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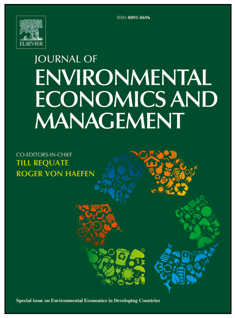

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Environmental Policy in the Presence of an Informal Sector[1]

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February 2018

Abstract

We demonstrate how the presence of an informal sector can sharply lower the cost of environmental and energy tax policy through two mechanisms. First, energy taxes indirectly tax the informal sector because even informal firms must buy formal sector sources of energy such as electricity. Second, a revenue-neutral shift in the tax base toward energy can decrease the tax burden on goods which are substituted for by the informal sector. These mechanisms can lead to welfare-enhancing substitution from informal labor into the formal sector. We consider the magnitude of these effects in a stylized model of the U.S. tax system. Even though the U.S. informal sector is relatively small, we find that distortionary costs of energy taxes are reduced by more than half. In developing countries, where the informal sector is typically much larger, the effect we identify here become even more relevant: we find negative gross costs in many cases. Finally, we address two potentially important countervailing effects: the use of informal fuels in developing countries and the potential for informal production to substitute for energy-intensive goods. We show how these different types of informality compete, and find that welfare enhancing effects typically dominate.

Keywords: Environmental policy; Informal sector; Second-best; Energy taxes
JEL classification: H23; H21; Q58

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1 Introduction

According to the World Bank (2016), 40 national jurisdictions and more than 20 cities, states, and regions have put a price on carbon, covering about 13 percent of global greenhouse gas emissions. Notably, China and India have also recently agreed to control carbon emissions. Carbon and other environmental taxes are under consideration in a rapidly growing number of countries.

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.

One common feature of these studies is the inclusion of a pre-existing tax that covers all goods in the economy. However, it is well documented that even the most efficient tax systems fail to cover a collection of economic activities occurring in the informal sector.[1] This sector is estimated to comprise 8.4% of GDP in the U.S and 16.1% of GDP in OECD countries, with even higher shares in less developed regions.[2]

Our contribution here is a model allowing the presence of informal activity, re-examining 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. 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, specifically 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, services produced in the formal sector, and services produced in an informal sector. Consistent with empirical evidence, the energy intensity of manufactured goods is higher than that of services.

Our central result is that a revenue neutral shift toward an energy tax can produce a double dividend due to two underlying interactions between the energy tax and the informal sector. First, energy taxes indirectly fall on the informal sector through purchases of formal energy commodities such as electricity and gasoline. Second, the tax swap toward an environmental tax and away from the pre-existing tax can act to shift the tax burden toward the energy-intense manufacturing sector and away from formal services. Both of these interactions reduce the incentive to substitute from formal services into informal services. A smaller informal sector increases the tax base, improving the efficiency of revenue collection.

Our results complement an existing group of studies demonstrating inefficiencies in the tax system that reduce the cost of environmental tax swaps.[3] In contrast to these studies, where the inefficiency is typically separate from labor supply, the mechanism we identify here is

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[1] The informal sector can include activities that are difficult or costly to track, such as migrant labor or domestic employment, or illegal activities that operate entirely out of the government's view.

[2] Estimates are from Schneider (2005). The informal economy is estimate to be much larger in Asia (26.3% of GDP) and Africa (41.2% of GDP).

[3] 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.

embedded within the elasticity of labor supply with respect to the after-tax wage. Our effect appears when a portion of this elasticity comes from substitution to informal production.

Our result on welfare cost also relates to a broader literature examining optimal taxation in the context of an informal sector.[4] Keen (2008) shows how the VAT acts as an input tax on the informal sector since operators in the informal sector purchase goods where the VAT has already been paid. Koreshkova (2006) argues that inflation can act as an indirect tax on the informal economy; an optimal policy in an economy with high informality may be a low income tax rate and a high inflation rate.

After demonstrating the theoretical result we introduce a simulation model to investigate the effects of an energy tax over 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 a 10% cut in emissions by more than half. For pollution reductions up to 6%, the effect is so strong that the net welfare cost is negative. In these cases, increases in the overall tax base through substitution away from informal services more than offset the efficiency cost of imposing the environmental tax. As a result, even with uncertainty about the benefits from environmental policy, the environmental tax should be part of the optimal tax system.

We then extend the simulation to explore the role of our results in the case of developing countries, where the informal sector can be substantially larger and also include more energy-intensive activities. We 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 additional source of cost, we show that our findings on the lowered cost of energy taxes remain and in fact appear stronger than in the U.S. case.

We qualify our result noting that the energy tax we simulate is a second-best method of reducing the size of the informal economy: explicit substitution away from taxes affecting sectors with informal substitutes could even more directly target the same welfare-enhancing shifts in labor.[5]

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[4] We note that there is also an extensive literature that has utilized empirical estimates of the taxable income elasticity. In this approach, pioneered by Feldstein (1999), tradeoffs from tax policy are measured using the full efficiency cost of taxes, including a broad range of distortions, such as tax evasion, informality, and tax-preferred spending. This approach has the advantage of capturing all behavioral responses to higher taxes.
While reduced form estimates of burden from different taxes could indeed be contrasted to estimate the overall benefit of revenue recycling we believe there are two important advantages to our approach here: First, we argue that illuminating individual sources of the difference in burden is of interest in advancing our understanding of the way environmental taxes work and identifying other potential tax swaps that could be (gross) welfare enhancing. For example, the particular types of energy or pollution taxes that might prove most beneficial will depend on interactions with informality. Second, we believe there are many plausible settings, especially in developing countries, where good empirical estimates of tax burdens are unavailable. Even rough estimates of the effect of informality, and how it makes those tax systems different from the better-studied ones in developed economies, could provide valuable input into policy.

[5] Some economies, such as those in the European Union, differentially reduces taxes on sectors exposed to the informal economy, like gardeners and hairdressers. This differentiation makes the existing system closer to optimal and therefore reduces the benefits we study.

Our results therefore apply to cases where the initial tax system does not differentiate across sectors based on informal substitution, such as the income tax system in the U.S. Most generally stated, we show here that carbon taxes provide an instrument that can differentially target informality, providing the existing tax system has not already done so.

Our study of the informal sector also relates to work in Liu (2013). While Liu focuses on tax evasion, our work here is concerned with informal production much more broadly defined.[6] Liu points out the difficulty of evading taxes on energy, and studies how shifting the tax base toward energy taxes can decrease spending on tax avoidance and evasion. In that paper, the key difference is between tax instruments, pointing out that carbon taxes are more difficult to evade than other forms of taxes. The effects of tax avoidance and evasion on environmental policy enter primarily through changes in direct expenditure on evasion on resources like accountants and consultants. In our present work, the key difference is between sectors, showing how environmental tax increases fall on sectors that are hard to substitute for in the informal economy. The key mechanism involves shifts between the taxable labor market and the untaxable informal sector. We also show here how the presence of an informal economy alters the marginal excess burden of labor taxation. These changes appear even with no direct spending on evasion and are present even when the only connection between the informal sector and the environmental tax is through the recycling of revenue.

Our work is similar in some ways to that of Parry and Bento (2000), who analyze the implications of tax-favored consumption for environmental tax reform. We argue that tax-favored consumption and the informal sector are empirically quite distinct, and likely to be present in very different proportions in different economies. Another important difference between the two relates to endogenous changes to the tax code: tax-favored activity could remain favored (for example for political reasons) even after the imposition of a carbon tax. For example a government might increase the amount of such activity that can be deducted or introduce new deductions for complementary goods. In contrast, most governments already desire to reduce informal activity and so we argue there are less likely to be endogenous policy shifts offsetting gains from the informal sector.

The remainder of the paper is organized as follows: Section 2 describes our analytical model and derives the cost of energy taxes with and without an informal sector. Section 3 calculates the magnitude of the effect in a numerical simulation. 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

[6] Schneider and Enste (2000) define the informal sector as a shadow economy comprised of all activities contributing to economic activity that are unregistered. By contrast, tax evasion and avoidance are much more narrow and we note that a large share of tax avoidance is in fact undertaken by formal firms. There are also important empirical differences between tax evasion and informality: for example Johns and Slemrod (2010) show that tax evasion tends to take place among the wealthy while informal activity is concentrated among lower income groups in the form of unregistered small-scale production.

throughout, considering manufactured goods (M) , formal services (S^F), and informal services (S^I).[7] M and S^F will be the formal, taxed sectors and S^I will be the informal, untaxed sector. Piggott and Whalley show that a revenue-neutral tax reform that broadens a tax from covering only M to including both M and S^F can actually worsen welfare if the resulting expansion of the informal sector (reducing the size of the tax base) dominates.

We introduce an energy input and use it to illustrate a converse effect to that in Piggott and Whalley (2001). A broad labor tax in our model will initially fall equally on M and S^F. We show that a tax system introducing an energy tax to replace some of the labor tax revenue will perform more efficiently when the informal sector S^I is present. Intuitively, both the lessened dependence on a labor tax and the increased deployment of the energy tax cause substitution from S^I to S^F, increasing the size of the tax base and improving welfare.

Our model develops a set of points related to the results in Corlett and Hague (1953), who show that complements to untaxed goods should be taxed more heavily while substitutes to untaxed goods should be taxed more lightly. In our formulation, the untaxed good is the informal economy. We point out that energy taxes fall more heavily on manufactured goods, which have relatively fewer substitutes in the informal economy, while labor taxes fall more heavily on services, which have the best substitutes in the informal sector.

2.1 Model Structure

2.1.1 Firms

The model has four types of firms: energy firms that produce E, manufacturers that produce a good M, formal services S^F, and informal services S^I.[8]

[7] Following the convention of Piggott and Whalley (2001), we use the terms "manufactured goods" and "services" to describe the main sectors of the economy. However, sectors M and S^F are distinguished only by whether good substitutes for the good exist in the informal economy. Portions of the economy included in S^F will differ depending on the economy under consideration. In the U.S., S^F may include only domestic help or agricultural services; in China or Mexico, S^F may include more diverse goods such as small-scale manufacturing. We discuss this point further in section 3.4, where we perform numerical simulations of developing countries.

[8] It may be noted that carbon emissions are generated not just by the manufacturing and service sectors, but also in a variety of other sectors. These can be placed in our model depending on their degree of substitutability with the informal economy. Electric power generation rarely occurs in the informal economy and would be part of sector E. Intermediates to this production, including activities such as refining and fossil fuel production, would also occur here.

Transportation services could be in either sector M or S, depending on whether they have good substitutes in the informal economy. Transportation is more likely to be formal in the U.S. because unregistered vehicles are a very small part of transport. In developing countries, some forms of transport do have good informal substitutes (i.e. taxis) and might fit best in the "services" category, but a large part including rail, bus, and most trucking is still well-controlled, and might be part of sector M. Most carbon emissions from home production occur from residential electricity and natural gas use, and so would be part of sector M.

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

$$E = L_E \qquad (1)$$

Energy firms are taxed in two ways. First, they must pay a labor tax, τ_L, on each unit of labor employed. Since the model has only a single factor, labor, the tax τ_L intuitively represents not only labor taxes but also income taxes or general taxes on business. Second, energy firms pay a per-unit environmental tax on production, τ_E. Workers receive an after-tax wage normalized to 1 so the cost of wages to firms is 1+ τ_L. Hence, the price of energy is:

$$p_E = 1 + \tau_L + \tau_E \qquad (2)$$

Firms that produce manufactured goods M use labor L_M and energy E_M as inputs. Production is increasing in inputs and constant returns to scale:

$$M = M(L_M, E_M)$$

Define the price of M using the cost function $\gamma_M(\cdot)$:

$$p_M = \gamma_M(\tau_L, \tau_E) \qquad (3)$$

Firms that produce formal sector services S^F use labor L_F and energy D_F as inputs and again are constant returns to scale in production:

$$S^F = S_F(L_F, E_F) \qquad (4)$$

We define the price of formal sector services using the cost function $\gamma_{SF}(\cdot)$:

$$p_{SF} = \gamma_{SF}(\tau_L, \tau_E) \qquad (5)$$

Finally, we have production of informal sector services S^I. This sector also uses labor and energy 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 without bringing their activities into the formal sector.

We assume informal sector production follows:

$$S^I = (L_{SI})^{\theta_L}(E_{SI})^{\theta_E} \qquad (6)$$

We assume that θ_L and θ_E are both between 0 and 1, and that their sum is less than 1. Together, they control the degree to which marginal cost rises as production increases. Because informal services are decreasing returns to scale the energy intensity of these goods can change as the level of production changes, and is also not constrained to be the same as energy intensity in the formal sector.

We combine rising marginal cost with the assumption that formal sector services S^F and informal sector services S^I 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 parameters θ_L and θ_E. This mechanism, which we draw directly from Piggott and Whalley, provides a simple way to generate co-existence of both formal and informal sectors.[9] Informal sector firms will produce along their supply curve until marginal cost (and therefore price) equals that in the formal sector. The price for all services p_S is then:

$$p_S = p_{SI} = p_{SF} \qquad (7)$$

As a result of rising marginal cost informal firms accumulate rents on inframarginal production.[10] Since households own all firms, the rents accruing to the representative household are:

$$\pi = (p_{SI}S^I - L_{SI} - p_E E_{SI})/N \qquad (8)$$

2.1.2 Households

The representative consumer gains utility from per capita consumption of manufactured goods m, service goods s, and leisure l. Service goods are a combination of per capita formal services s^F and informal services s^I:[11]

$$s = s^F + s^I \qquad (9)$$

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

$$U = u(m, s, l) - \phi(E) \qquad (10)$$

$u(\cdot)$ 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 (10) implies that the demands for m, s, and l 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:

$$p_M m + p_S s = L + g + \pi \qquad (11)$$

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

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

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[9] See also Keen (2008) and Koreshkova (2006).

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

[11] Many similar goods produced in the formal and informal sectors may not be perfect substitutes; for example, unbranded clothing produced in the Chinese informal economy will not substitute perfectly for branded clothing produced in its formal clothing plants. The purpose of this assumption is to provide a mechanism governing the size of the informal sector to which we can apply the elasticity of substitution between the size of the informal sector and the tax rate in the numerical simulations. Other mechanisms yielding the same elasticity would apply equally well.

$$NL = L_M + L_{SF} + L_{SI} + L_E$$

where N is the number of households in the economy.

2.1.3 Government

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

$$G = gN = \tau_L(NL - L_{SI}) + \tau_E E \qquad (12)$$

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 (10) and (11) the household optimization problem is given by:

$$W = u(m, s, l) - \phi(E) - \lambda[p_M m - p_S s - L - g - \pi] \qquad (13)$$

Totally differentiating with respect to τ_E yields:

$$\frac{N}{\lambda}\frac{dW}{d\tau_E} = -\frac{N}{\lambda}\phi'(E)\frac{dE}{d\tau_E} - \frac{dp_M}{d\tau_E}M - \frac{dp_{SF}}{d\tau_E}S + N\frac{d\pi}{d\tau_E} \qquad (14)$$

After plugging in the the derivative for the household budget constraint from equation (11) and using the firms' envelope conditions (the algebra for this appears in the appendix) we can summarize the welfare change from the policy reform as:

$$\frac{N}{\lambda}\frac{dW}{d\tau_E} = \underbrace{\left[\left(\frac{N}{\lambda}\phi'(E) - \tau_E\right)\left(-\frac{dE}{d\tau_E}\right)\right]}_{dWP} + \underbrace{\left[\tau_L \frac{d(NL - L_{SI})}{d\tau_E}\right]}_{dWS} \qquad (15)$$

In this equation, dWP denotes the primary welfare gain of the policy. It equals the wedge between the marginal environmental damages 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]).

The second term, dWS in (15) reflects the welfare effects of the change in taxable labor supply. It will include tax-interaction and revenue-recycling effects as in the prior literature,[12] but the

[12] Goulder (1995) and other authors show that a negative tax interaction effect from the energy tax will dominate any benefits from lower labor taxes coming through revenue recycling. In the standard model, rises in the price level created by the tax swap lower real wages and decrease labor supply, negatively affecting welfare.

existence of the informal sector now allows a third effect coming through substitution out of informal labor. This third effect is the core of our theoretical result; in contrast to prior studies, it permits labor supply and welfare effects to be positive.

To see how, we analyze the behavior of informal services firms in response to the policy:

$$N\pi_{SI} = p_{SI}S^I - p_{LI}L_{SI} - p_E E_{SI}$$

$$= p_{SI}{L_{SI}}^{\theta_L}{E_{SI}}^{\theta_E} - L_{SI} - p_E E_{SI}$$

$$From\ F.O.C.: \frac{\theta_L}{\theta_E}\frac{E_{SI}}{L_{SI}} = \frac{1}{p_E}$$

$${L_{SI}}^{1-\theta_L-\theta_E} = p_{SI}{\theta_L}^{1-\theta_E}{\theta_E}^{\theta_E}\left(\frac{1}{p_E}\right)^{\theta_E} \qquad (16)$$

The last line in equation (16) suggests two distinct mechanisms through which environmental tax reform can decrease informal labor. First, demand for informal labor is decreasing in the price of energy. Intuitively, informal firms cannot escape energy taxes on formal sources of energy such as electricity or gasoline, so an energy tax will increase the cost of the informal good and make it less attractive relative to formal services.

Second, environmental tax reform can lower the value of the informal good via a reduction in the price of services. If the price of services falls, high marginal cost firms in the informal sector will leave, again leading to a movement of labor out of informality. In what follows we analyze the conditions under which the price of services will fall and discuss a set of sufficient conditions that may be helpful for assessing the strength of this mechanism in practice.

Because the market for formal services is competitive, $p_{SF}S^F = p_L L_F + p_E E_F$. Since $p_L = 1 + \tau_L$ and $p_E = 1 + \tau_L + \tau_E$, the change in the price of services under the policy is: $\frac{dp_{SF}}{d\tau_E} = \frac{d\tau_L}{d\tau_E}\left(\frac{L_F+E_F}{S^F}\right) + \frac{E_F}{S^F}$. This allows us to derive the condition under which the price of services will decrease:

$$\frac{dp_{SF}}{d\tau_E} < 0 \Leftrightarrow \frac{d\tau_L}{d\tau_E} < -\frac{E_F}{L_F+E_F} \qquad (17)$$

We observe first that this requires $\frac{d\tau_L}{d\tau_E} < 0$: this will be the case when the increase in the energy tax increases energy tax revenue, allowing for a decreased tax on labor. By contrast, if an increase in the energy tax lowers energy tax revenue (because the initial tax is so high that it

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We point out that decreases in the real wage which lower the total labor supply can still increase the tax base, which is composed only of the formal labor supply. Decreases in the real wage will affect the total labor supply because workers in our model receive the same wages and are therefore indifferent to working in the formal and informal sectors. In other words, even if the total labor supply NL decreases, the formal labor supply ($NL - L_{SI}$) can increase if decreases in L_{SI} are sufficiently large.

Also note that the corresponding results in the literature are often expressed in per-capita terms (dividing both sides above by N). Given the nature of the informal sector it is more intuitive in this case to express the aggregate welfare effect.

places the economy on the downward sloping side of the Laffer curve), the labor tax will not be reduced. The condition on $\frac{d\tau_L}{d\tau_E}$ is sufficient by itself for a fall in services price when no energy is used in the production of formal services. In practical terms, if a sector with competition from informality has zero or very small energy use, the mechanism we study will hold subject only to tax rates starting from the rising part of the energy tax Laffer curve.

More generally, non-zero energy use in services is still consistent with a fall in services price as long as i) the services energy intensity is less than the energy intensity in manufacturing and ii) changes in the tax base resulting from the policy are not large.[13] To show this we can differentiate equation (12) under the constraint of revenue neutrality to obtain $\frac{d\tau_L}{d\tau_E} = \frac{-E-\tau_L\frac{d(NL-L_{SI})}{d\tau_E}-\tau_E\frac{dE}{d\tau_E}}{(NL-L_{SI})}$. When the two terms describing the change in the tax base ($\tau_L \frac{d(NL-L_{SI})}{d\tau_E}$ and $\tau_E \frac{dE}{d\tau_E}$) are small relative to overall energy use E we have $\frac{d\tau_L}{d\tau_E} \approx \frac{-E}{(NL-L_{SI})}$.[14] Substituting this into equation (17) and using the assumption that services have a lower energy intensity than manufacturing we have $\frac{dp_{SF}}{d\tau_E} < 0$ because $\frac{E_F}{L_F+E_F} < \frac{E_F+E_M}{L_F+E_F+L_M+E_M} < \frac{E_F+E_M+E_{SI}}{L_F+E_F+L_M+E_M+E_{SI}} = \frac{E}{(NL-L_{SI})}$. The first inequality follows using the assumption on energy intensities and the second follows because $\frac{X}{Y} < \frac{X+Z}{Y+Z}$ for positive values of X, Y, and Z where $X < Y$.

Intuitively, the ratio of tax bases $\frac{E}{NL-L_{SI}}$ provides an approximation for how much the labor tax rate can be reduced using energy tax revenue. The price of formal services can fall through two changes stemming from this tax shift: energy gets more expensive, but labor gets less expensive (as long as we are on the rising portion of the Laffer curve) and since the services sector is likely more labor-intensive than energy-intensive, the net effect is to reduce unit costs for services. The greater the energy intensity in manufacturing relative to that of formal services, the larger the decrease in the labor tax and the more likely that the price of services will fall. The necessary condition regarding the relative magnitudes of changes in τ_E and τ_L appears in equation (17).

Returning to equation (16), there are two key mechanisms through which an energy tax reform can decrease the demand for informal labor. The first is a new tax burden on the informal sector to the extent informal production involves energy. The second, acting through a fall in the price of services, requires intuitive conditions on changes in the tax base and the energy

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[13] While we argue that typical conditions will lead to a decline in services price, the reverse may be true in some settings (i.e. violations of the condition in (17)). This will lead to an increase, or smaller decline, in the size of the informal sector and the net effect will be governed by the relationship given in (16).

[14] The first tax base term will be small when pre-existing labor taxes are small or the labor supply elasticity is low. The second term will be zero for a new energy tax (regardless of the derivative) since the pre-existing energy tax in that setting is zero. In our central case simulations below we calculate that, in the U.S. where energy is 4.1% of the economy, $E = 4.1$, $\frac{d(NL-L_{SI})}{d\tau_E} = 0.05$, and $\frac{dE}{d\tau_E} = -0.41$, implying that E will be much larger than the tax base effects and so the approximation is quite good. In all of our sensitivity analyses (even when changing the relevant elasticities dramatically) this approximation remains very close.

intensity in the formal services sector. The magnitude of the combined effect on informal labor will depend on the relative size of the informal sector and key elasticities. After a discussion on the assumption of relative energy intensities, we explore the potential magnitude of effects on informal labor in the remainder of the paper.

2.3 Assumptions on Energy Intensity and Informal Goods

As the energy intensity of manufacturing relative to formal services rises, the effectiveness of environmental tax policy in drawing labor out of informal production is strengthened. We investigate a range of energy intensities in our numerical simulations, while noting that the empirical evidence strongly suggests manufacturing and industry are more energy intense than services.[15]

A second key assumption for our model is 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. Evidence on the informal economy is limited by its nature, but Lemieux *et al* (1994) offer 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.[16] These facts are 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.

Another stylized fact supporting our assumptions is the greater capital intensity of formal firms relative to informal ones. For example, Soderbom and Teal (2000) show that firms with more than 100 employees operate with three to four times more physical capital per employee than smaller, informal firms in Cameroon, Ghana, Kenya and Zimbabwe. To the extent that energy and capital are complements, this further suggests that taxes on energy will fall on formal rather than informal production.

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 are calibrated to estimates of energy intensities and informal sector activity in the U.S. We find that the presence of an informal sector reduces welfare costs dramatically, even though the U.S. has a

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

[16] The U.S. Department of Energy also reports energy intensity across sectors. In the latest reported year, the manufacturing industry's energy intensity was 10.52 kBtu per dollar. The energy intensity of non-manufacturing industries was 2.25 kBtu per dollar. These include agriculture, mining and construction and are more likely to have a presence in the shadow economy. Other production in the shadow economy is likely to have even lower energy intensity (for example financial services), making the calibration conservative.

relatively small informal sector. 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 the developing economies of China and India. We expect that the effect of the informal sector will be more important in these settings, where the informal sector is much larger. The main labor supply flow effect is partially offset by a new factor. Developing economies also tend to use much larger quantities of untaxed, "informal" sources of energy, such as dung or firewood. This second source of informality creates a new form of leakage: substitution into informal fuels when formal energy sources are taxed. When we include both informal services and informal fuels we still find a "double dividend"—negative gross welfare costs—in both China and India. This suggests that the effect of labor flowing out of informal services dominates the cost of leakage into informal fuels.

3.1 Numerical Model

Households

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

$$U = \left(\alpha_{UC} C^{\frac{\sigma_U - 1}{\sigma_U}} + \alpha_{Ul} l^{\frac{\sigma_U - 1}{\sigma_U}}\right)^{\frac{\sigma_U}{\sigma_U - 1}} \quad (18)$$

$$C = \left(\alpha_{Cm} m^{\frac{\sigma_C - 1}{\sigma_C}} + \alpha_{CS} s^{\frac{\sigma_C - 1}{\sigma_C}}\right)^{\frac{\sigma_C}{\sigma_C - 1}} \quad (19)$$

where l is leisure and C is the utility derived from consumption of goods and services. Per capita consumption of the manufactured good is represented by m and per capita consumption of services by s. The parameters σ_U, σ_C, α_{UC}, and α_{Cm} are calibrated and control the substitution elasticities and baseline sizes of the sectors. In household utility, environmental damages are omitted in order to present results in terms of cost to achieve varying reductions in energy use; we calculate these environmental damages in table 2 to show how big environmental costs typically are relative to benefits for various sizes of emissions cuts.

Firms

Production is given as follows:

$$E = L_E \quad (20)$$

$$M = \gamma_M \left(\alpha_{LM}{}^{1/\sigma_M} L_M{}^{\frac{\sigma_M - 1}{\sigma_M}} + \alpha_{EM}{}^{1/\sigma_M} E_M{}^{\frac{\sigma_M - 1}{\sigma_M}}\right)^{\frac{\sigma_M}{\sigma_M - 1}} \quad (21)$$

$$S^F = \gamma_{SF} (L_{SF})^{\theta_{LF}} (E_{SF})^{\theta_{EF}} \quad (22)$$

$$S^I = \gamma_{SI} (L_{SI})^{\theta_{LI}} (E_{SI})^{\theta_{EI}} \quad (23)$$

As in the analytical model above, L_i and E_i represent the amounts of labor and energy used in production of good i. The parameter σ_M controls the elasticity of substitution between inputs, while α MG and α EM determine baseline input shares. In the production of services, the parameters γ_{SF}, γ_{SI}, θ_{LF}, θ_{EF}, θ_{LI}, and θ_{EI} govern the productivity of inputs to S^F and S^I.

The parameters γ_{SI}, θ_{LI}, and θ_{EI} control the relationship between informal sector labor L_{SI} and informal sector production S^I. These are key to the responsiveness of informal labor to tax policy, so it is important to give this parameter a wide degree of flexibility in our model calibration. As in the analytical model, informal sector services are produced with increasing marginal cost, so $\theta_{LI} + \theta_{EI} < 1$. Informal services are produced up to the point where their marginal cost equals that of formal sector services; after this point formal services meet remaining demand.

Solution

Equilibrium is a set of tax rates and prices such that i) the pre-set emissions reduction goal is achieved (here, equivalent to a reduction in energy use), ii) government revenue is maintained at G , and iii) the goods and labor markets clear. The model sets the pre-tax wage as the numeraire and uses a derivative-based search over energy and labor tax rates 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.

Table 1: Central Case Simulation Model Parameters

Informal Sector	
Fraction of economy	8.4%
Energy intensity	2.6%
θ_{LI}	0.37
θ_{EI}	0.03
Composition of economy	
Formal services (energy intensity)	80% (2.6%)
Manufacturing (energy intensity)	20% (8.2%)
Substitution elasticities and base tax	

rates	
σ_U	0.9
σ_C	1.01
σ_M	1.01
τ_E	0
τ_L	0.4

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; these parameters are particularly important because they determine the reaction of the formal sector to our tax reform. In our central case we follow Piggott and Whalley, using a baseline specification such that $\theta_{LI} + \theta_{EI} = 0.4$ (with shares determined to match the energy intensities below). This corresponds to an elasticity of the informal sector with respect to the labor tax rate of 0.2. A larger elasticity here will increase the magnitude of our result. For example, Duncan and Peter (2014) use a panel of countries to estimate that the elasticity of the informal sector with respect to the corporate income tax rate is 0.78. By comparison, the smaller value of 0.2 in our central case provides us with conservative estimates of the cost savings.[17] 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 determined using U.S. Bureau of Economic Analysis input-output tables. The services sector spends 2.6% of output value on energy while manufacturing spends 8.2%. Using a World Bank survey of developing countries, La Porta and Shleifer (2008) find that the energy intensity of informal firms and formal ones in the same areas is identical: in line with their result, we assume that formal service firms and informal service firms start with the same energy intensities (we relax this assumption in sensitivity analysis). 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.[18] 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 unitary substitution and similar to prior work (see Liu [2013]). 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

[17] The conservative choice of elasticity slows down transitions from informal sector activity to formal sector activity; this may be especially relevant for developing countries where capital shortage or excess regulation may make expansion of the formal sector difficult.

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

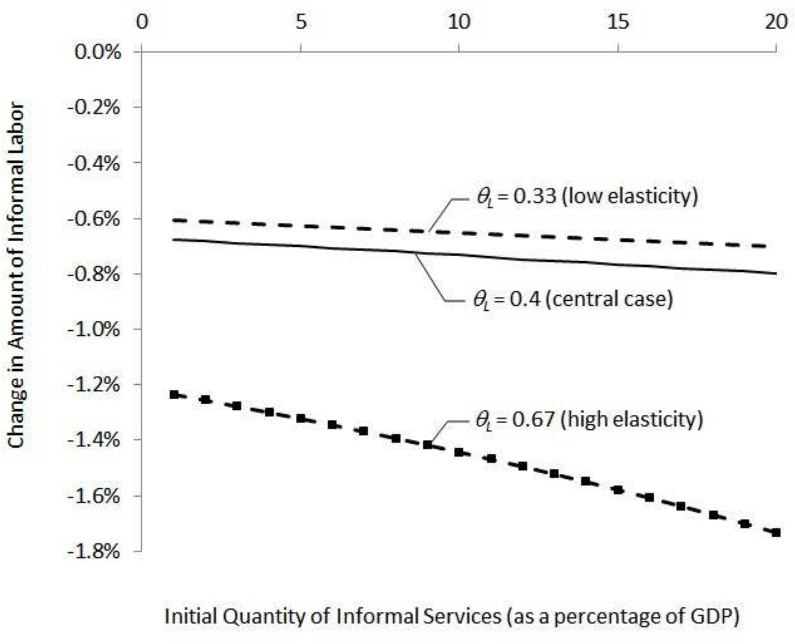
makes our main results more easily comparable with earlier studies. We consider a broad range of values in the sensitivity analysis below.

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, showing how energy taxes affect informal 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 represents a separate simulation, assuming in each a different initial size for the informal sector. The policy is a revenue-neutral energy tax large enough to reduce energy use by 10%. In our central case for the U.S., the initial size of the informal sector is 8.4% of GDP; the solid line without markers shows that informal labor supply decreases in this case by about 0.7%. Changes in informal labor supply depend strongly on the elasticity of the informal sector with respect to the labor tax (0.2 in our central case, corresponding to a $\theta_{LI} + \theta_{EI} = 0.4$), with the percentage changes roughly constant across different initial magnitudes of informal production.

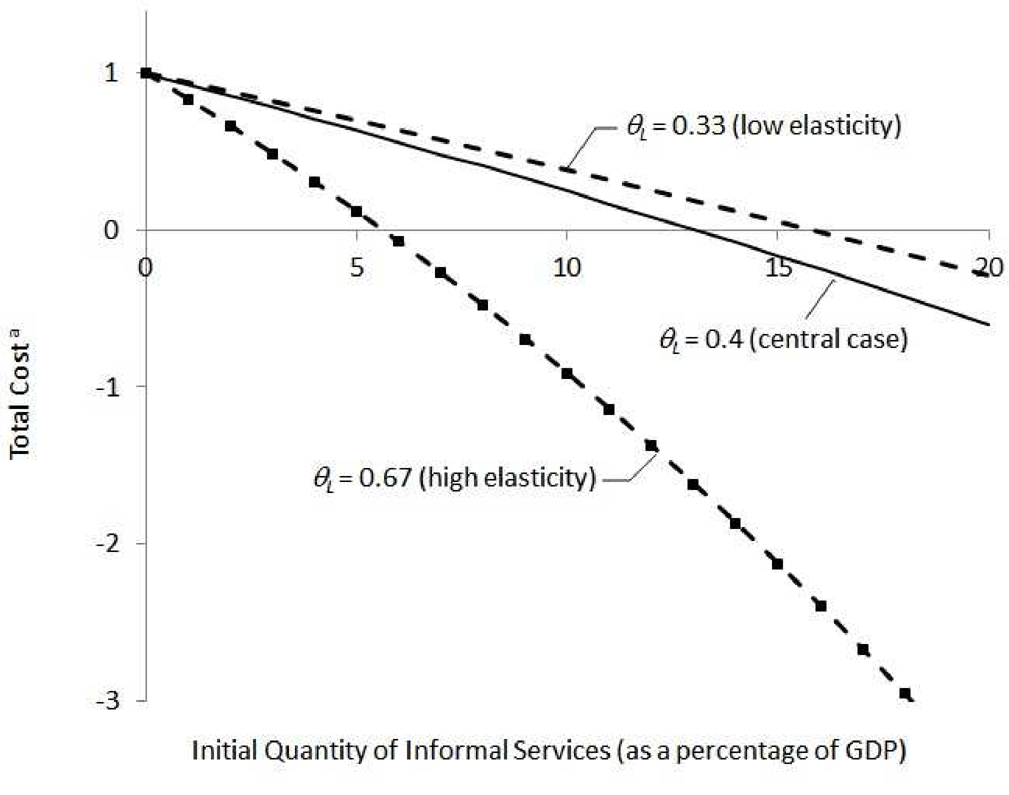
Figure 1: Tax-Induced Substitution out of the Informal Sector



Notes: Each point on the horizontal axis represents a separate simulation. The policy in each case is a revenue-neutral tax swap large enough to reduce energy use by 10%.

The effect of these shifts in labor supply on cost appears in Figure 2: it shows a sharp decline in total cost as we move away from the baseline with no informal sector toward cases with a large initial informal sector. Labor flows between the informal sector into the formal one make ever-more important contributions to the taxable base, reducing the cost of policy until, in our central case, 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. In the context of the marginal excess burden (MEB), the effect appears as a wedge between the MEB of the labor tax and the environmental tax, driven primarily by the increased efficiency cost of the former as it induces substitution into the informal sector.[19]

Figure 2: Total Cost of Emissions Reduction



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

[19] In the absence of an informal sector the MEB of the pollution tax is 0.384 while the MEB of the labor tax is 0.383. In the presence of an informal sector comprising 8.4% of GDP, the MEB of the pollution tax rises only slightly to 0.385, while the MEB of the labor tax increases more sharply to 0.426.

Notes: Each point on the horizontal axis represents a separate simulation. The policy in each case is a revenue-neutral tax swap large enough to reduce energy use by 10%.

Table 2 shows how key outcomes in our simulation move as we introduce an energy tax to our central case, varying the policy goal between a 10% and 50% reduction in emissions. As the energy tax is introduced, the labor tax rate falls and labor flows from the informal sector into the formal sector. These effects appear on the first four lines of the table. The next two rows display changes in sectoral consumption. In the next row, we show the equivalent variation of the policy when the shadow economy is present. We contrast these figures with the equivalent variation with no shadow economy present, and see large reductions in the equivalent variation cost of environment policy.

In the last column of this table, we examine the cut in the cost of environmental policy under the emissions reductions commitments of the Paris climate agreement of 2015. The U.S. agreed to reduce emissions 27%, while China and India agreed to 40% and 20%, respectively. For each country, the table shows that the cost of the policy has been reduced dramatically when the informal economy is present.

Table 2: Central Case Simulation Results

U.S.				
Pollution reduction	10%	25%	50%	27% *
Pollution tax rate	0.16	0.48	1.42	0.53
Labor tax rate (initial value 0.4)	0.394	0.385	0.374	0.384
Change in formal labor (%)	0.03	0.07	0.13	0.08
Change in informal labor (%)	-0.72	-1.72	-3.05	-1.84
Change in manufacturing sector size (%)	-0.48	-1.41	-3.79	-1.56
Change in services sector size (%)	0.13	0.24	0.10	0.25
Equivalent variation, as % of GDP	-0.012	-0.180	-1.074	-0.219
Equivalent variation with no shadow economy, as % of GDP	-0.033	-0.230	-1.164	-0.272
China				
Pollution reduction	10%	25%	50%	40% *
Pollution tax rate	0.17	0.50	1.45	0.98
Labor tax rate (initial value 0.4)	0.384	0.362	0.334	0.344

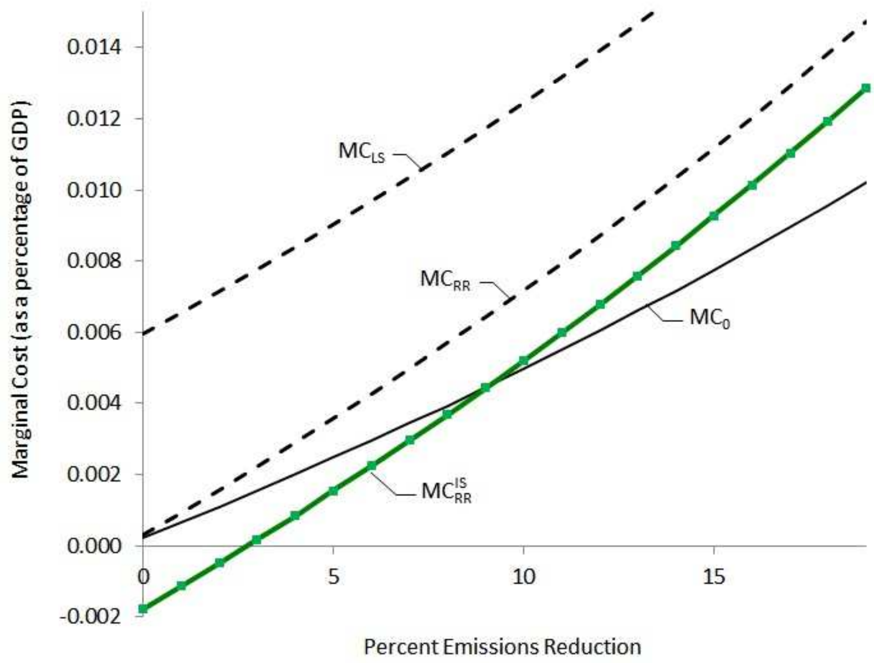
Change in formal labor (%)	0.13	0.30	0.50	0.43
Change in informal labor (%)	-1.69	-3.89	-6.51	-5.65
Change in manufacturing sector size (%)	-0.87	-2.60	-7.10	-4.99
Change in services sector size (%)	0.69	1.59	2.63	2.31
Equivalent variation, as % of GDP	0.006	-0.361	-2.463	-1.335
Equivalent variation with no shadow economy, as % of GDP	-0.081	-0.560	-2.793	-1.621
India				
Pollution reduction	10%	25%	50%	20% *
Pollution tax rate	0.17	0.51	1.48	0.39
Labor tax rate (initial value 0.4)	0.378	0.349	0.312	0.358
Change in formal labor (%)	0.22	0.50	0.78	0.42
Change in informal labor (%)	-1.97	-4.40	-6.83	-3.66
Change in manufacturing sector size (%)	-1.54	-4.42	-11.37	-3.37
Change in services sector size (%)	0.55	1.13	1.20	0.98
Equivalent variation, as % of GDP	0.051	-0.388	-3.095	-0.165
Equivalent variation with no shadow economy, as % of GDP	-0.101	-0.704	-3.527	-0.434

* In the Paris Climate Change Agreement, the U.S. agreed to a reduction of greenhouse gas emissions between 26-28%, so we analyze the effect of the informal economy on a 27% reduction. China agreed to a commitment of 40%, while India agreed to a commitment of 20%.

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, with all parameters set according to our central case. The line MC_0 in figure 3 illustrates the primary cost of the energy tax alone. This cost is increasing and convex with respect to the amount of emissions reductions because increasingly large tax shifts are necessary to induce the next marginal unit of abatement. The dashed MC_{LS} line illustrates the importance of tax interactions: it adds a pre-existing labor tax to the simulation, with revenue from the energy tax returned lump sum. In line MC_{RR}, we recycle the revenue from the energy tax to reduce the labor tax, the optimal second-best case examined in previous work. Note that MC_{RR} lies strictly between MC_0 and MC_{LS} at all points, reflecting on one hand the cost of tax interactions and on the other the reduced cost that can be realized through efficient deployment of environmental tax revenues. Finally, $MC_{RR}{}^{IS}$ displays our key result: if energy tax revenue is recycled and an informal sector is present. Marginal costs of policy are sharply reduced relative to MC_{RR} at all emissions reductions levels.

Figure 3: Marginal Cost of Emissions Reductions



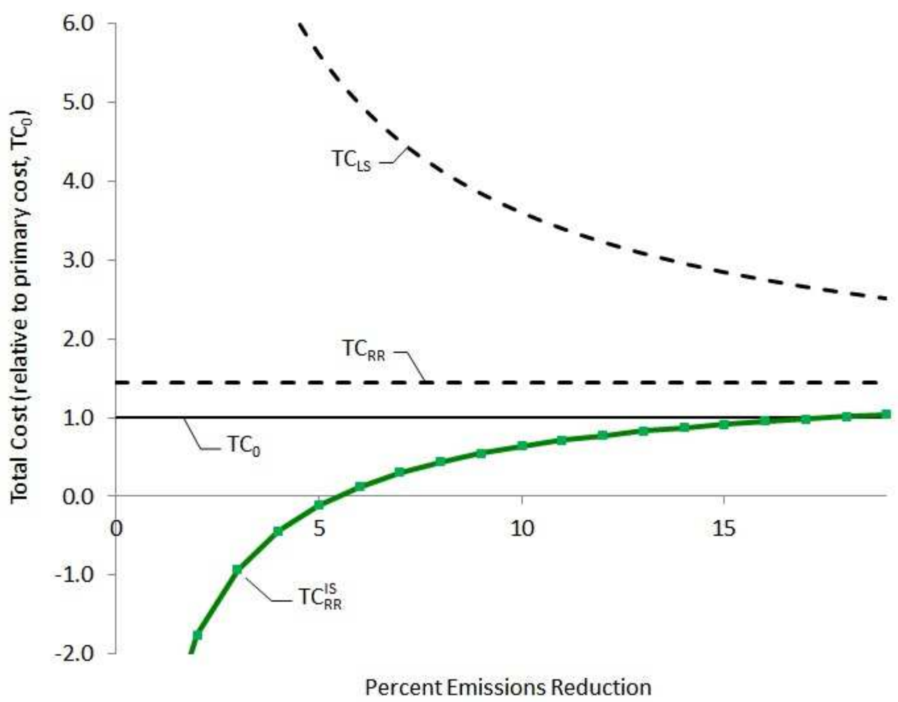
Notes: Each point on the horizontal axis represents a separate simulation. The policy in each case is a revenue-neutral tax swap large enough to reduce energy use by the indicated percentage.

Figure 4 presents the corresponding total costs, now expressed as ratios relative to total primary cost. As shown in TC_{RR}, the tax interaction effect results in a roughly 40% increase over primary cost, even when revenues are recycled.[20] Now $TC_{RR}{}^{IS}$ illustrates our full model with an informal sector present. The informal sector always reduces the cost of the policy relative to TC_{RR}. Since the presence of an informal sector causes a vertical shift in marginal cost, its impact is felt much more strongly at lower levels of emissions reductions when marginal costs are low. 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

[20] These baseline tax interactions are somewhat larger than the 30% found in earlier studies (e.g. Bento and Jacobsen [2007]). In this present model, energy is included in the production of both commodities, lessening the role of demand substitution. 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.

primary cost TC_0 when no pre-existing tax distortions are present. These results directly imply that the optimal tax on energy lies above the (first-best) pigouvian level.

Figure 4: Total Cost of Emissions Reduction



Notes: Each point on the horizontal axis represents a separate simulation. The policy in each case is a revenue-neutral tax swap large enough to reduce energy use by the indicated percentage.

3.3.3 Alternative Parameters

We test the sensitivity of our main simulation findings to alternative parameters, summarized in Table 3. Each number in the table is 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. For example, the value of 0.38 from the first line indicates that we calculate a 62% reduction in total cost when we consider the informal sector.

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
Elasticity of the informal sector with respect to the labor tax rate			
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

Each number in this table represents the ratio of total cost between the case when the informal sector is not present to the case when it is present. Numbers below 1.0 represent reductions in total cost; for example, 0.38 indicates that a 62% reduction in total cost has been realized.

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 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 of the informal sector:

This elasticity, the sum of the θ LI and θ EI parameters, governs the key mechanism in our analysis: the elasticity of informal labor with respect to the labor tax rate. Our central estimate is $\theta_{LI} + \theta_{EI} = 0.4$, corresponding to an 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. In our low case, it comprises 1% of the economy; in our high case, 10%. As the polluting sector grows in size the cost of emissions tax distortions grows somewhat more rapidly than the benefit from recycled revenues. This reduces the relative importance of growth in the formal tax base, since it depends on emissions tax revenue.

Varying the relative energy intensity of manufacturing and services:

One key finding from our analytical model is that the size of flows between the informal to the formal sector depend 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 some energy intensive goods in the informal portion of the economy, raising the average energy intensity of the sector with strong informal substitutes. As a result, 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 table 3) we still find important reductions in cost. Equal energy intensities slow down the flow of labor between services and formal ones because the tax swap does not lower the price of formal services. However, the energy tax still serves as a surrogate method for taxing the informal sector, reducing its cost advantage over formal services. If services use very little energy relative to manufacturing ("high" in table 3), the importance of the labor tax cut on formal services is magnified, and we see stronger effects from the presence of the informal economy.

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 vary energy intensity of informal services separately. Table 3 examines both the case where informal services use more energy than formal services ("high" corresponding to a ratio of 2) and less ("low" corresponding to a ratio of 2/3).

When informal services are more energy intensive than formal services, cost reductions are amplified: the emissions tax increases the price of 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 intensive than the services 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. While developing economies like China and India are typically less reliant on labor taxes or personal income taxes than the U.S., they still have substantial distortionary taxes in place that informal firms must pay if they join the formal economy.[21] In both China and India the potential revenue from carbon taxes, on the order of 1% of GDP, provides substantial opportunity to cut taxes that are barriers to informal enterprise.

In this setting we observe that a second type of informal sector activity becomes relevant: informal energy use. Many developing economies rely significantly on 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).[22]

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. Informal energy leakage could allow 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.[23] We consider two possible methods of allocating informal energy across sectors. In the most conservative (from the perspective of our results) approach, we allocate all informal energy to the informal services sector. Informal energy gives this sector an added cost advantage when the formal energy tax is put into place, muting the shift out of informal labor. As an alternative view, we allow informal energy to be used just as intensely in the formal sector as it is in the informal sector. Equal use of informal

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[21] According to the China Statistical Yearbook, 75% of tax revenue comes from taxes on businesses, including the VAT (26%), the corporate income tax (20%), the sales tax (24%), and the VAT for exports and imports (5%). Many of these taxes apply to small businesses. Services businesses typically must pay the sales tax and the corporate income tax when they formalize.
According to Dikshit (2012), India's direct taxes like the corporate tax and the personal income tax account for around 60% of central tax collections. The statutory corporate tax rate is very high (around 33%), suggesting that gains in terms of reduced informality could still be achieved by slashing tax rates.

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

[23] 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.

energy distributes the cost of informal energy leakage because formal firms can also increase their use of informal energy in response to the policy.

The first three rows of Table 4 show the key ways in which the calibration for China and India differ from the U.S. Energy use is a larger share of GDP in both countries, and both have much larger informal sectors (following Schneider [2005]). Finally, informal energy can be potentially quite important, particularly in India. The remaining elasticities and parameters all remain as in the central case.

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. This is our conservative scenario where informal energy is only used in the informal sector. 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 case, our alternative view, 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. This result relies on two components. First, informal sector firms must pay energy taxes when they purchase electricity, gasoline, and natural gas as inputs. Second, energy taxes can fall with asymmetrical strength on manufactured goods 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. Both of these substantially reduce 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. As a consequence, the optimal tax on externalities associated with energy use is well above the Pigouvian level. We note that the appropriate Pigouvian tax on carbon taxes may include not just effects of the tax on climate change, but also its effects on air pollution and congestion. These are much larger in developing countries like China and India (Parry et al. 2014).

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. However, even when leakage to informal fuels is at its strongest, the impact of labor flows from the informal sector still dominates. This suggests that developing countries may be even better venues to deploy energy taxes in that energy taxes both correct environmental externalities and more efficiently collect revenue.

Our result also has bearing on the issue of energy subsidies. Electricity and diesel fuel in India provide particularly important examples.[24] The effects we identify suggest that the cost of providing these subsidies is much greater than has been assumed previously: energy subsidies not only narrow the tax base (see Parry (1998)) but also increase switching to the informal sector. If redistribution is the intention of these subsidies, alternative policies like conditional cash transfers may 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.

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

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Appendix: Derivation of Equation (15)

Our objective is to derive equation (15), starting from equation (14).

We being by taking the derivative of the individual budget constraint from equation (11) and multiplying by the number of households N:

$$\frac{dp_M}{d\tau_E}M + p_M\frac{dM}{d\tau_E} + \frac{dp_S}{d\tau_E}S + p_S\frac{dS}{d\tau_E} = N\frac{dL}{d\tau_E} + 0 + N\frac{d\pi}{d\tau_E}$$

Plugging this result into equation (14) yields:

$\frac{N}{\lambda}\frac{dW}{d\tau_E} = -\frac{N}{\lambda}\phi'(E)\frac{dE}{d\tau_E} + p_M\frac{dM}{d\tau_E}p_S\frac{dS}{d\tau_E} - N\frac{dL}{d\tau_E}$

Firms take prices as given and re-optimize their inputs accordingly. As the environmental tax is enacted, profit maximizing firms producing M , S F , and S I will satisfy:

$$p_M\frac{dM}{d\tau_E} = (1+\tau_L)\frac{dL_M}{d\tau_E} + (1+\tau_L+\tau_E)\frac{dE_M}{d\tau_E}$$

$$p_{SF}\frac{dS^F}{d\tau_E} = (1+\tau_L)\frac{dL_F}{d\tau_E} + (1+\tau_L+\tau_E)\frac{dE_F}{d\tau_E}$$

$$p_{SI}\frac{dS^I}{d\tau_E} = \frac{dL_{SI}}{d\tau_E} + (1+\tau_L+\tau_E)\frac{dE_{SI}}{d\tau_E}$$

By equations (7) and (9), $p_S = p_{SF} = p_{SI}$ and$S = S^F + S^I$. With these and the firm-optimzation conditions, we can now solve for $\frac{N}{\lambda}\frac{dW}{d\tau_E}$:

$$\begin{aligned}\frac{N}{\lambda}\frac{dW}{d\tau_E} = -\frac{N}{\lambda}\phi'(E)\frac{dE}{d\tau_E} + (1+\tau_L)\frac{dL_M}{d\tau_E} + (1+\tau_L+\tau_E)\frac{dE_M}{d\tau_E} + (1+\tau_L)\frac{dL_F}{d\tau_E} \\ + (1+\tau_L+\tau_E)\frac{dE_F}{d\tau_E} + \frac{dL_{SI}}{d\tau_E} + (1+\tau_L+\tau_E)\frac{dE_{SI}}{d\tau_E} - N\frac{dL}{d\tau_E}\end{aligned}$$

$=\left[\left(\frac{N}{\lambda}\phi'(E) - \tau_E\right)\left(-\frac{dE}{d\tau_E}\right)\right] + \tau_L\frac{d[L_M+E_M+L_F+E_F+E_{SI}]}{d\tau_E} + \tau_L\frac{d[L_M+E_M+L_F+E_F+E_{SI}+L_{SI}]}{d\tau_E} - N\frac{dL}{d\tau_E}$

$$= \left[\left(\frac{N}{\lambda}\phi'(E) - \tau_E\right)\left(-\frac{dE}{d\tau_E}\right)\right] + \left[\tau_L\frac{d(NL - L_{SI})}{d\tau_E}\right]$$

The second equality follows because total energy $E = E_M + E_F + E_{SI}$. The third equality follows because total labor $NL = L_M + L_F + L_{SI} + L_E$ and $L_E = E = E_M + E_F + E_{SI}$.