May, 2001

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ELSEVIER

Journal of Public Economics 80 (2001) 249–267

JOURNAL OF PUBLIC ECONOMICS

www.elsevier.nl/locate/econbase

Environmental controls, scarcity rents, and pre-existing distortions

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Received 31 March 1999; received in revised form 31 December 1999; accepted 31 January 2000

Abstract

One might suppose that an emissions tax has an advantage over command and control (CAC) regulations since it raises revenue that can be used to cut other distorting taxes. In this paper, we show that the focus on revenue raising is misplaced. In a simple analytical general equilibrium model, we show that the same welfare effects of environmental protection can be achieved, by taxes that raise revenue, certain command and control regulations that raise no revenue, and even subsidies that cost revenue. Instead, the pre-existing labor tax distortion is exacerbated by policies that generate privately-retained scarcity rents.

Keywords: Emissions tax; Scarcity rents; Command and control regulations

JEL classification: H2; Q2

1. Introduction

A large literature considers the choice among environmental policy instruments such as emission taxes, abatement subsidies, tradeable permits, or command and control (CAC) regulations. For a given amount of environmental protection, one might naturally suppose that the emissions tax has the important advantage that the revenues can be used to reduce other distorting taxes on labor or capital incomes.

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0047-2727/01/$ – see front matter
PII: S0047-2727(00)00087-6

In contrast, CAC regulations raise no revenue at all. Using this logic, an environmental subsidy would rank lowest on efficiency grounds, since the government must cover the cost of the subsidy by *raising* other distorting taxes.[1]

A related literature on the 'double-dividend hypothesis' does not compare instruments for a given amount of environmental protection, but instead considers whether a pollution tax can *increase* environmental protection and also raise revenue that can be used to reduce other distorting taxes. Again, note the role of revenues in this early statement of the hypothesis (Pearce, 1991, p. 940):

> Governments may then adopt a fiscally neutral stance on the carbon tax, using revenues to finance reductions in incentive-distorting taxes such as income tax, or corporation tax. This 'double-dividend' feature of a pollution tax is of critical importance in the political debate about the means of securing a 'carbon convention'.

As shown in Bovenberg and de Mooij (1994) and Parry (1995), the pollution tax itself raises product prices, which reduces the real net wage and further distorts labor supply. Thus the double dividend is in doubt, but raising revenue is still considered important for cutting labor tax rates and offsetting that effect.[2]

In this paper, we offer a different perspective on the role of revenue. Using an analytical general equilibrium model similar to those in a number of papers listed above, we compare different policy instruments and show an important sense in which the revenue from an environmental tax is *irrelevant*. Specifically, earlier studies typically show that the incremental environmental policies that are least costly are those that raise revenue. Although these studies show that raising revenue is not a sufficient condition for zero marginal costs of abatement at the origin (see, for example, cases of emissions taxes with lump-sum recycling of the revenue), they can leave the impression that raising revenue is necessary. This paper demonstrates that raising revenue is neither necessary nor sufficient.[3]

[1]Tullock (1967) first suggested that emission taxes have no excess burden but instead have 'excess benefit', and that the revenue may be 'free' (p. 643). Terkla (1984) also considers the 'efficiency value of effluent tax revenues'. The idea that subsidies are inferior on the basis of the lost revenue appears in, for example, Ballard and Medema (1993, p. 215) and Rosen (1995, p. 102).

[2]Other papers that discuss the revenue value of pollution taxes include Lee and Misiolek (1986), Repetto et al. (1992), Bovenberg and Goulder (1996), Parry (1997), and Goulder et al. (1997). The 'double dividend' is reviewed in Goulder (1995) and Oates (1995).

[3]We thank Larry Goulder for helping us clarify the differences among papers in this literature. Those earlier papers compare only two kinds of policies. They find that the 'revenue-raising' (RR) policy results in substantially higher welfare than the 'non-revenue-raising' (NRR) policy. Goulder et al. (1997) are careful to distinguish between revenue-recycling effects and revenue raising. Revenue-recycling refers to the use of environmental tax revenues to cut other distorting taxes as opposed to returning the monies in a lump sum fashion. However, the use of 'revenue raising' and 'non-revenue raising' can lead the casual reader to obscure the difference between revenue raising and revenue-recycling.

We use our model to provide comparable analyses of at least five kinds of environmental policies including: a tax, a subsidy, tradeable permits, a CAC policy that restricts emissions, and a different CAC policy that restricts technology. In this way, we are able to show that *some* non-revenue-raising policies perform just as well as revenue-raising policies. In particular, the same welfare-raising effects of environmental protection can be achieved, without exacerbating pre-existing labor tax distortions, by a tax that raises revenue, the CAC technology restriction that raises no revenue, and even a subsidy that costs revenue. Thus, raising revenue is *not* necessary for raising welfare. Instead, the exacerbation of the pre-existing tax distortion is associated with policies that generate privately-retained scarcity rents. Such policies include both the quantity-restricting CAC regulation and the marketable permit policy in which the permits are given to existing polluters. The problem with such policies is that the output price must rise by more than necessary to cover the cost of abatement technologies; below we show that price must rise by an additional amount equal to scarcity rents that arise as a result of the emissions restrictions. The higher output price reduces the real net wage and exacerbates the labor tax distortion. That higher price is not such a problem if government captures the rents by using a pollution tax or by selling the permits, because then the labor tax can be reduced.[4]

Thus the NRR policy in those earlier papers performs poorly because it generates rents and fails to capture them. Public revenues from an environmental policy help indicate where the scarcity rents accrue, and so revenues are positively related to the welfare performance of alternative policies (Schöb, 1996). Revenue is not the key determinant, however, because other NRR policies can avoid the creation of those rents and provide the same welfare gain as RR policies.

Many other papers with heterogeneous abatement costs have shown that imperfect CAC regulations can be many times more expensive than the minimum total abatement cost made possible by incentive-based policies like taxes or permits.[5] Thus, when we show that a perfectly-designed CAC regulation can avoid the creation of scarcity rents and perform just as well as an environmental tax, we certainly do not mean to endorse CAC regulations. Instead, the point is just that the difference is not due to revenue. Moreover, if policymakers are to limit themselves to imperfect CAC regulations, they could avoid ones that unnecessarily hand out profits. Those profits are not just a transfer, because they raise product prices and exacerbate labor distortions.

[4]The rents interpretation is also consistent with the revenue-recycling interpretation described above. It does, however, have three useful features. Firstly, it avoids any confusion about the necessity of revenue raising for welfare improvements. Secondly, it provides a useful link to the political economy literature on instrument choice in papers such as Buchanan and Tullock (1975) and Maloney and McCormick (1982). Thirdly, it provides a conceptual link to other literature on import quotas and tariffs that have high excess burden by creating scarcity rents (e.g. Bizer and Stuart, 1987).

[5]See Atkinson and Lewis (1974), Seskin et al. (1983), and other studies surveyed in Cropper and Oates (1992, p. 686).

2. The model

Our goal is to analyze and compare the impacts of five different kinds of policies such as tradeable pollution permits, a command and control (CAC) limit on emissions, a tax on emissions, a subsidy to clean production, or a CAC restriction on technology. In particular, we wish to compare all such policies within a single model. For this purpose, we develop a simple static model with N identical individuals who own a single resource and sell it in the market to earn income that can be used to buy two different goods.[6] We assume perfect certainty, no transactions costs, and constant returns to scale production.[7]

For simplicity we refer to the resource as time available for labor supply, but under some conditions it can be interpreted more generally as a fixed total amount of labor, capital, land, and any other resource that can be sold in the market (in amount L) or used at home (in amount L_H). Distinction among these inputs is not necessary for any of the points we make below. The resource kept at home could be interpreted either as leisure or as a resource used in home production.

Each individual receives utility from per-capita amounts of a nonpolluting good (X), a polluting good (Y), and leisure (L_H), and from the total amounts of a government-provided nonrival public good (G), and another nonrival public good called environmental quality (E). The per-capita amount X is produced using just labor L_X, while Y is produced using labor L_Y and emissions Z. One might write a production function for the dirty good where both the output and the waste by-product are produced using inputs like labor, capital, and other resources. Using a device common in environmental economics, however, we simply move the waste emissions to the other side of the equation. In other words, we view emissions as an input to production, with its own downward sloping marginal product curve (since successive units of emissions are less crucial to production). Total emissions (NZ) negatively affect the environment through:

$$E = e(NZ), \quad \text{where } e' < 0. \tag{1}$$

The other goods are produced according to:

$$X = L_X \tag{2a}$$

$$Y = F(L_Y, Z) \tag{2b}$$

[6] If government cannot observe individual differences, then it cannot use individual-specific lump sum taxes. We abstract from heterogeneity, but still assume that the government cannot use lump sum taxes. For an interpretation that incorporates heterogeneity, see Kaplow (1996).

[7] These considerations might also affect the choice among policy instruments. Other models have analyzed uncertainty (Weitzman, 1974), monitoring and enforcement costs (Russell, 1990), and transactions costs (Stavins, 1995). The large literature on the choice among policy instruments is reviewed in Bohm and Russell (1985).

$$G = NL_G. \tag{2c}$$

We define a unit of X as the amount that can be produced using one unit of labor. The numeraire good is L, or equivalently X. Then Y is produced in a constant returns to scale function (F), using clean labor (L_Y) and emissions (Z). The elasticity of substitution between these two inputs will help determine pollution abatement possibilities. Emissions may include gaseous, liquid, or solid wastes that require some private costs for removal and disposal. These private costs must come in the form of resources, so we define one unit of emissions as the amount that requires one unit of private resources ($Z = L_Z$).[8] Thus, the private cost of Z is always 1. We define a unit of Y such that its initial competitive equilibrium price is $p_Y = 1$. Finally, labor (L_G) is also used to produce the public good. The combination of these production relationships provides the overall resource constraint:

$$NL = NX + N(L_Y + L_Z) + G. \tag{3}$$

Individuals maximize:

$$\mathscr{L} = U(X, Y, L_H, G, E) + \lambda[(1 - t_L)L + M - X - p_Y Y] \tag{4}$$

by their choice of X, Y, and L_H, where t_L is the tax rate on resource (labor) supply, and M is nonlabor income (discussed below). Taxable labor supply is $L = L_X + L_Y + L_Z + L_G$. A subscript on U indicates a partial derivative (marginal utility), and U_H is the partial of U with respect to L_H, so these individuals set $U_X = U_Y / p_Y = U_H/(1 - t_L) = \lambda$, the marginal utility of income.

Our approach is to start at an initial competitive equilibrium with an existing tax on labor, but without any policy correction for the external effect of Z on E, and then to analyze small changes. As shown in Appendix A, the general equilibrium impact of changes on utility following a restriction on emissions is given by:

$$\frac{dU}{\lambda L} = t_L \hat{L} - \mu\left(\frac{Z}{L}\right)\hat{Z} \tag{5}$$

where a hat over a variable indicates a proportional change (e.g. $\hat{L} = dL/L$), and where μ is defined as $-NU_E e'/\lambda$. This term μ is the dollar value of lost utility to all individuals from a marginal increase in emissions, that is, 'marginal environmental damage'.

This equation is a variation on Eq. (5) in Bovenberg and de Mooij (1994). The left-hand side is the dollar value of the change in utility (dU/λ), divided by total

[8] Note that emissions are positively related to the use of these resources: L_Z is not to clean up or reduce emissions, but just to cart it away. Abatement is undertaken by substituting away from Z and into L_Y. This overall production function is still constant returns to scale, since Z is a linear function of L_Z. The private cost for emissions helps justify our assumption of an internal solution with a finite choice for Z, even without corrective government policy.

income (L). On the right-hand side are two terms. The policy under consideration is a mandated reduction in emissions, or some incentive that reduces emissions, so $\hat{Z}<0$. Thus the second term on the right-hand side of (5) is an unambiguous increase in utility from abating pollution. The impact will depend on the importance of the externality (size of μ), the reduction in Z, and the initial size of Z relative to the size of the economy. In the first term, however, utility is also affected by a pre-existing labor tax ($t_L>0$). If the policy reduces labor supply, utility will fall by the exacerbation of a pre-existing labor distortion. The overall effect on welfare depends on the change in labor and on the relative size of these two terms.

In order to derive an expression for the change in labor supply, $\hat{L}$, we need to trace the effect of the policy on the price of emissions, the price of output, and thus on the real net wage. We also need to trace the effect of the policy on income flows that might also affect labor supply. These income effects include the possibility that the policy generates private profits.

Any policy to reduce Z will raise the marginal product of Z above its private cost. If the government imposes a tax on emissions, or sells a limited number of emission permits, then the firm faces an effective 'price' p_Z that equals the private resource cost plus the tax or the price of the permit. The price p_Z is simply the marginal product of emissions in equilibrium. For these two policies, the scarcity rent goes to the government.

If the limited number of permits are handed out for free, however, then the scarcity rent goes to the permit recipient. These permits can be used by the recipients, to yield a marginal product of emissions greater than the private cost of emissions, or they can be sold. Either way, the policy has generated a private profit (i.e. producer surplus). We define these profits as:

$$\Pi=(p_Z-1)Z. \tag{6}$$

The rules for the initial allocation of these permits do not matter in our model, because our N identical agents must own whatever firm or other entity is given the permits. These profits become part of nonlabor income, M, in Eq. (4).

These profits may arise for some kinds of command-and-control (CAC) policies as well. One example is a 'new source performance standard' that requires an expensive technology for new firms only, raising the marginal cost of production (and thus the equilibrium price of output) without affecting the cost of production for old firms. The result is an entry barrier that provides profits to old firms.[9] Our model does not distinguish new firms from old firms, but profits can arise in other ways. For the simplest example, consider the special case where production of Y

[9]See Buchanan and Tullock (1975) or Maloney and McCormick (1982). Nielsen et al. (1995) investigate a tax reform in which regulation with grandfathering is replaced by environmental taxes. They also stress the role of rents.

uses fixed combinations of L_Y and Z. Then a restriction on Z is equivalent to a restriction on Y. What happens if all firms are required to produce at 90% of last year's level? The result is a government-mandated cartel that allows all firms to charge a price greater than marginal cost.[10]

We start at a competitive equilibrium with no environmental policy and zero profits, and we introduce a new policy such as $\hat{Z} < 0$. Any generated profits might affect consumer behavior and government revenue. Thus, prior to any policy, $p_Z = 1$ and Π in Eq. (6) is zero. The change in profits ($d\Pi$) equals ($Zdp_Z + p_Z dZ - dZ$), which equals Zdp_Z (since the initial p_Z is 1).

The government budget constraint is:

$$G = Nt_L L + Nt_\Pi \Pi \tag{7}$$

where t_Π is a tax on profits. We can then set this tax rate (exogenously) to 1.0 for any case where government receives the scarcity rent, such as for an emissions tax or sale of permits, and we set it to zero for the other extreme where private parties keep the rents. This specification also allows us to consider the case where a pre-existing corporate profits tax rate would take part of the firm's private profits. We do not adjust this tax rate endogenously to help maintain the necessary revenue to pay for G, but its existence greatly affects the amount by which the labor tax might have to be adjusted. Suppose, for example, that a permit or CAC policy generates profits but also reduces labor supply and thus labor tax revenue. If the tax rate on profits is zero, then the government will have to raise the labor tax rate and exacerbate labor supply distortions. If t_Π equals 1, then the government may be able to reduce the labor tax rate.

Differentiate the government budget (Eq. (7)), set $dG = 0$, and use $d\Pi = Zdp_Z$ to get:

$$\hat{t}_L = -\left(\frac{t_L}{1 - t_L}\right)\hat{L} - t_\Pi\left(\varphi\frac{Z}{Y}\right)\hat{p}_Z \tag{8}$$

where $\hat{t}_L = dt_L/(1 - t_L)$ and $\varphi = p_Y Y/(X + p_Y Y) = p_Y Y/(1 - t_L)L$ is the share of consumer expenditures on the dirty good. Eq. (8) indicates the rate at which government has to change the labor tax. To evaluate this expression, we need to solve for $\hat{L}$ and $\hat{p}_Z$.

To determine specific effects on labor supply, we follow Bovenberg and de Mooij (1994) by assuming that G and E are separable in utility from leisure and

[10] These profits still arise with substitution between L_Y and Z. In our model, with perfect competition and constant returns to scale, identical firms would have no reason to buy or sell permits from each other anyway, so the tradeable permit equilibrium (with scarcity rents) must be functionally equivalent to the CAC equilibrium (with each firm's emissions limited to 90% of last year's level). The point is that the firm does not have to sell the permit to receive a profit: a mandated restriction still raises the marginal product of Z above its cost.

consumption, and that the combination of consumption goods is homothetic and separable from leisure:

$$U = U(V[Q(X, Y), L_H], G, E) \tag{9}$$

where Q is a homothetic function of X and Y.[11] The household budget is given by:

$$X + p_Y Y = (1 - t_L)L + (1 - t_\Pi)\Pi. \tag{10}$$

Define w as the real net wage, so $w = (1 - t_L)/p_Q$ where p_Q is a price index on $Q(X, Y)$. This index assigns the weight φ to p_Y, so $\hat{p}_Q = \varphi\hat{p}_Y$. Totally differentiate w to get:

$$\hat{w} = -\hat{t}_L - \varphi\hat{p}_Y. \tag{11}$$

This equation says that the real net wage falls if either the tax on labor were to rise, or if the price of consumption goods were to rise. In Appendix B, we show how the change in the price of emissions affects the price of Y, the real net wage, and labor supply. In addition, we show how labor supply ultimately depends on the policy shock (emission restriction):

$$\begin{aligned}\hat{L} &= (1 - t_\Pi)\left\{\frac{(1 - t_L)\varphi(\eta - \varepsilon)}{(1 - t_\Pi)\varphi(\eta - \varepsilon) - [\sigma_Q(1 - \varphi) + \sigma_Y(L_Y/Z)](1 - t_L - \varepsilon t_L)}\right\}\hat{Z} \\ &\equiv (1 - t_\Pi)\Omega\hat{Z}\end{aligned} \tag{12}$$

where σ_Q is the elasticity of substitution between X and Y in consumption, σ_Y is the elasticity of substitution between L_Y and Z in production of Y, ε is the uncompensated labor supply wage elasticity, and η is the labor supply income elasticity.[12] The term in curled brackets (Ω) must be positive if we assume that leisure is a normal good ($\eta < 0$), labor supply is not backward bending ($\varepsilon \geq 0$), and t_L is on the normal side of the Laffer Curve [$(1 - t_L - \varepsilon t_L) > 0$].[13]

The point of this equation is that environmental policy raises the cost of emissions, and thus the cost of output, in a way that reduces w and affects

[11] These assumptions imply that both goods are equal substitutes for leisure. Thus, when starting from a zero pollution tax, we show below that the introduction of a small pollution tax raises the price of Y and affects the real net wage and labor supply in a way that exactly offsets the reduction in the labor tax rate. This special case allows for a simple analytical solution to our model, but it is a central special case. If Y were a relative complement (or substitute) to leisure, then the pollution tax would reduce labor supply by less (or more) than exactly enough to offset the reduction in the labor tax rate. Also, even with equal substitutes, an increase in a pre-existing pollution tax would reduce labor by more than enough to offset the reduction in the labor tax rate.

[12] This equation could also be expressed in terms of the compensated elasticity $\varepsilon^C = \varepsilon - \eta$. Fullerton and Metcalf (1997) use $\varepsilon = 0.1$ and $\eta = -0.2$, for example, so their compensated elasticity is 0.3.

[13] This last term will be positive if the initial point is on the normal side of the Laffer curve. Define revenue as $R = Lt_L$, totally differentiate, and rearrange to get $\hat{R}/\hat{t}_L = (1 - t_L)/t_L - \varepsilon$.

equilibrium labor supply. With Ω positive and $\hat{Z}$ negative, the equation says that equilibrium labor supply must fall. Notice that the tax on profits t_Π is very important for damping the impact of a price change on labor supply. In the limit when all profits are taxed away, labor supply is not affected at all.

3. Interpretation of results

We now use the welfare effect in Eq. (5) to compare several policies. Firstly, consider a CAC restriction on emissions with no capture of rents ($t_\Pi = 0$). This policy is equivalent, in our model, to handing out a limited number of tradeable pollution permits. Since $\hat{Z}$ is negative in Eq. (5), the second term in brackets $[-\mu(Z/L)\hat{Z}]$ is the unambiguous gain from correcting the externality. The first term is $t_L\hat{L}$, the loss from the labor distortion. For reasonable parameter values, Fullerton and Metcalf (1997) show that the first term loss can exceed the second term gain. In this case, the very first step toward correcting the pollution externality has a net *negative* effect on welfare.[14] Regardless of whether the negative labor supply effect is large enough to offset the positive environmental effect, however, the point is that the negative labor supply effect arises from creating scarcity rents ($\mathrm{d}\Pi > 0$) and leaving them in private hands ($t_\Pi = 0$).

Further intuition is provided by Neary and Roberts' (1980) result that a regulation can be interpreted as a 'virtual' tax. This virtual tax is either recycled lump sum, by grandfathered permits, or it can be captured by government and used to reduce labor taxes. What is crucial is the way the tax is recycled, not whether the revenue appears explicitly in the government budget.

Secondly, suppose the government sells some of the permits or otherwise captures part of the rents ($0 < t_\Pi < 1$). Then (12) shows that labor supply still falls. The negative labor supply effect is smaller, but it can still offset part or all of the positive environmental effect. With t_Π strictly positive, this policy is a 'revenue-raising' policy, but it can provide a net welfare loss (Fullerton and Metcalf, 1997). Thus revenue raising is not sufficient for positive welfare effects (Goulder et al., 1997).

Thirdly, suppose that government captures *all* of the rents ($t_\Pi = 1$) by using an emissions tax, selling all of the permits, or imposing a 100% profits tax. Then (12) shows that $\hat{L}$ is zero. The first term in (5) disappears, leaving only the positive welfare effect of improving the environment.

[14] Similar numerical results were obtained by Parry (1997) and Goulder et al. (1997), where a pollution quota has a 'tax-interaction effect' (raising output prices that reduce the real net wage) and no 'revenue-recycling effect' (lowering the labor tax rate to raise the real net wage). The net effect on welfare also can be negative even *with* $t_\Pi = 1$, if revenues are used for lump-sum rebates or for reduction of a tax on a fixed factor (Bovenberg and Goulder, 1996).

Fourthly, consider a subsidy per unit of abatement from a baseline level. Schöb (1996) shows that this policy is equivalent to the combination of a *tax* per unit of emissions (the subsidy foregone) plus a lump-sum transfer to firms (the subsidy rate times baseline emissions). The higher opportunity cost of emissions still raises the equilibrium output price and therefore lowers the real net wage, but this negative effect on labor supply is exacerbated by the transfer (since leisure is a normal good). This policy performs quite poorly in simulations of Ballard and Medema (1993) or Parry (1998).

Some might attribute this last result to the fact that the subsidy loses revenue instead of raising revenue, but we attribute it to the creation and handout of rents. To demonstrate this point, we now show that a revenue *losing* subsidy can be just as effective as a revenue *raising* policy.

Fifthly, therefore, consider a different kind of subsidy. To simplify, we revert temporarily to a model with no abatement in production ($Y = Z$). We then consider a subsidy (s) to consumption of the clean good (X), so the household budget constraint becomes $X(1 - s) + p_{Y}Y = (1 - t_{L})L$. This policy tilts consumers toward purchase of X, and therefore away from Y. It reduces the overall price index, which would raise the real net wage, but the necessary increase in the labor tax offsets that effect. Since the added tax on labor is equivalent to a tax on *both* goods, the tax on labor plus subsidy to the clean good is just a renormalization (Fullerton, 1997; Schöb, 1997). It is identical to the tax on pollution with complete capture of rents. This policy has no effect on the real net wage and no effect on the pre-existing labor distortion. It has only the positive effect of improving the environment.

Sixthly, return to the model of emissions in production, and consider a similar renormalization: a subsidy to the clean input (L_{Y}).[15] Instead of raising the cost of production, like the subsidy per unit of abatement, this subsidy reduces the cost of production. If it is financed by a tax on output of Y, this 'two-part instrument' is equivalent to the tax on emissions (Fullerton and Wolverton, 1999). This subsidy does not create scarcity rents, so it does not exacerbate labor distortions.

A final type of policy is a technology restriction, considered in the next section.

4. A technology restriction

Do all command and control policies raise production costs and exacerbate the labor supply distortion? If environmental authorities hand out a limited number of permits, or otherwise restrict the quantity of emissions, they create a scarce resource. Whoever owns the 'rights' to those limited emissions earns a scarcity rent. Similarly, a 'new source performance standard' erects a barrier to entry by

[15] An example is a subsidy for the use of low-sulfur coal, but note that our simple model has only two inputs. With more inputs, the subsidy would have to apply to all inputs other than emissions.

raising costs for new firms only. Suppose instead, however, that the authorities were to impose a technological requirement on the production process for *all* firms. For example, suppose every firm must have a scrubber on every smokestack. This rule might raise costs, but it does not restrict entry, and it does not provide an advantage to existing firms. We show below that this type of requirement reduces equilibrium emissions, even though it does not legally restrict emissions. It cannot generate profits in our model, because other firms have access to the exact same constant-returns-to-scale technology and would enter to share those profits.

This technological restriction can be analyzed in our model as a forced change in emissions (Z) per unit of output (Y), or equivalently, a forced change in the ratio of inputs (L_{Y}/Z). In other words, instead of the policy $\hat{Z}<0$, we analyze the policy $(\hat{L}_{\mathrm{Y}}-\hat{Z})>0$. Firms have a number of ways to comply with this restriction. They can cut emissions, or they can just use more of the clean input. They could even increase emissions, so long as they increase clean inputs more. In order to look at the firm's problem in terms of levels, rather than changes, suppose the initial equilibrium quantities are $Y^0=F(L_{\mathrm{Y}}^0, Z^0)$. Then the new policy restricts the choice of L_{Y} and Z such that

$$\left(\frac{L_{\mathrm{Y}}}{Z}-\frac{L_{\mathrm{Y}}^0}{Z^0}\right)\geq r>0. \tag{13}$$

The initial ratio (L_{Y}^0/Z^0) is taken as given by policy makers, existing firms, and even entrants.[16] Policy makers specify the required increase in that ratio (r). Any existing firm or entrant takes those two parameters (L_{Y}^0/Z^0 and r) as given.

The initial equilibrium has no restriction ($r=0$), and we find a new equilibrium with a small increase in r. Perhaps surprisingly, we find that a small increase in r has no effect on production costs and therefore no effect on the price of Y. It thus has no effect on the real net wage or the pre-existing labor supply distortion. In general, the firm chooses L_{Y} and Z to minimize:

$$\mathscr{L}=p_{\mathrm{L}}L_{\mathrm{Y}}+p_{\mathrm{Z}}Z+\xi_1[Y-F(L_{\mathrm{Y}},Z)]+\xi_2\left(r-\left(\frac{L_{\mathrm{Y}}}{Z}-\frac{L_{\mathrm{Y}}^0}{Z^0}\right)\right). \tag{14}$$

Define C^* as the optimized cost function. By the envelope theorem, ξ_1 is the marginal cost of production ($\partial C^*/\partial Y$) while ξ_2 is the shadow price of the regulatory constraint ($\partial C^*/\partial r$). We want to know how the policy (r) affects the marginal cost of production (ξ_1), that is, the magnitude of $\partial\xi_1/\partial r$. Second partials are invariant to the order of differentiation, so:

$$\frac{\partial^2 C^*}{\partial Y\partial r}=\frac{\partial\xi_1}{\partial r}=\frac{\partial\xi_2}{\partial Y}. \tag{15}$$

[16] Because of constant returns to scale, in this model, the same ratio of inputs would be used by all firms. The ratio matters, but not the initial level of each input.

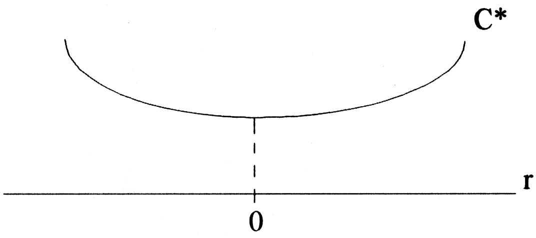

Fig. 1. Marginal cost and regulation.

Thus, to see how marginal cost changes with r, we need only consider how the shadow price on the regulatory constraint changes with Y. At the initial point where $r = 0$, and therefore the initial $\xi_2 = 0$, constant returns to scale in $F(L_Y, Z)$ implies that output Y can vary with *no change* in the factor ratio (given factor prices). In other words, changes in Y have no impact on ξ_2. Since $\partial\xi_2/\partial Y = 0$ at that point, Eq. (15) implies that $\partial\xi_1/\partial r = 0$. And with competition among firms, no change in marginal cost means no change in output price. Thus the policy does not affect the real net wage.

In the absence of profits, labor supply is $\hat{L} = \varepsilon\hat{w} = 0$. Also, since the price of Y is unchanged, the demand for Y must be unchanged. Essentially, firms switch from $Z = L_Z$ into L_Y with no change in total use of resources L, and no change in output. But since Z falls, welfare unambiguously increases.

How can an environmental restriction leave the marginal cost of production unchanged? To provide some intuition, Fig. 1 shows how the optimized cost function C^* is related to the regulatory parameter r. Because of constant returns to scale, this total cost can be taken for one unit of output and interpreted as marginal cost. This cost is minimized by the firm's unrestricted choices at the initial point where $r = 0$, so it must be higher at any $r \neq 0$. Thus costs *are* higher with $r \neq 0$, as one would expect. But, evaluated at $r = 0$, the curve is flat. From the initial starting point, a small change in r has no perceptible effect on cost. As the policy becomes restrictive, however, it would begin to raise the cost of production. Since the marginal cost of environmental protection is the increment to production cost, we have just shown that the marginal cost curve for this type of environmental protection starts at the origin.[17] A small but finite restriction has only second-order

[17]This 'origin property' is shared by the emissions tax (when revenues are used to cut the labor tax). While both the emissions tax and the technology restriction reduce pollution per unit output, only the emissions tax can also reduce output optimally. Thus, as shown by Goulder et al. (1999), a *large* policy of technology restriction can become more expensive per marginal unit of abatement than the emission tax and can even become more expensive than the quota (CAC quantity restriction or handout of permits). This distinction between large and small policies is important, but it is not the same as the distinction between starting at the origin and starting away from the origin.

effect on cost, but it has first-order effect on environmental benefits (since μ is strictly positive). We do not find the optimal degree of protection, that is, where the rising marginal cost curve intersects the falling marginal benefit curve. We only show that, for positive initial marginal benefits of protection, the first small restriction unambiguously raises welfare.[18]

The technology restriction $(\hat{L}_{Y} - \hat{Z}) > 0$ generates a cross-subsidy within the firm. Emissions may be reduced, such that the marginal product F_{Z} rises above private cost ($p_{Z} = 1$), but, to produce the same output, labor is increased such that its marginal product F_{L} falls *below* private cost ($p_{L} = 1$). Implicitly, profits on emissions are offset by losses on use of labor, as necessary to satisfy the restriction, with no net profits.

Thus the technology restriction is equivalent to the revenue-neutral combination of a small 'virtual' tax on Z and subsidy to L_{Y} (using Neary and Roberts (1980)).[19] In one case the government collects the 'profits' on Z to cover 'losses' on L_{Y}, and in the other case the government forces the firm to use profits on Z to cover its own losses on L_{Y}. The two outcomes are equivalent. Again, this result clarifies that the important distinction is not whether the policy raises revenue, but whether it generates privately-retained rents.

5. Conclusion

We have considered a number of environmental policies in a simple general equilibrium model to assess how these policies interact with pre-existing distortions. Whether we analyze tradeable pollution permits, direct controls on emissions, subsidies for non-polluting activities, or mandated technology adoptions, we find a common theme in our results. The magnitude of the welfare gain (or possibly the loss) due to new environmental policies in the face of pre-existing distortions depends critically on (1) whether the policy generates scarcity rents and (2) whether those rents are captured by the government and used to lower other distorting taxes. Environmental policies enhance welfare by reducing pollution but

[18] The pollution tax has both a substitution effect (by raising the cost of Z relative to L_{Y}) and an output effect (by raising the price of Y and discouraging purchases). In contrast, this technological restriction reduces pollution only through the mix of inputs. Walls and Palmer (1997) show that full equivalence to the pollution tax can be restored by placing a tax on output. Also, our model does not capture differences among firms' abatement costs. If these costs differ, then to remain efficient, a technology-based CAC policy would have to specify which firms must change which technologies. Information problems may become prohibitive. Finally, note that the pollution tax might provide more dynamic efficiency through incentives to invent new technologies.

[19] de Mooij and Bovenberg (1998) show that a shift from a capital tax to a pollution tax can induce inflow of mobile capital, increase output, and ultimately increase pollution. In our closed economy model, the cross-subsidy has no effect on production cost, so it cannot change output price or output. With $\hat{Y}=0$, and $(\hat{L}_{Y} - \hat{Z}) > 0$, we must have L_{Y} rise and pollution fall.

can reduce welfare by discouraging labor supply. The net welfare change depends on the relative size of these two factors. The key to understanding the impact on labor supply is to focus on the real net wage. When a policy generates scarcity rents, it leads to an increase in the price level that reduces the real net wage and hence labor supply. The only way to avoid this adverse effect on efficiency is for government to capture the rents (through a 100% tax on profits, or the sale of all tradeable permits), or to avoid generating the rents (through mandated technologies for all existing firms and entrants). Thus, much of the focus in our paper is on the sources and disposition of these scarcity rents.

Recognizing the importance of scarcity rents clarifies a source of possible confusion in the 'instrument choice' and 'double dividend' literature. Much of the emphasis in this literature has been the role that the revenue from the Pigouvian tax plays in allowing a reduction in other tax rates. Our analysis of different policies shows that this emphasis is misplaced. Following the assumption in that literature that the budget is balanced by adjusting the labor tax rate, we demonstrate equivalent welfare results whether government were to (1) raise revenue by taxing pollution or selling tradeable permits, (2) lose revenue by subsidizing the clean alternative to the polluting good or input, or (3) collect no revenue by using a technology mandate. Small changes in any of these three directions have no effect on the real net wage or on the labor market distortion.

Acknowledgements

The authors gratefully acknowledge the comments of Richard Arnott, Lans Bovenberg, Larry Goulder, Dan Hamermesh, Michael Hanemann, Ian Parry, Jon Skinner, Kerry Smith, Pete Wilcoxen, and three anonymous referees. This research was partially supported by grants to the first author from the Environmental Protection Agency (EPA R824740-01-0) and to the second author from the National Science Foundation (NSF SBR-9514989). This paper is part of NBER's research program in Public Economics. Any opinions expressed are those of the authors and not those of the EPA, the NSF, or the National Bureau of Economic Research.

Appendix A. Impact of the emissions restriction on utility (Eq. (5))

First totally differentiate utility (holding G fixed):[20]

$$\mathrm{d}U = U_{\mathrm{X}}\mathrm{d}X + U_{\mathrm{Y}}\mathrm{d}Y - U_{\mathrm{H}}\mathrm{d}L + U_{\mathrm{E}}e'N\mathrm{d}Z. \tag{A.1}$$

[20] This G is required in the model to justify the collection of taxes (see Eq. (7)).

To balance the government's budget, a policy that reduces labor must also specify how the lost labor tax revenue will be recovered. Substituting the consumer's first order conditions into (A.1) yields:

$$dU = \lambda dX + \lambda p_Y dY - \lambda(1 - t_L)dL + U_E e' N dZ. \tag{A.2}$$

Totally differentiate the resource constraint (3), with $dG = 0$, to get $dX = dL - dL_Y - dL_Z$, and substitute into (A.2):

$$dU/\lambda = t_L dL - \mu dZ + (p_Y dY - dL_Y - dL_Z) \tag{A.3}$$

where $dL_Z = dZ$, and where μ is defined as $-NU_E e'/\lambda$. Next, totally differentiate the production function for Y:

$$dY = F_L dL_Y + F_Z dZ \tag{A.4}$$

where F_L and F_Z are the marginal products of L_Y and Z. Assuming profit maximization (and a zero initial tax on emissions), these marginal products are equal to factor prices divided by output price: $F_L = F_Z = 1/p_Y = 1$. Thus, from (A.4), the expression in parentheses in (A.3) is zero. We divide (A.3) by L (and use $\hat{L} \equiv dL/L$) to get (5) in the text.

Appendix B. Impact of the emissions restriction on labor supply (Eq. (12))

First we show how p_Y is related to the cost of Z by using the zero-profits condition to show that $\hat{p}_Y = (Z/Y)\hat{p}_Z$.[21] Then, using (8) in (11), we have:

$$\hat{w} = \left(\frac{t_L}{1 - t_L}\right)\hat{L} - (1 - t_\Pi)\varphi\left(\frac{Z}{Y}\right)\hat{p}_Z. \tag{B.1}$$

Labor is chosen by maximizing the sub-utility function $V(Q, L_H)$ subject to:

$$Q = wL + (1 - t_\Pi)\Pi/p_Q. \tag{B.2}$$

We can write the labor supply function resulting from this maximization problem as $L = L(w, (1 - t_\Pi)\Pi/p_Q)$. That is, labor supply depends on uncompensated effects of the real net wage, and it depends on additional income effects of real net profits. Totally differentiating this function yields:

$$\hat{L} = \varepsilon\hat{w} + (1 - t_\Pi)\eta\varphi\left(\frac{Z}{Y}\right)\hat{p}_Z \tag{B.3}$$

where ε is the uncompensated labor supply elasticity, and η is the income

[21] Profits are created by $p_Z > 1$, but the firm breaks even on output given that higher cost of Z. The zero-profits condition is $p_Y Y = L_Y + p_Z Z$. Totally differentiate, and use the fact shown above (at Eq. (A.4)) that $dY = dL_Y + dZ$, to get $dp_Y Y = dp_Z Z$. Initial prices are one, so $\hat{p}_Y = (Z/Y)\hat{p}_Z$.

elasticity of labor supply. Substituting Eq. (B.1) into (B.3) gives the labor supply response as a function of $\hat{p}_Z$:

$$\hat{L} = \frac{(1 - t_\Pi)(1 - t_L)(\eta - \varepsilon)\varphi}{1 - t_L - \varepsilon t_L}\left(\frac{Z}{Y}\right)\hat{p}_Z. \tag{B.4}$$

Next, we need to relate $\hat{p}_Z$ to the emissions restriction. In general, this relationship depends on the demand for emissions, which depends on the demand for the output. The demand for Y is based on the consumer's maximization of $Q(X, Y)$, where we define σ_Q as the elasticity of substitution between X and Y in consumption. Given this definition, and given that the price of X always equals 1, we have the basic behavioral relationship:

$$\hat{Y} = \hat{X} - \sigma_Q \hat{p}_Y. \tag{B.5}$$

We need to eliminate $\hat{X}$ from this expression. Totally differentiate the household budget constraint (10), without holding any variables constant, and rearrange to solve for $\hat{X}$. Substitute that expression into (B.5), and rearrange to get:

$$\hat{Y} = \hat{L} + \hat{w} + \varphi(1 - t_\Pi)\hat{p}_Y - \sigma_Q(1 - \varphi)\hat{p}_Y. \tag{B.6}$$

The first two terms give the income effect on Y from the change in labor income, which implicitly incorporates the government's adjustment of t_L. The third term represents the income effect of profits on the demand for Y. The last term is the substitution effect.

Next, substitute Eqs. (B.1) and (B.4) into (B.6) to obtain $\hat{Y}$ as a function of $\hat{p}_Y$:

$$\hat{Y} = \left\{\frac{(1 - t_\Pi)\varphi(\eta - \varepsilon) - \sigma_Q(1 - \varphi)(1 - t_L - \varepsilon t_L)}{1 - t_L - \varepsilon t_L}\right\}\hat{p}_Y \equiv \gamma_Y \hat{p}_Y. \tag{B.7}$$

The expression γ_Y represents the full general equilibrium response of Y to a change in its price, incorporating household behavior as well as the government budget constraint. We combine Eqs. (B.4) and (B.7) to obtain:

$$\begin{aligned}\hat{L} &= (1 - t_\Pi)\left\{\frac{(1 - t_L)\varphi(\eta - \varepsilon)}{(1 - t_\Pi)\varphi(\eta - \varepsilon) - \sigma_Q(1 - \varphi)(1 - t_L - \varepsilon t_L)}\right\}\hat{Y} \\ &\equiv (1 - t_\Pi)\Delta\hat{Y}.\end{aligned} \tag{B.8}$$

Next we relate changes in output to changes in emissions. Let σ_Y represent the elasticity of substitution in production of Y between the two inputs (L_Y and Z). Then, by definition:

$$\hat{L}_Y - \hat{Z} = \sigma_Y(\hat{p}_Z - \hat{p}_L). \tag{B.9}$$

The price of labor is fixed, however, so Eq. (B.9) can be written as:

$$\hat{L}_Y = \hat{Z} + \sigma_Y \hat{p}_Z. \tag{B.10}$$

We showed above that $dY = dL_Y + dZ$ (Eq. (A.4)), so the percentage change in output of Y can be expressed as a weighted average of the percentage changes in the two inputs:

$$\hat{Y} = \left(\frac{L_Y}{Y}\right)\hat{L}_Y + \left(\frac{Z}{Y}\right)\hat{Z}. \tag{B.11}$$

Recall that the firm makes zero profits on output, given the raised price of emissions necessary to cover the scarcity rents, so:

$$p_Y Y = p_L L_Y + p_Z Z. \tag{B.12}$$

Evaluated at initial prices of one (prior to the regulation), we have $Y = L_Y + Z$. Substitute Eq. (B.10) into (B.11) and use the relationship $Y = L_Y + Z$ to obtain:

$$\hat{Y} = \hat{Z} + \sigma_Y \left(\frac{L_Y}{Y}\right)\hat{p}_Z. \tag{B.13}$$

Now recall that the full equilibrium effect on Y, in Eq. (B.7), is $\hat{Y} = \gamma_Y \hat{p}_Y$ and that $\hat{p}_Y = (Z/Y)\hat{p}_Z$. Together, these two relationships imply:

$$\hat{p}_Z = \left(\frac{Y}{Z\gamma_Y}\right)\hat{Y}. \tag{B.14}$$

Substituting (B.14) into (B.13) provides the equilibrium relationship between Y and Z:

$$\hat{Y} = \left(\frac{\gamma_Y}{\gamma_Y - \left(\frac{L_Y}{Z}\right)\sigma_Y}\right)\hat{Z}. \tag{B.15}$$

Finally, we substitute Eq. (B.15) into (B.8) and use the expression for γ_Y to get (12) in the text.

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