Environmental Policy in the Presence of an Informal Sector

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Abstract

We demonstrate how the presence of an untaxed informal sector can sharply lower the cost of environmental and energy tax policy. The mechanism involves substitution between formal and informal labor supply: energy or environmental taxes can improve the efficiency of the tax system by drawing activity into the formal sector. Our result applies to broad classes of corrective taxes and we first present it in a simple analytical framework. We then investigate its magnitude in a simulation model using the case of an energy tax in the U.S., where the informal sector is relatively small. Even so, we find the cost of energy taxes is negative for abatement up to 6% and substantially reduced for large policies. Developing countries provide an important extension: they have much larger informal sectors but at the same time include the potential for substitution into informal fuels. We model these countervailing features and show that the welfare enhancing effect typically dominates, making the efficiency improvements even greater than in the U.S. case.

Keywords: Environmental policy; Informal sector; Second-best; Energy taxes

JEL classification: H23; H21; Q58

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1 Introduction

In recent years, several countries have considered the introduction of environmental and energy taxes in their tax systems.[1] Proponents of these taxes argue that they have the potential to generate a double dividend by simultaneously improving environmental quality and increasing the efficiency of the tax system. Unfortunately, existing literature rejects the validity of this hypothesis (see for example Bovenberg and de Mooij [1994], Goulder [1995], and Parry [1995]). Two competing effects lead to the failure of the double dividend. First, by driving up the price of final (polluting) goods relative to leisure, environmental taxes exacerbate factor market distortions caused by pre-existing taxes. This *tax-interaction effect* produces a negative welfare impact. Second, environmental taxes generate revenues that can be recycled through cuts in pre-existing marginal tax rates. This *revenue-recycling effect* produces a positive welfare impact. Earlier studies show that the revenue-recycling effect is not strong enough to compensate for the tax-interaction effect. As a consequence environmental tax swaps typically exacerbate rather than alleviate the gross efficiency costs of the tax system. A direct implication is that the second best environmental tax should be set below the (first best) Pigouvian level.

Our concern is that these studies typically assume that, prior to the introduction of the environmental tax, the tax system is optimal and consists of a uniform factor tax (i.e. the pre-existing labor tax). However, it is well documented that even the most efficient tax systems fail to cover a collection of economic activities occurring in an informal sector.[2] Estimates of the size of this sector range from 8.4% of GDP

[1] For example Australia began taxing emissions of carbon dioxide at a rate of approximately 24 dollars per ton in July of 2012. Broader taxes on energy use, closely linked to many environmental externalities, have long histories.

[2] The informal sector can include activities that are difficult or costly to track, such as migrant

in the U.S to 16.1% of GDP across OECD countries, with even higher shares in less developed regions.[3]

We allow the presence of informal activity and re-examine the role that environmental taxes play in an optimal tax system. We build on Piggott and Whalley (2001), who show that the gross cost of generating revenue through broad-based taxes can increase substantially in the presence of an informal sector. This is because informal production introduces a second channel (in addition to substitution to leisure) through which formal labor supply is reduced when the labor tax increases. We will show how certain narrower taxes, importantly including those placed on environmental externalities, can conversely become more efficient in the presence of an informal sector.

Our re-examination of the double dividend hypothesis relies on a simple analytical and simulation model. In the spirit of Piggott and Whalley (2001), we model a static economy where households allocate their time between leisure and labor. Labor can be supplied either formally or informally. Households consume manufactured goods, market-traded services, and non-market traded services produced by the informal sector. Consistent with empirical evidence, the energy intensity of manufactured goods will be higher than that for services. We link the higher energy intensity to increased environmental damage.

Our central finding is that a revenue neutral shift toward an energy tax produces a double dividend. This is due to a strengthened revenue-recycling component when taxes are reduced on goods with strong informal substitutes (services in our model).

labor or domestic employment, or illegal activities that operate entirely out of the government's view.

[3]Estimates are from Schneider (2011). 30.4% of GDP in Asia and 43.2% in Africa are estimated to be informal.

The tax swap effectively moves the tax burden toward the energy-intense manufacturing sector, creating lower incentives for substitution from market-traded services into non-market traded services. As the size of the informal sector shrinks the overall tax base increases, improving the efficiency of revenue collection.

The results from our model complement an existing group of studies demonstrating inefficiencies in the tax system that reduce the cost of environmental tax swaps.[4] In contrast to these studies the mechanism we identify here is embedded in the underlying labor supply elasticity. Our effect appears when a portion of this elasticity comes from substitution to informal production, and the goods involved in that substitution are less polluting than average.

We next introduce a simulation model to investigate the magnitude of the effect for a range of plausible parameter values. In a stylized version of the U.S. economy we find that the net impact is to reduce the economic cost of the tax system for pollution reductions of at least 20%. For pollution reductions up to 6% the net cost is negative. This implies that even if there is uncertainty about the benefits from environmental policy, the environmental tax should be part of the optimal tax system.

Finally, we explore the influence of our central findings in the case of developing countries, where the informal sector can be substantially larger and also include more energy-intense activities. We extend the model to account for the fact that energy markets in developing economies may themselves include an informal portion, creating a countervailing leakage effect when formal energy is taxed. In spite of this, we show that our findings on the lowered cost of energy taxes remain and in fact appear

[4]Parry and Bento (2000) show how an environmental tax swap reduces distortions from pre-existing tax exemptions, Bento and Jacobsen (2007) find that energy taxes can capture part of untaxed Ricardian rents, and Liu (forthcoming) shows how energy taxes can fall directly on sectors currently engaged in costly tax-evasion.

stronger than in the U.S. case. To the extent energy is currently subsidized in many developing economies our results also apply: our model suggests a substantial increase in the distortionary cost of a subsidy when an informal sector is present.

Section 2 describes our analytical model and derives the cost of energy taxes with and without an informal sector. Section 3 estimates the magnitude of the effect in a numerical simulation and Section 4 concludes.

2 Model

Piggott and Whalley (2001) introduce a model of optimal taxes that captures substitution between formal and informal parts 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 $\left(S^N\right)$. G and S^M will be the formal, taxed sectors and S^N will be the informal, untaxed sector. Piggott and Whalley show that a revenue-neutral tax reform that broadens a tax from covering only G to including both G and S^M can actually worsen welfare if the resulting expansion of the informal sector (reducing the size of the tax base) dominates.

Our model introduces an energy input to the manufacturing sector and uses it to illustrate the converse effect. As in Piggott and Whalley, a broad labor tax in our model will fall equally on G and S^M. We show that a tax system introducing an energy tax (falling only on G via the energy input) to replace some of the labor tax revenue will perform more efficiently. Intuitively, the lessened dependence on a labor tax causes substitution from S^N to S^M, increasing the size of the tax base and improving welfare.

2.1 Model Structure

2.1.1 Firms

There are four types 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 external damages as a result of pollution in the amount $\phi(E)$. Labor is the only underlying factor of production and production is constant returns to scale:

$$E = L_E \tag{1}$$

Energy firms are taxed in two ways. First, they must pay a labor tax, τ_L, on the labor used. Second, they pay an environmental tax proportional to production, τ_E, which we will increase in the policy scenario. Workers receive an after-tax wage normalized to 1 so the cost of wages to firms is $1 + \tau_L$. Hence, the price of energy is:

$$p_E = 1 + \tau_L + \tau_E \tag{2}$$

Firms that produce manufactured goods G use labor L_G and energy E as inputs. Production is increasing in inputs and constant returns to scale:

$$G = G(L_G, E)$$

Define the price of G using the cost function $C(\cdot)$:

$$p_G = C(\tau_L, \tau_E) \tag{3}$$

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

$$S^M = L_M$$

The price of formal sector services is:

$$p_{SM} = 1 + \tau_L \tag{4}$$

Finally, we have production of informal sector services S^N. This sector again uses only labor but we will now assume rising marginal costs of production and consequently an upward sloping supply curve. The rising marginal cost for informal firms may capture, for example, their inability to scale up capital inputs without bringing their activities into the formal sector.

We assume informal sector production follows:

$$S^N = (L_N)^{\theta_L} \tag{5}$$

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

We combine rising marginal cost with the assumption that formal sector services S^M and informal sector services S^N are perfect substitutes in consumption. The limit to the size of the informal sector, and importantly its elasticity with respect to the tax rate, is then governed by the parameter θ_L. This mechanism, which we draw directly from Piggott and Whalley, provides a simple way to generate co-existence of both formal and informal sectors.[5] Informal sector firms will produce along their supply

[5] See also Keen (2008) and Koreshkoba (2006).

curve until marginal cost (and therefore price) equals that in the formal sector:

$$p_{SN} = 1 + \tau_L \tag{6}$$

As a result of rising marginal cost informal firms accumulate rents on inframarginal production.[6] If informal firms have a marginal cost of labor given by the function $MC(L)$, the rents, accruing to the representative household, are in the amount of:

$$\pi_{SN} = \int_0^{MC^{-1}(p_{SN})} \left[p_{SN} - MC(L)\right] dL \tag{7}$$

2.1.2 Households

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

$$S = S^M + S^N \tag{8}$$

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:

$$U = u\left(G, S, \overline{L} - L\right) - \phi(E) \tag{9}$$

$u(.)$ is the utility from non-environmental goods and is quasi-concave. $\phi(\cdot)$ is the disutility from emissions and is weakly convex. The separability restriction in (9)

[6] We include the equation for completeness, but note that the rents will have no influence on welfare at the margin.

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:

$$p_G G + p_S S = L + h + \pi \tag{10}$$

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

Total labor supply is the sum of all labor used in the economy:

$$L = L_G + L_E + L_M + L_N$$

2.1.3 Government

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

$$hN = \tau_L \left(L - L_N\right) + \tau_E E \tag{11}$$

where N is the number of households in the economy.

2.2 Welfare Analysis

We now express the cost of an increment to the energy tax (with revenue used to cut labor taxes) as a function of the initial size of the informal sector. We first differentiate the household optimization problem above with respect to the energy tax and then impose revenue neutrality through the government budget constraint. This tilts the tax system more toward an environmental tax, holding total revenue raised fixed. We show that, in the setting above, the larger is the informal sector the lower the cost of the environmental tax swap.

Using equations (9) and (10) the household optimization problem is given by:

$$W = u\left(G, S, \overline{L} - L\right) - \phi\left(E\right) - \lambda\left[p_G G + p_S S - L - h - \pi\right] \tag{12}$$

Totally differentiating with respect to τ_E yields:

$$\frac{1}{\lambda}\frac{dW}{d\tau_E} = -\frac{1}{\lambda}\phi'\left(E\right)\frac{dE}{d\tau_E} - \frac{dp_G}{d\tau_E}G - \frac{dp_{SM}}{d\tau_E}S + \frac{d\pi}{d\tau_E} \tag{13}$$

Our proposed tax reform involves the revenue-neutral substitution of energy taxes for labor taxes. Totally differentiating the government budget constraint with respect to τ_E implies:

$$\frac{dhN}{d\tau_E} = \tau_L\frac{d\left(L - L_N\right)}{d\tau_E} + \frac{d\tau_L}{d\tau_E}\left(L - L_N\right) + E + \tau_E\frac{dE}{d\tau_E} = 0 \tag{14}$$

We have $\frac{dp_G}{d\tau_E} = \frac{d\tau_L}{d\tau_E} + \frac{E}{G}$ and $\frac{dp_{SM}}{d\tau_E} = \frac{d\tau_L}{d\tau_E}$ from equations (3) and (4). Finally, we can state profits from equation (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 $\frac{d\pi}{d\tau_E} = L_N\frac{d\tau_L}{d\tau_E}$.

Placing these constraints back into the household problem shown in (13) we can summarize the welfare effect of the energy tax increase:

$$\frac{1}{\lambda}\frac{dW}{d\tau_E} = \underbrace{\left[\left(\frac{1}{\lambda}\phi'\left(E\right) - \tau_E\right)\left(-\frac{dE}{d\tau_E}\right)\right]}_{dWP} + \underbrace{\left[\tau_L\frac{d\left(L - L_N\right)}{d\tau_E}\right]}_{dWS} \tag{15}$$

dWP denotes the primary welfare gain of the policy. It equals the wedge between the social costs of emissions and the energy tax multiplied by the change in emissions. To the extent that the energy tax induces a reduction in emissions, it generates a 'first dividend', that is an improvement in environmental quality (Parry and Bento [2000] and Bento and Jacobsen [2007]).

dWS in (15) reflects the change in total taxable labor supply. It will include tax-interaction and revenue-recycling effects as in the prior literature,[7] but now also includes a third effect coming through substitution out of informal labor. This is the core of our theoretical result and, in contrast to prior studies, permits labor supply and welfare effects to be positive.

To see how, we further decompose the term to look at the change in informal labor supply given in $\frac{dL_N}{d\tau_E}$. We show that L_N unambiguously declines as a result of the energy tax, increasing formal labor supply. This always reduces the cost of policy relative to settings without this channel, and in some cases will be enough to reverse the sign of the overall labor supply change. The magnitude of the effect will depend on the relative size of the informal sector and key elasticities, examined in simulation.

Change in informal labor:

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

[7]Goulder (1995) shows that a negative tax interaction effect from the energy tax will dominate any benefits from lower labor taxes coming through revenue recycling. The net effect is a reduction in labor supply and a negative effect on welfare.

The derivative on the last line is negative as long as the energy tax raises revenue: θ_L is a parameter between 0 and 1 and the added revenue allows the labor tax rate to decline. The size of the switch out of informal labor is also increasing in θ_L. Intuitively, the larger is θ_L the better the substitution between formal and informal labor in production of services.

2.3 Assumptions on Energy Intensity and Informal Goods

A key assumption above is that energy enters only through the manufacturing sector. We have experimented with an extension of the analytical model allowing energy consumption in both manufacturing and services. We show that the direction of the welfare effect then depends on the relative energy intensities: when manufacturing is more energy intense (as above), the policy draws labor out of informal production and enhances welfare. Conversely if services (or other goods with strong informal substitutes) are more energy intense the policy instead pushes labor into the informal informal sector and reduces welfare.[8] We investigate a range of energy intensities below, noting that the empirical evidence strongly suggests manufacturing and industry are more energy intense than services.[9]

We also assume above that services (as opposed to industry or manufacturing) have the best informal substitutes. Some empirical support for this assumption can be offered by examining the composition of production in the informal sector. The evidence is limited by the nature of informal production, but Lemieux *et al* (1994) offer

[8]Interestingly, the case with large amounts of energy use in services also introduces a countervailing effect: energy taxes may now act as a surrogate tax on the informal sector itself. This is in the spirit of earlier work in Liu (forthcoming) and operates to improve welfare.

[9]In the U.S. the manufacturing sector is approximately 3.1 times as energy intense as services. Details appear in the calibration below.

some insight: in their survey, total informal labor market participation is estimated to be 8.5%, with 2.8% of all workers employed in informal construction, 2.7% in informal services, and the remainder mainly in transportation, trade, and finance. This is consistent with the idea that the informal sector provides a closer substitute for low energy-intensity services than it does for high energy-intensity industrial and manufacturing output.

3 Simulation

We conduct a set of simulations investigating the magnitude of the effect identified above. The central results appearing in Section 3.3 follow the theoretical model closely and calibrate to estimates of energy intensities and informal sector activity in the U.S. We find that the presence of an informal sector reduces costs dramatically. We consider a broad range of alternative parameterizations, particularly investigating sensitivity to labor supply elasticities.

Section 3.4 presents a second set of simulations where we instead calibrate to developing economies. The informal sector is much larger, increasing the importance of the effect we study. Developing economies also tend to use much larger quantities of untaxed, "informal" sources of energy (e.g. firewood). This second source of informality creates a countervailing effect coming from leakage to informal fuels when formal energy sources are taxed. The simulation in Section 3.4 therefore includes both factors, moving somewhat farther from the simple theoretical model. The results suggest that the effect from substitution in informal goods dominates leakage to informal fuels; when we include both types of informality overall costs are still reduced.

3.1 Numerical Model

Households Utility is now specified to follow a nested constant elasticity of substitution (CES) form:

$$U = \left(\alpha_{UG} C^{\frac{\sigma_U - 1}{\sigma_U}} + \alpha_{Ul} l^{\frac{\sigma_U - 1}{\sigma_U}}\right)^{\frac{\sigma_U}{\sigma_U - 1}} \quad (16)$$

$$C = \left(\alpha_{CG} G^{\frac{\sigma_C - 1}{\sigma_C}} + \alpha_{CS} S^{\frac{\sigma_C - 1}{\sigma_C}}\right)^{\frac{\sigma_C}{\sigma_C - 1}} \quad (17)$$

where l is leisure and C is the utility derived from consumption of goods and services. 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 baseline sizes of the sectors. We abstract from environmental damages to utility for the simulations and present results in terms of cost to achieve varying reductions in energy use. Estimates of the size of the environmental benefit could later be paired with our cost results to determine an optimal corrective tax.

As in the analytical model market-traded services $\left(S^M\right)$ and informal sector services $\left(S^N\right)$ are perfect substitutes in consumption (we again limit the overall ease of substitution between the two using production function parameters):

$$S = S^M + S^N \quad (18)$$

The household budget constraint is:

$$p_G G + p_S S = L + h + \pi \quad (19)$$

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. The price of S^N and S^M is p_S.

Firms As above there will be four types of firms, producing energy (E), manufactured goods (G), formal sector services $\left(S^M\right)$, and informal sector services $\left(S^N\right)$. Here we make a key departure from the theoretical model: we relax the assumption that only G consumes the energy intermediate and allow energy to enter the production of both goods: E_{SM} and E_{SN} will indicate energy use in services and when calibrated allow us to capture cases like those in many developing economies where the informal sector itself consumes significant quantities of energy. We investigate a variety of cases in the sensitivity analysis.

Production is given as follows:

$$E = L_E \tag{20}$$

$$G = \gamma_G \left(\alpha_{LG}^{1/\sigma_G} L_G^{\frac{\sigma_G - 1}{\sigma_G}} + \alpha_{EG}^{1/\sigma_G} E_G^{\frac{\sigma_G - 1}{\sigma_G}} \right)^{\frac{\sigma_G}{\sigma_G - 1}} \tag{21}$$

$$S^M = \gamma_{SM} \left(L_{SM}\right)^{\theta_{LM}} \left(E_{SM}\right)^{\theta_{EM}} \tag{22}$$

$$S^N = \gamma_{SN} \left(L_{SN}\right)^{\theta_{LN}} \left(E_{SN}\right)^{\theta_{EN}} \tag{23}$$

L_i and E_i represent the amounts of labor and energy used in production of good i. The parameter σ_G controls the elasticity of substitution between inputs and α_{LG} and α_{EG} determine baseline 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.

The parameters γ_{SN}, θ_{LN}, and θ_{EN} control the relationship between informal sector labor L_N and informal sector production S^N. These are key to the elasticity of informal labor use and so we explore a variety of different calibrations below. 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, which meet remaining demand. The upward sloping supply curve in the informal sector results in inframarginal rents that accrue back to the household:[10]

$$\pi_N = p_S S^N - L_N - p_E E_{SN} \tag{24}$$

L_E, L_G, L_M, and L_N comprise total labor supply (L). Total energy (E) is represented by the equation:

$$E = E_G + E_{SM} + E_{SN} \tag{25}$$

Government The government receives revenue from taxes on labor and from the energy tax when levied. We assume the energy tax increase is always revenue neutral:

$$\tau_L L + \tau_E E = H = hN \tag{26}$$

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

Solution Equilibrium is a set of taxes and prices such that i) the emissions reduction goal is achieved (here, equivalent to a reduction in energy use), ii) government revenue is maintained at H, and iii) the goods and labor markets clear. The model sets the

[10] These effects turn out to be small economically; we include them for completeness in closing the equilibrium model.

Table 1: Simulation Model Parameters

Informal Sector	
Fraction of economy	8.4%
θ_{LN}	0.37
θ_{EN}	0.03
Composition of economy	
Formal services (energy intensity)	80% (2.6%)
Industry (energy intensity)	20% (8.2%)
Demand elasticities and base tax rates	
σ_U	0.9
σ_C	1.01
τ_E	0
τ_L	0.4

pre-tax wage as the numeraire and uses a derivative-based search over energy and labor taxes to meet the emissions and revenue constraints.

3.2 Calibration

The baseline is a simplified version of the U.S. economy with three sectors (manufactured goods, formal services, and informal services), and taxes on labor and energy inputs. Table 1 lists the central case parameter values we employ.

We first calibrate to the result from Schneider (2005) that the informal sector makes up 8.4% of the U.S. economy. We vary this value between zero and 40% in alternative simulations. We next specify the parameters governing production in the informal sector. This appears as the elasticity of substitution between formal and informal production, determined in the model via θ_{LN} and θ_{EN}. In our central case we follow Piggott and Whalley, using a baseline specification such that $\theta_{LN} + \theta_{EN} = 0.4$

(with shares determined to match the energy intensities below). This corresponds to an elasticity between the labor tax rate and the size of the informal sector of 0.2. Larger elasticities will increase the magnitude of our result: for example Peter (2009) uses a panel of tax rate changes and informal sector activity to estimate values for this elasticity between 0.7 and 0.9. By comparison, the smaller value of 0.2 in our central case provides us with conservative estimates of the cost savings. Larger and smaller elasticities as well as differences in the size of the informal sector overall are explored in the sensitivity analysis.

The size and energy intensities of the formal production sectors are defined using U.S. Bureau of Economic Analysis input-output tables. Energy intensity (in value terms) for services is 2.6%, and the energy intensity for industry is 8.2%. The baseline size of the energy sector as a whole is 4.1% of the economy, consistent with the value of fossil fuel production and imports relative to GDP.[11] Sensitivity to these share parameters is also considered below.

Finally, the elasticities of substitution in utility σ_U and σ_C are set at $\sigma_U = 0.9$ and $\sigma_C = 1.01$, implying close to average substitution and similar to prior work. We further assume a benchmark labor tax of $\tau_L = 0.4$, also following the literature (see Bento and Jacobsen [2007]). Drawing from the literature in setting these elasticities and baseline tax rates makes our main results more easily comparable with earlier studies. We consider a broad range of values in the sensitivity analysis below.

[11] Taken from 2005 Energy Information Administration statistics on the value of fossil fuel production and net imports.

3.3 Simulation Results

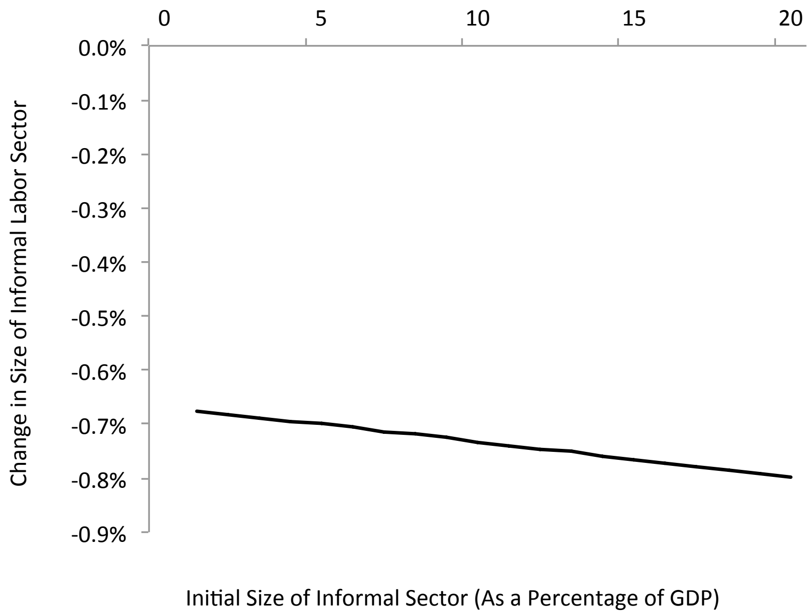
3.3.1 Tax Induced Substitution out of the Informal Sector

We begin by illustrating the mechanism at work in the analytical model, comparing the effects of energy taxes on labor markets as the informal sector becomes more important. Figure 1 illustrates the movement of labor away from the informal sector when the tax system focuses more on energy and less on labor taxes. Each point on the horizontal axis is a separate simulation, assuming different sizes for the informal sector and an energy tax large enough to reduce energy use by 10%. Our central case for the U.S. sets the informal sector size at 8.4%: corresponding on the figure to a decrease in informal labor supply of about 0.7%. Changes to the informal labor supply depend mainly on the elasticity with respect to the labor tax (0.2 in our central case), making the percentage changes roughly constant across different initial magnitudes of informal production.

In contrast, the total cost of policy depends on the absolute shift in labor supply. The effect on cost appears in Figure 2: there is a sharp decline in total cost as we move away from the baseline (no informal sector) case toward cases with large informal sectors. Flows from informal labor supply make ever-more important contributions to the taxable base, reducing the cost of policy until it becomes negative when the initial size of the informal sector exceeds 13% of GDP. In these cases, a "strong double dividend" as defined in Goulder (1995) is realized; the welfare gains from movements in labor become strong enough to fully offset the primary distortion from the energy tax.

Table 2 shows how each of the key variables in our simulation move as we introduce an energy tax, varying the policy goal between 10% and 50% reduction. As the energy

Figure 1: Tax-Induced Substitution out of the Informal Sector

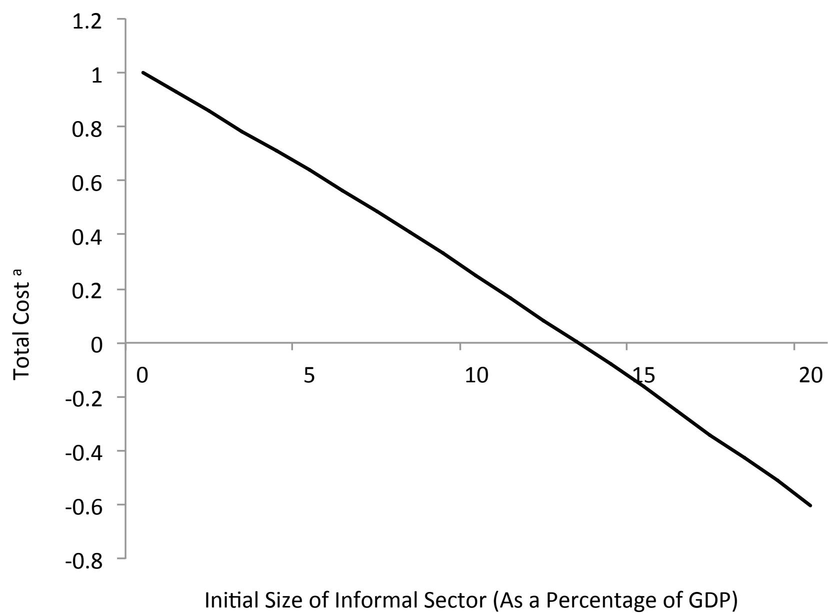


tax is introduced, labor taxes fall and labor flows out of the informal sector into the formal sector. These effects appear on the first four lines of the table. The final three rows display changes in aggregate consumption: changes in industrial output and welfare cost are relatively small in this case and are driven by the ease of substitution out of energy, a parameter we vary in the sensitivity analysis below.

3.3.2 Cost Under Alternative Emissions Goals

We now turn to the welfare costs of policy measured as equivalent variation. We allow the stringency of the emissions goal to vary, holding the size of the informal sector fixed at 8.4% (approximating the U.S. case). Figure 3 illustrates the components of marginal cost using four sets of simulations: the heavy, dashed "Primary Cost" line shows the distortions created by the energy tax alone, rising as the stringency of the

Figure 2: Total Cost of Emissions Reduction

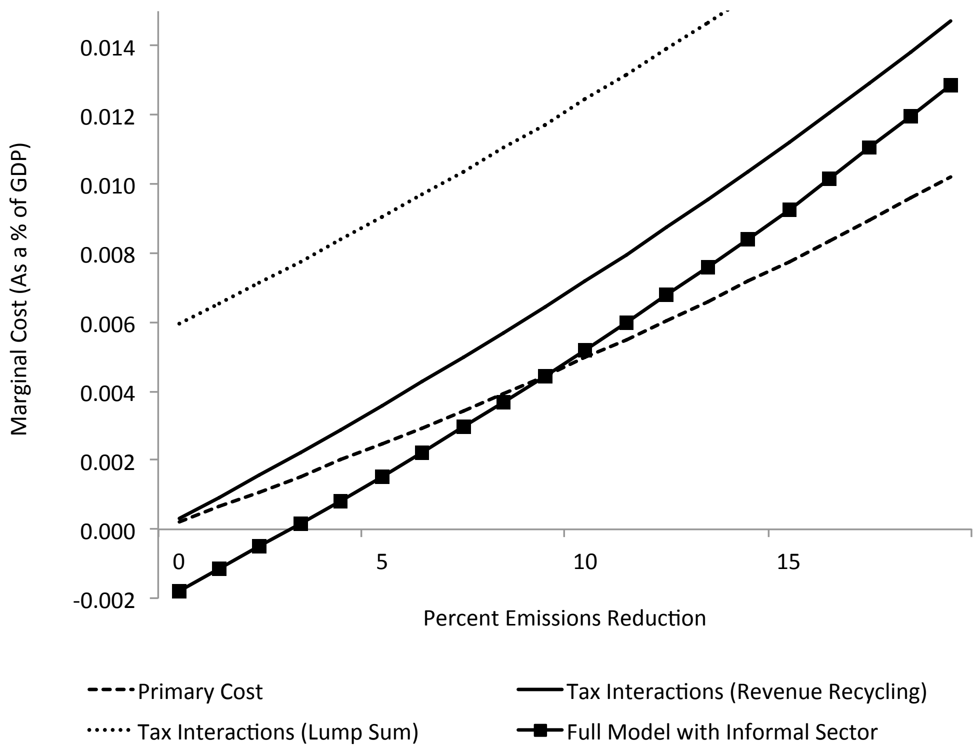


[a]Normalized to one in the case when there is no informal sector.

Table 2: Central Case Simulation Results

Pollution reduction	10%	25%	50%
Pollution tax rate	0.16	0.48	1.42
Labor tax rate (initial value 0.4)	0.394	0.385	0.374
Change in formal labor (%)	0.05	0.11	0.14
Change in informal labor (%)	-0.72	-1.72	-3.05
Change in industrial sector size (%)	-0.48	-1.41	-3.79
Change in services sector size (%)	0.13	0.24	0.10
Equivalent variation (% of total income)	-0.006	-0.084	-0.501

Figure 3: Marginal Cost of Emissions Reductions



target increases. The lightly dashed "Tax Interactions" line above it looks at the cost of policy in the presence of pre-existing labor taxes, assuming revenue is returned lump sum. In contrast, the solid "Tax Interactions" line displays the same policy when the revenue is instead recycled to reduce the distortionary labor taxes. This is the optimal second-best case examined in previous work. Finally, the "Full Model" line displays our key result: when the economy also includes an informal sector there is a sharp downward shift in marginal cost.

Figure 4 presents the corresponding total costs, now expressed as ratios relative to primary cost. Tax interactions create a roughly 40% increase over primary cost, shown in the solid line.[12] Since the presence of an informal sector causes a shift in marginal cost, in contrast to the proportional change from interactions, its impact is felt much more strongly for less stringent policies. For the U.S., a country with relatively little informal production, negative total costs can be achieved while cutting emissions up to 6%. Under more ambitious energy tax policies achieving up to 20% abatement, total cost in the presence of the informal sector is lower than the primary cost when no pre-existing tax distortions are present. These results suggest that the optimal tax on energy may lie well above the (first-best) pigouvian level.

3.3.3 Alternative Parameters

We test the sensitivity of our main simulation findings to alternative parameters, summarized in Table 3. The numbers in the table show the ratio of total cost with an informal sector to total cost without an informal sector for fixed reductions in energy use of 10, 25, and 50%. Numbers less than 1.0 therefore indicate cost savings of the sort we describe above. The value of 0.38 appearing on the first line, for example, is the ratio between the heavy solid line and the dashed line on Figure 4 at a 10% emissions reduction: it indicates a 62% reduction in total cost when considering the informal sector.

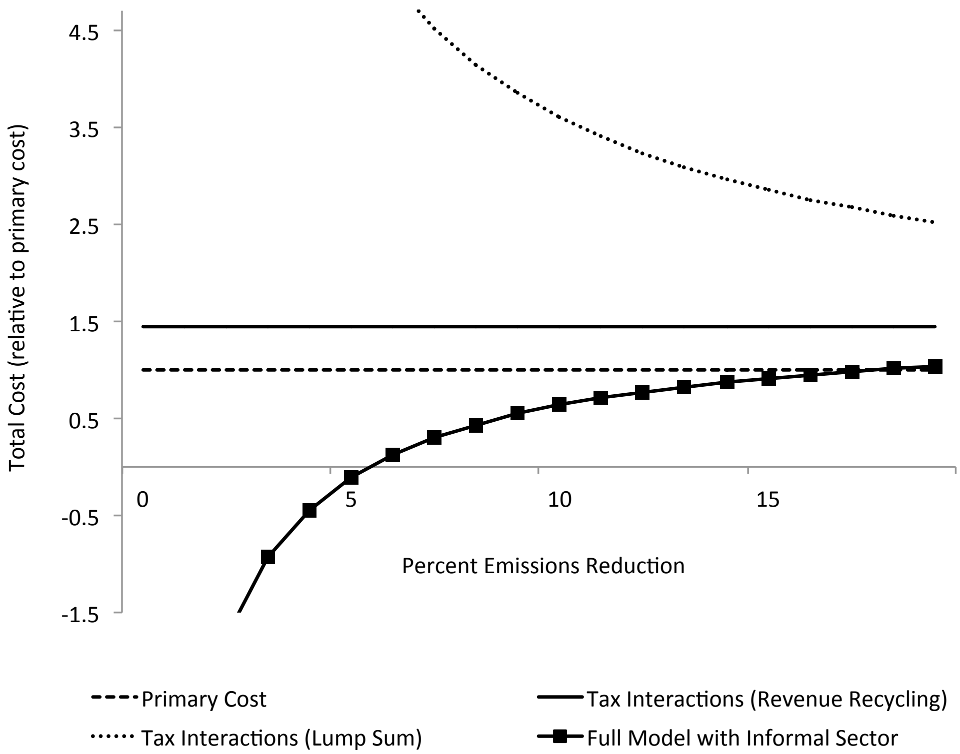
Varying the size of the informal sector: The central case follows the U.S. with a relatively small informal sector comprising 8.4% of GDP. Schneider (2005) reports a larger average for the OECD (about 15%, "medium" in the table), with even greater

[12] These baseline tax interactions are somewhat larger than the 30% found in earlier studies (e.g. Bento and Jacobsen [2007]). This comes from our inclusion of energy in production of both commodities, lessening the role of substitution in demand. This increases the energy tax (and therefore the tax interactions) associated with any given emissions goal. It makes our results more conservative in that the initial distortion is harder to overcome.

Table 3: Ratio of Total Cost With an Informal Sector to Total Cost Without

Pollution reduction	10%	25%	50%
Central Case	0.38	0.79	0.92
Size of informal sector			
Medium	-0.16	0.60	0.86
High	-1.06	0.30	0.75
Highest	-2.63	-0.23	0.56
Informal production elasticity			
Low	0.49	0.82	0.94
High	-0.56	0.48	0.82
Size of polluting industry			
Low	0.33	0.77	0.92
High	0.45	0.82	0.93
Relative energy intensity of manufacturing and services			
Very Low	0.58	0.87	0.96
Low	0.47	0.82	0.94
High	0.33	0.77	0.91
Energy intensity of the informal services sector			
High	0.02	0.65	0.86
Low	0.51	0.84	0.95

Figure 4: Total Cost of Emissions Reduction



values for Asia (25%, "high") and Africa and Latin America (40%, "highest").

The size of the informal sector plays a key role in the magnitude of our results: all three of these cases result in negative costs for a 10% reduction in energy use. Further, important cost savings now also appear even at much higher levels of abatement.

Varying the elasticity between formal and informal production: This elasticity, the sum of the θ_{LN} and θ_{EN} parameters, governs the key mechanism in our analysis: elasticity of informal labor with respect to the tax rate. Our central estimate is $\theta_{LN} + \theta_{EN} = 0.4$ (for a tax rate elasticity of 0.2). We vary the sum of these parameters between 0.33 (low) and 0.67 (high), translating to a range of tax rate elasticities between 0.1 (low) and 0.7 (high). High elasticities magnify our effect – more labor will be drawn out of the informal sector due to the tax swap. Even in the low case we find the informal sector remains very important at 10% abatement, still reducing the cost of policy by half relative to a case without informal labor.

Varying the size of the polluting industry: The polluting industry is 4.1% of the total economy in the central case, varied here between 1% (low) and 10% (high). As the polluting sector grows in size the cost of emissions tax distortions grows somewhat more rapidly than revenues. This reduces the relative importance of growth in the formal tax base (since it depends on emissions tax revenue), adjusting the cost savings slightly.

Varying the relative energy intensity of manufacturing and services: Our analysis depends on the relative energy intensity of goods with poor informal substitutes ("manufacturing" in the model) and those with strong informal substitutes ("services"). Our central case follows U.S. input-output data, indicating manufacturing uses about 3.1 times as much energy per dollar of output. However, developing countries in particular may produce certain energy intense goods in the informal portion of the economy. This will tend to raise the average energy intensity of the sector with strong informal substitutes. To explore this we vary the ratio of energy intensities considering equality (very low), 2 (low), and 4 (high).

When the energy intensities are equal ("very low" in the table) we still find important reductions in cost even though the informal labor channel is no longer at work. In this case the energy tax is serving as a surrogate method for taxing the informal sector, broadening the tax base directly rather than through shifts in labor supply. However, and in contrast to earlier studies, our findings in this paper do not rely on this effect. They in fact grow even stronger when the services and informal sectors use very little or no energy. The explanation returns to our main mechanism: when manufacturing uses all or most of the energy (the "high" ratio in the table) it magnifies the importance of the labor tax cut for the services sector. This tax cut determines the price wedge between the formal and informal service sectors, increasing the movement of labor out of informal services.

Varying the energy intensity of the informal services sector: We now assume that energy use in manufacturing and formal services are as in the central case, and now vary energy intensity of informal services separately. The table examines both the case where informal services use more energy than formal services ("high" corresponding to a ratio of 2) or less ("low" corresponding to a ratio of 2/3).

When informal services are more energy intense than formal services the cost reductions are amplified: the emissions tax falls more heavily on informal goods and narrows the cost advantage of operating in the informal sector. Tax-base broadening flows of labor are even stronger. Conversely, if informal services are less energy intense than the same service in the formal sector the cost saving is smaller.

3.4 Developing Economies and Informal Fuels

Table 3 suggests that the benefits from the tax swap could be even greater in developing economies, where much larger fractions of the labor force work informally. In this setting we observe that a second type of informal sector also becomes relevant: informal energy use. Many developing economies include significant use of fuels like agricultural residue, paper trash, or firewood for commercial service provision (e.g.

small restaurants and tea stalls) and manufacturing (e.g. brick kilns).[13] The energy tax we consider could cause substitution toward informal energy, creating leakage in emissions and therefore requiring a larger tax rate to achieve the same net reduction in emissions (Chaudhuri and Mukhopadhyay [2010] provide a review of this effect). In order to consider this potentially important source of leakage we extend the simulation model to consider both types of informality at the same time: this now allows the overall effect on cost to run either direction depending on the relative strength of the two effects.

We consider China and India as examples, calibrating informal energy use with estimates of biomass fuel burning in the global GAINS model.[14] We assign all of the informal energy to the untaxed informal sector: in addition to the leakage caused from switching away from formal fuels, the informal sector now also has an added cost advantage from this concentration of untaxed energy. This slows the shift away from informal labor, making our estimate more conservative.[15]

The first three rows of Table 4 show how the calibration for China and India differ from the U.S. case. Energy use is a larger share of GDP in both cases (in the first row), and in the second row the share of production in the informal sector is much larger (following Schneider [2005]). Finally, the third row shows that informal energy is potentially quite important, particularly in India. The remaining elasticities and parameters all remain as in the central case.

[13]Blackman *et al* (2006) discuss firewood use in Mexican brick kilns.

[14]The GAINS model is maintained by the International Institute for Applied Systems Analysis (IIASA): it includes a comprehensive database of local air pollutants and fuel sources, including informal burning of biomass energy sources like firewood and crop residues. Since it includes residential consumption of informal fuels we implicitly allow even broader scope for substitution between fuel types.

[15]To the extent informal fuels are also important sources of energy in formal production we do exclude that channel.

Table 4: Simulations Allowing Leakage to Informal Energy

	U.S.	China	India
Energy use as a share of GDP	4.1%	9.8%	11.8%
Informal sector as a share of GDP	8.4%	15.6%	25.6%
Informal energy share in informal services	1.1%	32.4%	40.0%
Base Welfare Cost	0.033%	0.083%	0.102%
Energy Tax Rate Required	16.1%	16.9%	17.3%
Include Informal Sector (No Informal Energy)			
Total Cost / Base Welfare Cost	0.38	-0.08	-0.50
Energy Tax Rate Required	16.1%	16.9%	17.4%
Include Informal Sector and Informal Energy			
Total Cost / Base Welfare Cost	0.38	-0.06	-0.47
Energy Tax Rate Required	16.1%	17.1%	18.3%
Include Informal Sector and Informal Energy, High Emissions Case			
Total Cost / Base Welfare Cost	0.39	0.07	0.01
Energy Tax Rate Required	16.2%	19.3%	25.4%
Include Informal Sector and Informal Energy in All Forms of Services			
Total Cost / Base Welfare Cost	0.38	-0.01	-0.11
Energy Tax Rate Required	16.2%	20.1%	30.9%

We decompose the countervailing effects by displaying simulation results grouped according to the assumptions made on the informal sector. The first set of results, "Base Welfare Cost," omits both informal labor and informal energy. The second group includes informal labor, still omitting the potential for substitution to informal energy. The ratio of total cost to base cost is less than 1 in all cases (replicating the 62% reduction in cost for the U.S.) and is negative for China and India. The negative values suggest a potentially large role for energy taxes in the efficient tax system.

The third set of simulations now includes both effects, our result on informal labor movement and leakage due to the presence of informal energy sources. In spite of potentially heavy use of informal fuels in China and India, we find that the effect of informal labor movement dominates in each of the cases we try. The cost ratio remains negative for both China and India.

Finally, the last two groups of results allow alternative assumptions on informal energy. The first of these, "High Emissions Case," multiplies by ten the pollution intensities of informal energy. This could represent larger externalities from these fuels or poor conversion of the heat energy contained in them. With this greatly magnified leakage effect the strong double dividend is removed, but total costs still remain at less than 10% of what would be assumed in the absence of the informal sector. The second alternative case allows informal energy use in all types of services, including those provided formally. This adds an extra channel through which savings from the energy tax could leak away, but again the overall costs of an energy tax are a very small fraction of what they would be without informal labor.

4 Conclusions

We show how energy taxes can create welfare gains by inducing substitution out of the informal sector. The result relies on an important asymmetry: energy taxes fall more heavily on goods (collectively labeled manufacturing) that have poor substitutes in the informal sector. Goods with strong informal substitutes therefore receive a lower share of the tax burden and production is drawn out of the informal sector. This substantially reduces the cost of energy tax policy when compared with models that omit informal production.

The results from a simulation model calibrated to the U.S. economy show that the effect is potentially very large. The marginal cost of the energy tax is negative for small amounts of abatement and the cost of reducing energy use by 10% is cut by more than half. This suggests that the optimal tax on externalities associated with energy use is well above the Pigouvian level.

We argue that these effects are likely to be even larger in developing economies, but note these regions also face an important countervailing source of leakage via informal fuels. We find that even when leakage to informal fuels is at its strongest our result on gains in the informal sector still dominates. This implies a much greater role for energy taxes, both in correcting externalities and in the efficient collection of revenue.

Our result is also relevant to countries where energy is currently subsidized. Electricity and diesel fuel in India provide particularly important examples.[16] The effect we identify suggests that the cost of providing these subsidies is much greater than has been assumed previously: energy subsidies not only narrow the tax base (see

[16]See International Monetary Fund (2013) for a detailed discussion of countries and subsidies.

Parry (1998)) but also disproportionately increase switching to the informal sector. To the extent energy subsidies have redistributional goals in mind our results suggest alternative policies like conditional cash transfers have a greater cost advantage than previously thought.

While our model applies in relatively general settings, the complex tax systems in individual countries create room for numerous additional interactions that we do not include. Future work could also consider informal production in more detailed tax simulations, additional sectors, and policy questions specific to particular economies.

References

Bento, Antonio, and Mark Jacobsen. 2007. "Ricardian Rents, Environmental Policy and the 'Double-dividend' Hypothesis." *Journal of Environmental Economics and Management*, 53: 17-31.

Blackman, Allen, Jhih-Shyang Shih, David Evans, and Michael Batz. 2006. "The benefits and costs of informal sector pollution control: Mexican brick kilns." *Environment and Development Economics* 11: 603–627.

Bovenberg, A. Lans. 1999. "Green Tax Reforms and the Double Dividend: an Updated Reader's Guide." *International 'Tax and Public Finance* 6: 421-443.

Bovenberg, A. Lans, and Ruud A. de Mooij. 1994. "Environmental levies and distortionary taxation." *American Economic Review* 84(4): 1085-1089.

Chaudhuri, Sarbajit, and U. Mukhopadhyay. 2010. *Revisiting the Informal Sector*. New York: Springer.

Goulder, Lawrence H. 1995. "Environmental Taxation and the 'Double Dividend': A Reader's Guide." *International Tax and Public Finance* 2(2): 157-183.

International Monetary Fund. 2013. "Energy Subsidy Reform: Lessons and Implications." Report available from http://www.imf.org/external/np/pp/eng/2013/012813.pdf.

Keen, Michael. 2008. "VAT, tariffs, and withholding: Border taxes and informality in developing countries." *Journal of Public Economics* 92: 1892-1906.

Koreshkoba, Tatyana A. 2006. "A quantitative analysis of inflation as a tax on the underground economy." *Journal of Monetary Economics* 53: 733-796.

Lemieux, Thomas, Bernard Fortin, and Pierre Fréchette. 1994. "The Effect of Taxes on Labor Supply in the Underground Economy." *American Economic Review* 84(1): 231-254.

Liu, Antung A. Forthcoming. "Tax Evasion and Optimal Environmental Taxes." *Journal of Environmental Economics and Management.*

Parry, Ian W.H. 1995. "Pollution Taxes and Revenue Recycling." *Journal of Environmental Economics and Management* 29: S64–S77.

Parry, Ian W.H. 1998. "A Second-Best Analysis of Environmental Subsidies." *International Tax and Public Finance* 5(2): 153–170.

Parry, Ian W.H. and Antonio M. Bento. 2000. "Tax Deductions, Environmental Policy, and the 'Double Dividend' Hypothesis." *Journal of Environmental Economics and Management* 39: 67-96.

Peter, Klara S. 2008. "Income Tax Flattening: Does it Help Reduce the Shadow Economy." Andrew Young School of Policy Studies Research Paper Series, Working Paper 08-09.

Piggott, John and John Whalley. 2001. "VAT Base Broadening, Self Supply, and the Informal Sector." *American Economic Review* 91(4): 1084-1094.

Schneider, Friedrich. 2005. "Shadow Economies of 145 Countries all over the World: What Do We Really Know?" Center for Research in Economies, Management, and the Arts Working Paper No. 2005-13.

Schneider, Friedrich. 2011. "The Shadow Economy and Shadow Economy Labor Force: What Do We (Not) Know?" IZA Discussion Paper Series No. 5769.