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RESOURCES FOR THE FUTURE

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Abstract

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.

Keywords: Environmental regulation; Pigouvian tax; tax evasion; green tax swap; tax interactions

JEL Classification Codes: H21; H26; Q53; Q54

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).

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

[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).

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 that 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.

2 A Two-Good Model Incorporating Costly Tax Evasion

2.1 Assumptions

2.1.1 Households

Consider a representative household economy, where each household must divide its 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 $L_X + L_Y + g = p_X X + p_Y Y$.

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:

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

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:

$$\pi_Y = \max_{L_Y, E_Y} \{p_Y Y - (1 + (1 - E_Y)\tau_L)L_Y - C_Y(E_Y)L_Y\} \tag{2}$$

[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.

2.1.3 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:

$$G = Ng = (1 - E_p)\,\tau_p X + (1 - E_X)\,\tau_L L_X + (1 - E_Y)\,\tau_L L_Y \tag{3}$$

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:

$$\frac{1}{\lambda}\frac{dW}{d\tau_p} = \underbrace{\left[\frac{1}{\lambda}\phi' - ((1 - E_p)\,\tau_p)\right]\left(-\frac{dX}{d\tau_p}\right)}_{Environmental\ Effect} + \underbrace{\sum_{i=X,Y}\left[(1 - E_i)\,\tau_L\right]\frac{dL_i}{d\tau_p}}_{Tax\ Base\ Effect} - \underbrace{\frac{dC_p\,(E_p)}{d\tau_p}X - \sum_{i=X,Y}\frac{dC_i\,(E_i)}{d\tau_p}L_i}_{Tax\ Evasion\ Effect} \tag{4}$$

Detail of this derivation is provided in Appendix A.

2.3 Relation to Prior Literature

In the absence of tax evasion, equation 4 can be rewritten:

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

This result corresponds to those of Bento and Jacobsen (2007) and Williams (2002):

$$\frac{1}{\lambda}\frac{dU}{d\tau_p} = \underbrace{\left(\frac{1}{\lambda}\phi' - \tau_p\right)\left(-\frac{dX}{d\tau_p}\right)}_{Environmental\ Effect} - \underbrace{\tau_L\frac{dl}{d\tau_p}}_{Tax\ Base\ Effect} \tag{5}$$

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

$$\frac{dL}{d\tau_p} = \underbrace{\frac{\partial L}{\partial \tau_L}\frac{d\tau_L}{d\tau_p}}_{Revenue-Recycling\ Effect} + \underbrace{\frac{\partial L}{\partial p_X}\frac{dp_X}{d\tau_p} + \frac{\partial L}{\partial p_Y}\frac{dp_Y}{d\tau_p}}_{Tax-Interaction\ Effect} \tag{6}$$

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

$$\begin{aligned} \tfrac{1}{\lambda}\tfrac{dW}{d\tau_p} &= \underbrace{\left(\frac{1}{\lambda}\phi' - (1-E_p)\,\tau_p\right)\left(-\frac{dX}{d\tau_p}\right)}_{Environmental\ Effect} \\ &+ \underbrace{\sum_{i=X,Y}\left[(1-E_i)\,\tau_L\right]\frac{\partial L_i}{\partial \tau_L}\frac{d\tau_L}{d\tau_p}}_{Revenue-Recycling\ Effect} \\ &+ \underbrace{\sum_{i=X,Y}\left[(1-E_i)\,\tau_L\right]\left(\frac{\partial L_i}{\partial p_X}\frac{dp_X}{d\tau_p} + \frac{\partial L_i}{\partial p_Y}\frac{dp_Y}{d\tau_p}\right)}_{Tax-Interaction\ Effect} \\ &\underbrace{-\frac{dC_p\left(E_p\right)}{d\tau_p}X - \sum_{i=X,Y}\frac{dC_i\left(E_i\right)}{d\tau_p}L_i}_{Tax\ Evasion\ Effect} \end{aligned} \tag{7}$$

2.4 Welfare Analysis

Comparing equation 7 with equations 5 and 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 that has been overlooked in the previous literature.

[4] Note that the revenue recycling effect can be rewritten:

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

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).

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 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 heterogeneous, is presented in section 3.

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.

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 that 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.

[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.

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 that 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 increased 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.

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 how much energy 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 that 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) studied design issues in implementing a carbon tax for the United States. They concluded that tax collection covering 80% of U.S. 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 embodied in equations 4 and 7 will still apply if the environmental tax is easy to evade, the effects described here may not be welfare-enhancing.

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 the absence of this 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 U.S. Department of Commerce, Bureau of Economic Analysis (2007), 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 that 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 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.

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-good 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 taxes 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 that 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.

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.

4.1 Structural Model

4.1.1 Households

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

$$U = \left(\alpha_{UG} C^{\frac{\sigma_U - 1}{\sigma_U}} + \alpha_{Ul} l^{\frac{\sigma_U - 1}{\sigma_U}}\right)^{\frac{\sigma_U}{\sigma_U - 1}} \tag{8}$$

$$C = \left(\alpha_{CX} X^{\frac{\sigma_G - 1}{\sigma_G}} + \alpha_{CY} Y^{\frac{\sigma_G - 1}{\sigma_G}} + \alpha_{CZ} Z^{\frac{\sigma_G - 1}{\sigma_G}}\right)^{\frac{\sigma_G}{\sigma_G - 1}} \tag{9}$$

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:

$$p_X X + p_Y Y + p_Z Z = L + g \tag{10}$$

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.

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:

$$C_i\left(E_i\right) = \frac{A_i}{N_i + 1} E_i^{N_i+1} \tag{11}$$

$$MC_i\left(E_i\right) = A_i E_i^{N_i} \tag{12}$$

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.

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.

$$\tau_L\left(\left(1 - E_X\right) L_X + \left(1 - E_Y\right) L_Y + \left(1 - E_Z\right) L_Z\right) + \tau_E\left(1 - E_p\right) X = G = gN \tag{13}$$

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.

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.

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 11 and 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) performed a unique study in which they estimate the response of tax evaders to flat-tax reform in Russia. This estimate is the most applicable for the purposes of this paper, since it evaluates a macroeconomic response to a systemwide tax reform. They report an elasticity of tax evasion with respect to the tax rate of 0.376.

The baseline size of the polluting sector is 2.7% of the economy, following Bento and

[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 (Office of Management and Budget 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.

Jacobsen (2007). This simulation uses the size of the self-employed sector as an identifying characteristic that 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 U.S. Department of Commerce, Bureau of Economic Analysis (2007), 7.4% of employees in the U.S. are self-employed.

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

4.3.1 The Tax Evasion Effect

Calibrated marginal cost curves of tax evasion are illustrated in figure 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 2. Each point along the horizontal axis 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 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 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.

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 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 are summarized in figure 6. As this diagram shows, the total reduction in welfare cost from a double dividend reform increases when the asymmetry being reduced is greater. Cost savings range between 30% and 60% for these simulations.

In the U.S., where the self-employed make up 7.4% of the employed, 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.

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.

5.1 Calibrating the Model

The countries selected for this section are the top 30 carbon dioxide emitters, as reported by the Millennium 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 Administration International 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 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 a 5% rate. Each country's initial tax level was set to its tax burden. Data are summarized in table 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.

[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 from 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.

[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.

5.2 Results

Table 2 summarizes these results.[12] Several observations are apparent by comparing the inputs from table 1 and the results in table 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 greater 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 greater portion of the welfare benefits than asymmetric evasion. In countries with high evasion, spending on evasion is likely to be high, the cost of evasion can even overwhelm the welfare cost of double dividend reform. Asymmetric evasion is important when high levels 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 that 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.

6 Conclusion

Many of the countries that are the most significant greenhouse gas emitters, such as 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 toward taxes that are difficult to evade. This paper has argued that, for many of these

[12] One area of heterogeneity between countries that is not explored in section 5 is the differences among tax rates among 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 provide incentives for 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.

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 structures 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 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 toward environmental taxes can have extremely low or negative costs, even when carbon taxes are implemented unilaterally.

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Figure 1: The marginal cost curves of labor tax and pollution tax evasion. Curves are calibrated to honesty rates and costs in the two-good model.

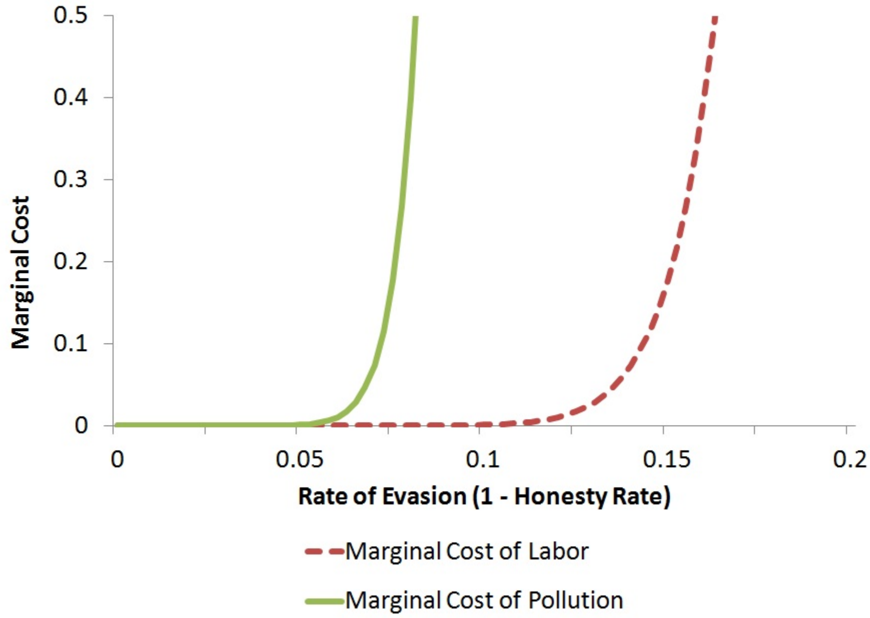

Figure 2: Labor tax and pollution tax rates necessary to cut emissions 10% while maintaining the same level of government spending

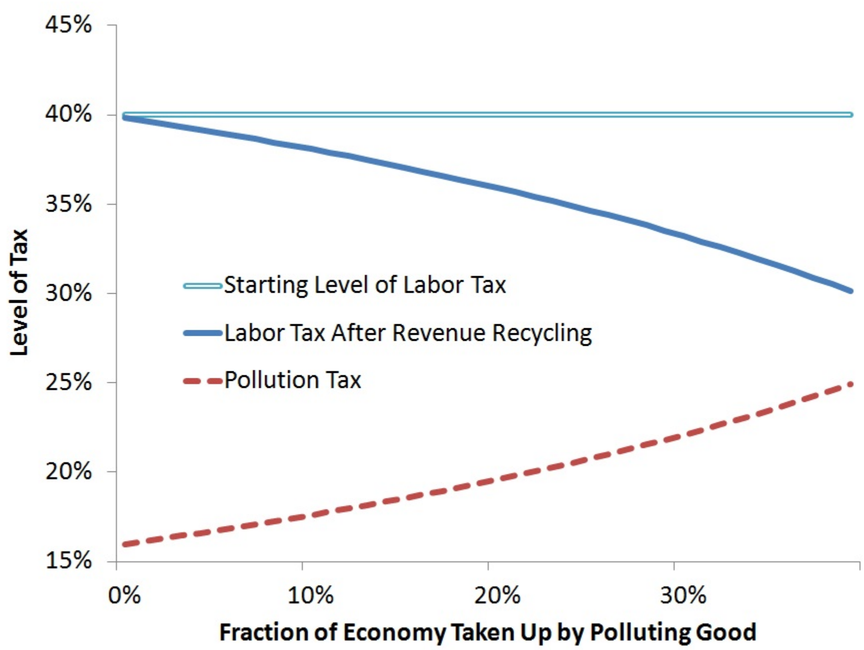

Figure 3: Total costs of evasion after a double dividend reform

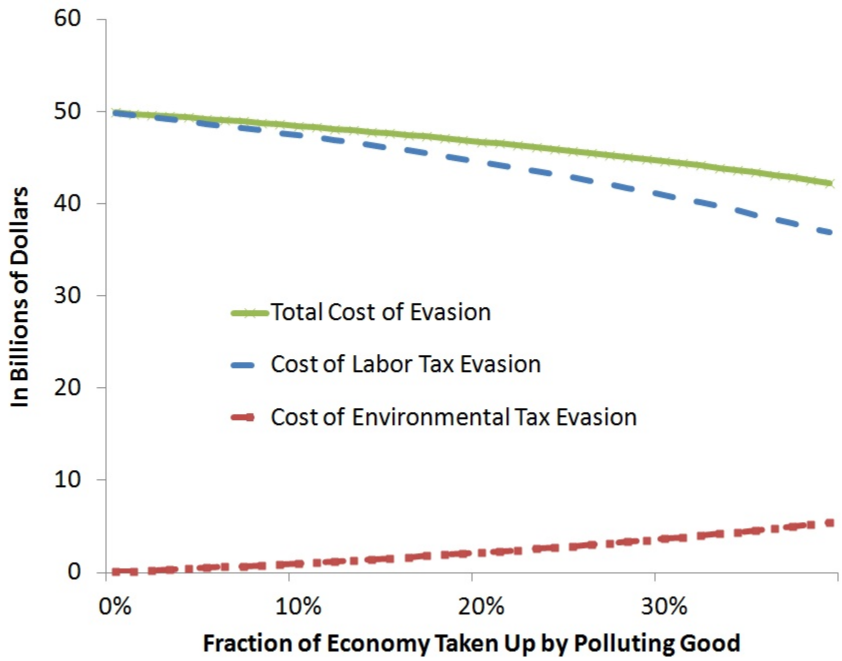

Figure 4: Total welfare cost of double dividend tax reform (10% cut in emissions)

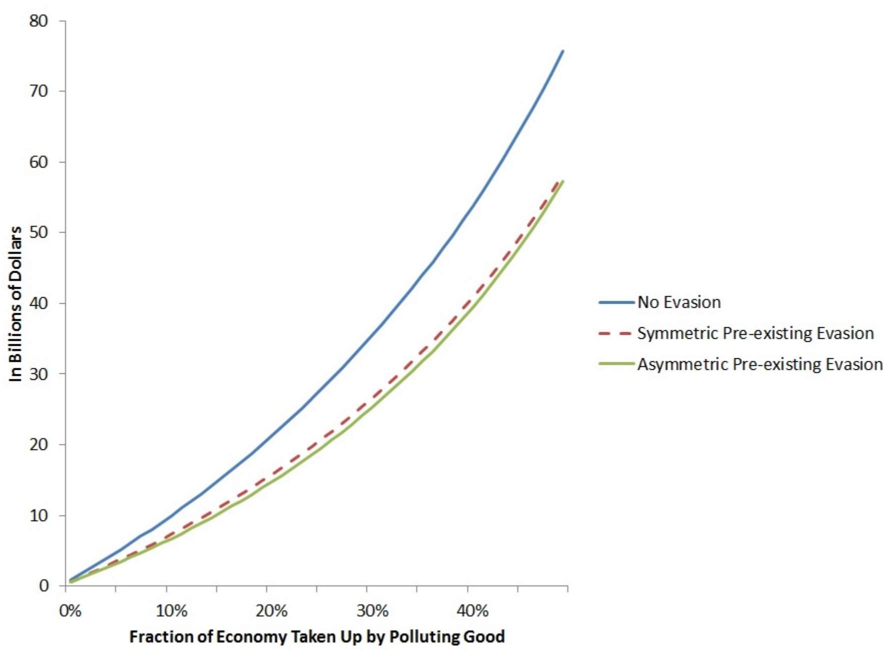

Figure 5: The total welfare cost of double dividend reform with a 10% cut in emissions for two cases are presented here. The first assumes that the clean goods evade labor taxes at the same rate; the second has different levels of evasion between sectors of clean goods.

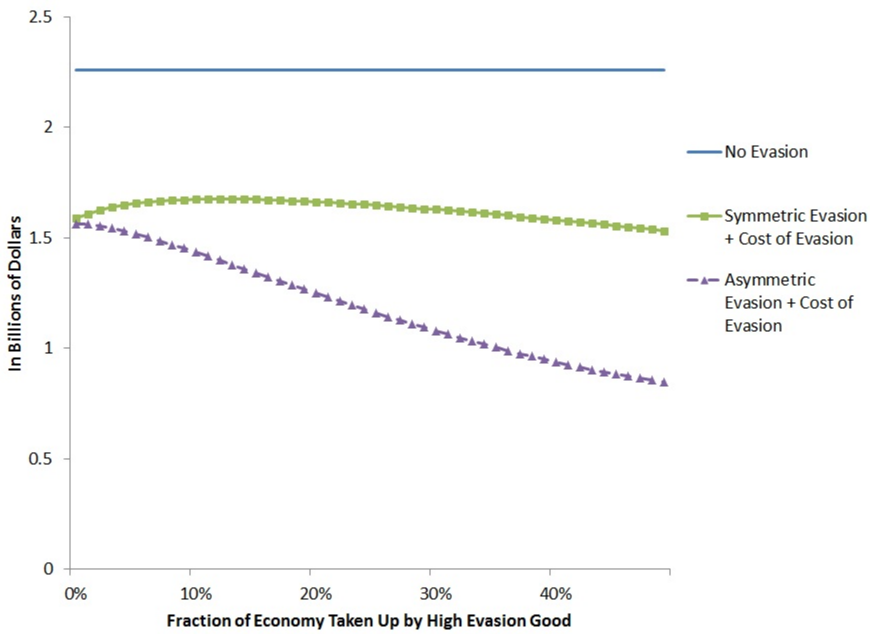

Figure 6: Percentage of welfare costs cut as a result of the existence of costly evasion, and as a result of the existence of asymmetric tax evasion

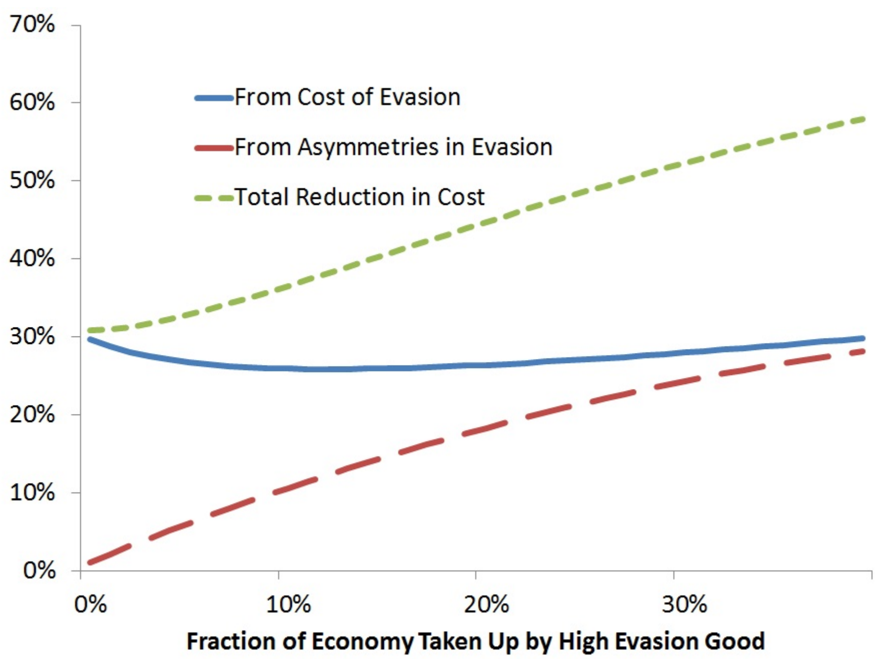

Table 1: Calibration parameters used in international version of model

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 Millennium 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 U.S. dollars, current prices. The sizes of each country's fossil fuel energy sectors are given in billions of dollars, current prices.

Table 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 three 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 4 and 20.

For the two-good model of equation 4, the constrained maximization problem for the household is:

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

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

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

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

$$\frac{1}{\lambda}\frac{dW}{d\tau_p} = -\frac{dp_X}{d\tau_p}X - \frac{dp_Y}{d\tau_P}Y - \frac{1}{\lambda}\phi'(X) \tag{14}$$

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

$$p_X = 1 + H_X\tau_L + H_p\tau_p + C_X(H_X) + C_p(H_p) \tag{15}$$

$$p_Y = 1 + H_Y\tau_L + C_Y(H_Y) \tag{16}$$

We take the derivatives of these functions with respect to τ_p and plug them into equation 14.

Next we observe that the derivative of government spending G from equation 3 with respect to τ_p must be 0 in the presence of a revenue-neutral tax reform. Hence,

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

Plugging this into the result from the above work, we derive equation 4.

Appendix B: Full Version of the Three-Good Model

Assumptions

To make it easier for the reader to compare this model with the model from section 2, we follow the same organization in this section. Assumptions stated here are in addition to those in section 2.1.

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 2.1.1 except there are now three goods.

Firms

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

$$Z = L_Z \tag{17}$$

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 2.1.2, we further assume:

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:

$$\pi_Z = \max_{L_Z, H_Z} \{p_Z Z - (1 + H_Z \tau_L) L_Z - C_Z(H_Z) L_Z\} \tag{18}$$

Government

The government now receives tax revenue from all three sectors:

$$G = Ng = H_p \tau_p X + H_X \tau_L L_X + H_Y \tau_L L_Y + H_Z \tau_L L_Z \tag{19}$$

[14] Self-employment has been widely linked to higher tax evasion opportunities. See, for example Engstrom and Holmlund (2006) or Torrini (2005).

Welfare Effects of a Pollution Tax

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

$$\frac{1}{\lambda}\frac{dU}{d\tau_p} = \underbrace{\left[\frac{1}{\lambda}\phi' - (H_p\tau_p)\right]\left(-\frac{dX}{d\tau_p}\right)}_{Environmental\ Effect} + \underbrace{\sum_{i=X,Y,Z}[H_i\tau_L]\frac{dL_i}{d\tau_p}}_{Tax\ Base\ Effect} - \underbrace{\frac{dC_p(H_p)}{d\tau_p}X - \sum_{i=X,Y,Z}\frac{dC_i(H_i)}{d\tau_p}L_i}_{Tax\ Evasion\ Effect} \tag{20}$$

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 19, the derivation for equation 20 is now straightforward.