Since changes to the informal labor supply are calibrated based on elasticities, this change in informal labor supply is roughly constant with different initial shadow economy sizes.

As the size of the shadow economy increases, the total cost of cutting emissions falls sharply, as shown in figure 3.2. When the shadow economy is a very minor factor in the economy, the cost is similar to the the baseline case. However, as the shadow economy becomes relatively more important we see that flows from informal labor supply make a bigger contribution to the taxable base. The cost of the policy to society diminishes sharply, becoming negative when the initial size of the shadow economy exceeds 13% of GDP. At this point, a "strong double dividend" (Goulder 1995) is realized.

3.3.5.2 Marginal and Total Cost

Figure 3.3 illustrates how the presence of the shadow economy affects the marginal cost of cutting emissions. In both the baseline case and when we consider the shadow economy the marginal cost of reducing emissions increases with emissions reduced, reflecting the necessity of using increasingly heavy environmental taxes.

The presence of the shadow economy lowers the marginal cost at every level. As larger environmental taxes are levied, they generate more revenue and allow bigger cuts in pre-existing taxes. Bigger tax cuts diminish the price advantage of the informal sector, and increase the flow of labor out of the informal sector.

Figure 3.4 illustrates how increasing emissions cuts affect the total cost of pollution-reducing taxes. The presence of the shadow economy offers quantitatively large reductions in the total cost, even when emissions reductions are large and expensive. For the U.S., a country with a relatively small shadow economy, negative total costs can be achieved while cutting emissions up to 6%. This suggests strongly that the optimal carbon tax rate, even without considering environmental benefits, is above zero.

3.3.5.3 Robustness Checks

We test the sensitivity of our main simulation findings to alternative parameters. Table 3.1 summarizes these results. In this table, all results are relative to the primary cost of reform, that is, the welfare cost of the tax reform without considering the shadow economy. Lower numbers indicate that the shadow economy is a bigger factor. Negative numbers indicate that the welfare cost is negative and that the reform is welfare improving.

Varying the size of the polluting industry In the central case, the polluting industry was 2.7% of the total economy. We vary the size of the polluting industry between 1% (low) and 10% (high). When the polluting industry is small, the primary cost of cutting emissions is relatively small. Tax base expansion via the shadow economy appears to play a relatively more important role.

Varying the size of the shadow economy: In central case, the shadow economy was calibrated to the United States, at around 8.4% of the economy. The United States has an unusually small shadow economy. Schneider (2005) reports that OECD shadow economies average around 15% of GDP (medium). Asian countries average around 25% of GDP (high), while Africa and the Latin American shadow economies average around 40% of GDP (highest).

The size of the shadow economy plays a very important role in the magnitude of these results. Since the equations are parameterized to fix the elasticity of informal labor with respect to the tax rate, a bigger shadow economy means that wider flows out of the informal labor sector are occurring. The table suggests that countries with large enough shadow economies may face negative costs for a range of emissions cuts.

Varying the elasticity between formal and informal production: The informal production parameters θ_{LN} and θ_{EN} govern the elasticity of substitution from the informal sector. Our central estimate was $\theta_{LN} + \theta_{EN} = 0.4$, following Pigott and Whalley (2001). We vary the sum of these parameters between 0.33 (low) and 0.67 (high).

Similar to the size of the shadow economy, informal production parameters play a relatively important role. Since these parameters govern the elasticity of the informal sector, high elasticities correspond to a greater importance of the effects described above.

Varying the relative energy intensity of manufacturing and services: Our analysis depends importantly on the relative energy intensity of manufactured goods (the category we assume has poor substitutes in the informal economy) and services (the category with stronger informal subsitutes). Our central estimate of this ratio is 3.1, following U.S. EIA and BEA data. Other OECD countries may have manufacturing sectors that are more or less energy intense. Further, some developing countries may have manufacturing that occurs in the informal economy, raising the average energy intensity of the category of goods with strong informal subsitutes. To explore these possibilities we vary the ratio of energy intensities between 1 (very low), 2 (low), and 4 (high).

This parameter strongly impacts the cost ratio. A low ratio indicates that the services category uses more energy, muting our results. In this case a revenue-neutral shift toward energy taxes has a smaller impact on the price of formal sector services, limiting the downward shift in demand for informal goods. The opposite holds as the ratio increases in the "high" case explored here.

Varying the energy intensity of the informal services sector: No studies that we are aware of have been conducted on the energy intensity of the informal sector. In the absence of such data, our central assumption is that they use energy at the same rate as the formal services that they subtitute for. In our sensitivity analysis we test both alternative possibilities; informal services may use more energy (a ratio between informal and formal of 2, "high") or less (a ratio of 0.67, "low").

If informal services are more energy intense than formal services the effects here become amplified. The emissions tax actually falls on informal goods and omits formal services, serving to narrow the cost advantage of operating in the informal sector. Tax-base broadening flows are even stronger. Conversely, if informal services are less energy intense than the same service in the formal sector, the effects are weakened.

3.4 Conclusions

We argue that energy tax reform, when used to reduce pre-existing labor taxes, has the benefit of inducing substitution into the formal sector. This broadens the tax base and reduces the welfare cost of an energy tax, the contrapositive of the result demonstrated in Pigott and Whalley's (2001) work. We first demonstrate the unambiguous direction of our result in a general analytical model, then employ a calibrated simulation to investigate the magnitude of the effect in a stylized version of the U.S. economy. It turns out to be quite large, reducing by 65% the distortionary cost of an energy tax. In the broader context of environmental policy, this suggests an optimal tax on energy that lies well above the Pigouvian level.

Future work will extend the model to allow differential rates of energy use across sectors of production, and calibrate to developing economies where we expect the effect to be even greater in magnitude. Greater detail on substitution rates across sectors, and on the composition of informal production in particular, would allow even more detailed simulations that could feed directly into tax policy.

Acknowledgments

Chapter 3, in part, is currently being prepared for submission for publication of the material. Bento, Antonio; Jacobsen, Mark. The dissertation author was the primary investigator and author of this material.

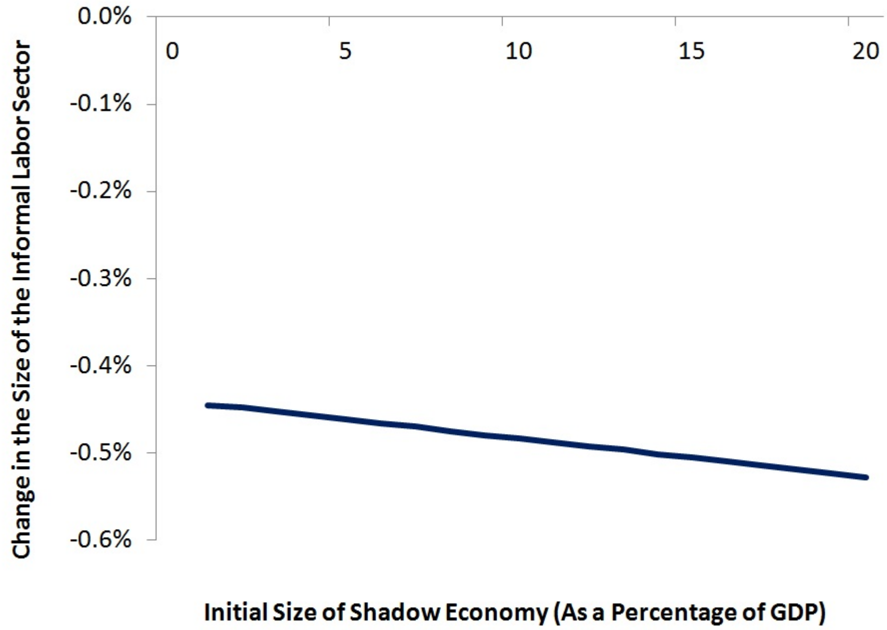

Figure 3.1: Tax-Induced Substitution out of the Informal Sector. All simulations refer to a 10% cut in the polluting good. Source: authors' simulations.

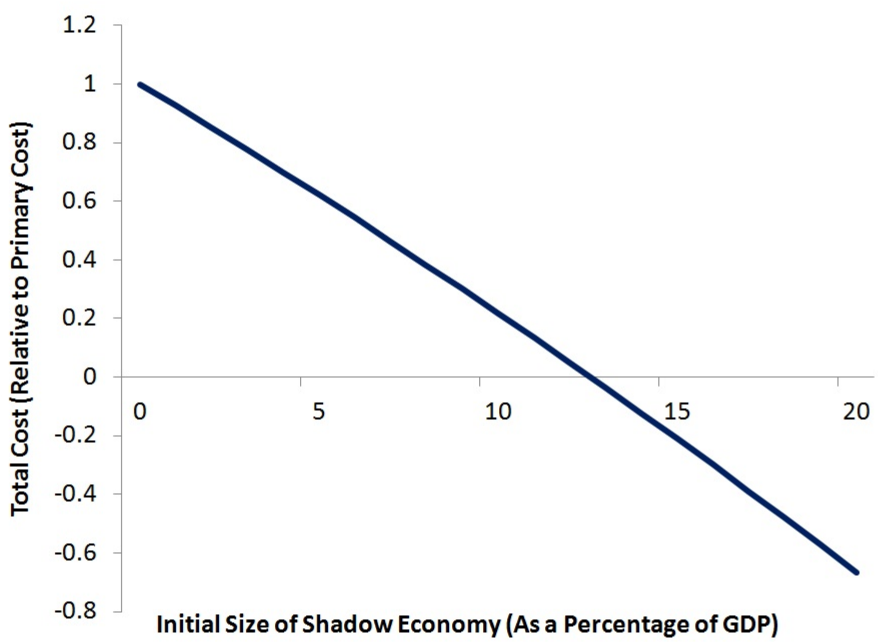

Figure 3.2: Total Cost of Emissions Reduction. All simulations refer to a 10% cut in the polluting good. Source: authors' simulations.

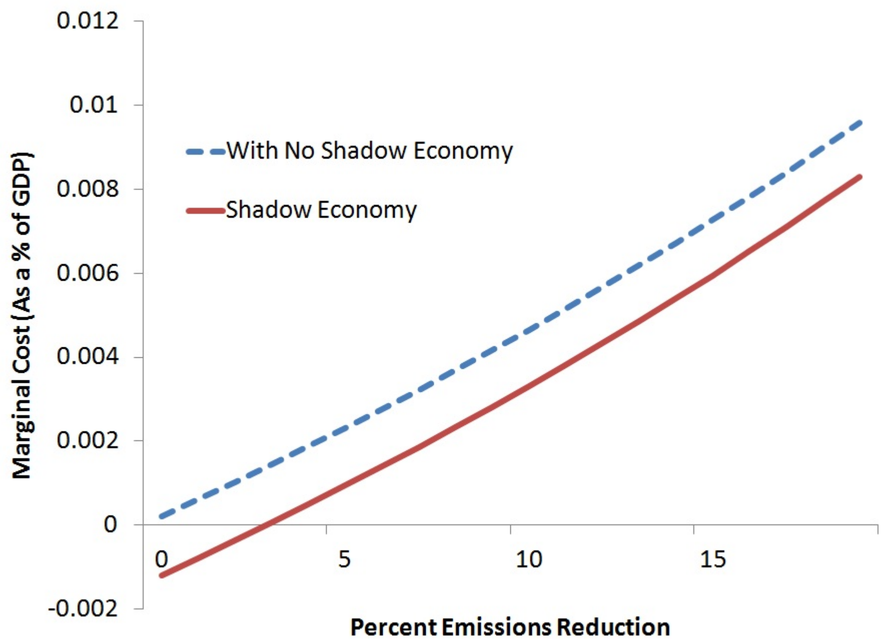

Figure 3.3: The Marginal Cost of a 1% Reduction in the Polluting Good. Source: authors' simulations.

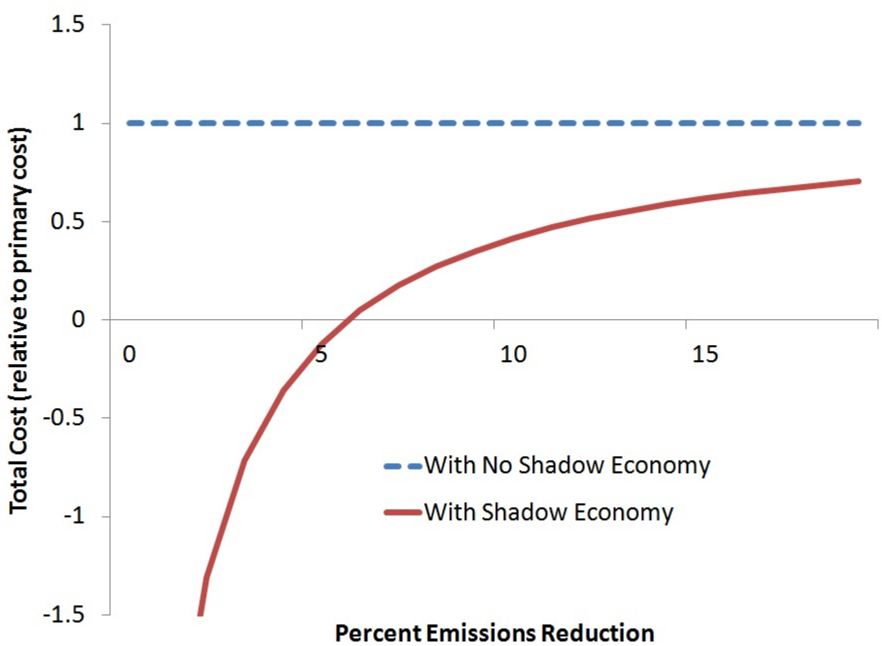

Figure 3.4: The Reduction in Total Cost of Emissions Reduction, as a Result of the Shadow Economy. Source: authors' simulations.

Table 3.1: Ratio of "second best" total cost to primary cost

Pollution reduction	10%	25%	50%
Central Case	0.35	0.78	0.92
Size of polluting industry			
Low	0.33	0.77	0.92
High	0.44	0.81	0.93
Size of shadow economy			
Medium	-0.21	0.58	0.85
High	-1.15	0.26	0.73
Highest	-2.80	-0.30	0.53
Informal production elasticity			
Low	0.47	0.82	0.93
High	-0.62	0.45	0.81
Ratio of energy intensity in manufacturing to formal services			
Very Low	0.63	0.89	0.97
Low	0.46	0.82	0.94
Medium	0.29	0.75	0.91
Ratio of energy intensity in formal services to informal services			
Low	0.01	0.65	0.86
High	0.47	0.83	0.94

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