Emissions Taxes Versus Intensity Standards: Second-Best Environmental Policies with Incomplete Regulation.

By: Stephen P. Holland

Holland, S.P. "Emissions Taxes Versus Intensity Standards: Second-Best Environmental Policies with Incomplete Regulation." *Journal of Environmental Economics and Management* (2012) 63(3): 375–387.

Made available courtesy of Elsevier: http://dx.doi.org/10.1016/j.jeem.2011.12.002

Abstract:

The best emissions tax or emissions cap may be an inferior instrument under incomplete regulation (leakage). Without leakage, an intensity standard (regulating emissions per unit of output) is inferior due to an implicit output subsidy. This inefficiency can be eliminated by an additional consumption tax. With leakage, an intensity standard can dominate the optimal emissions tax, since the implicit output subsidy prevents leakage. The addition of a consumption tax improves an intensity standard's efficiency, may prevent leakage, and may be efficient. Comparing intensity standards to output-based updating shows that the latter dominates if updating is sufficiently flexible.

Keywords: intensity standards | externality | emissions trading | emissions taxes | leakage | incomplete regulation | market power

Article:

1. Introduction

Emissions taxes and emissions markets are widely regarded as the preferred policy instruments for regulation of environmental externalities. Since these instruments can impose the correct price on a missing market, the instruments can mimic the first-best market mechanism and implement the efficient control of the externality. This paper investigates whether these instruments are indeed best in the presence of other market failures. Surprisingly, I show that these two instruments may be dominated by a third instrument, an intensity standard regulating emissions per unit of output, in the presence of incomplete regulation (leakage). In fact, since the analysis compares the second-best policies, the stronger result holds that under certain conditions any emissions tax (or cap) is dominated by an intensity standard.

The inefficiency of intensity standards was established by Helfand [21] and Fischer [11].1 More recently Holland et al. [23] argued that California's Low Carbon Fuel Standard (LCFS), an intensity standard regulating carbon emissions per unit of transportation fuel, cannot attain the first best, could increase carbon emissions, and has much higher abatement costs than an efficient policy. However, optimal intensity standards and optimal emissions taxes (or trading) have not been compared under leakage.2

Incomplete regulation or leakage can occur for two reasons. First, a political jurisdiction may not be geographically consistent with the region that suffers environmental damages or with the product market. For example, since carbon is a global pollutant, regulating carbon emissions within any region (e.g. state, country, or set of countries) may cause production and emissions to “leak” to regions which do not regulate carbon. International leakage is especially troublesome since attempts to tax foreign-produced goods based on carbon content would likely violate international trade law. Winchester et al. [34] estimate leakage rates up to 10% from a national emissions cap but argue that border carbon adjustments can cut the leakage rate to about 3% if such adjustments do not violate international trade agreements. In addition to international leakage, the failure of the U.S. to achieve a national carbon policy has led states to adopt greenhouse gas initiatives [9]. For example, California passed legislation in 2006 capping greenhouse gas emissions, and a group of eastern states adopted the Regional Greenhouse Gas Initiative (RGGI) in 2009. Policy makers recognized that leakage was a serious concern in both markets [29]. In particular, Fowlie [15] found the potential for dramatic leakage with the California cap. Note that the ability of regulators to limit interstate leakage is likely limited by the Interstate Commerce Clause.

Second, within a political jurisdiction some sectors may use political clout to avoid regulation, or there may be costs to expanding the regulated base to cover 100% of the emissions. Metcalf [26] argues for a carbon tax base that covers 90% of U.S.'s carbon emissions, and Stavins [32] states that “nearly all” U.S. CO2 emissions could be captured by regulating 2000 upstream entities. Bluestein [4] estimates that “about 1250 entities [are] required for 95%+ capture of domestic [CO2] production.” However, proposed legislation is much less comprehensive. For example, biofuels are largely exempt from proposed carbon legislation since indirect land use effects are excluded from the American Clean Energy and Security Act of 2009 (ACES Act), H.R. 2454, also known as the Waxman–Markey bill. Once the scope of the regulation is set, production (and emissions) will tend to leak to the unregulated firms.

While the main result of this paper, that an intensity standard can dominate the second-best emissions tax, is surprising in the light of the prior literature, the intuition is relatively

straightforward. Environmental market mechanisms reduce emissions through both substitution and output effects. Substitution effects reduce emissions by employing additional capital (e.g. emissions control technology) or more costly fuel inputs (e.g. switching to a cleaner fuel source). Output effects reduce emissions by reducing consumption of the polluting good (e.g. through car-pooling or investments in energy efficiency). Intensity standards fail because although they induce an implicit emissions tax, they also induce an implicit output subsidy. This implicit output subsidy leads to inefficient consumption. For example, Holland et al. argue that the LCFS does not efficiently encourage carpooling, reduced driving, or vehicular fuel efficiency. Alternatively, a tax or emissions cap efficiently reduces emissions through both substitution and output effects.

With leakage, an intensity standard can dominate because output effects from an emissions tax may be offset by leakage. If the supply of the unregulated sector is elastic enough and dirty enough, leakage from an emissions tax may even increase total emissions. An intensity standard can dominate since the implicit output subsidy can prevent leakage which might have occurred under an emissions tax.

The implicit output subsidy from an intensity standard can lead to too much consumption. I show that this inefficiency can be remedied with a consumption tax on the externality producing good. In fact, an intensity standard and consumption tax combination can be efficient in the absence of leakage. Even with leakage, a consumption tax can increase the efficiency of an intensity standard. In fact under certain conditions, an intensity standard combined with a consumption tax can prevent leakage and attain efficiency whereas an emissions tax combined with a consumption tax cannot.3 Moreover, a consumption tax can apply equally to domestic and foreign production and thus can comply with trade laws.

The implicit output subsidy of an intensity standard is similar to the incentives from output-based updating (also called output-based allocations) of emissions permits [13], [14] and [8]. Recent cap-and-trade legislation addressing climate change includes output-based updating for sectors susceptible to leakage.4,5 Both intensity standards and output-based updating pursue two objectives (penalizing emissions and encouraging output) with one instrument. Clearly two instruments would be superior, and I show that an optimal combined emissions tax and production subsidy (for the covered sector) dominate the optimal intensity standard. Whether output-based updating can dominate the optimal intensity standard depends on the degree to which the updating can mimic the optimal combined emissions tax and output subsidy.

Intensity standards also have advantages for regulating externalities produced by firms with market power. Market power's effect on environmental regulation was first discussed by Buchanan [7], and Barnett [2] showed that the optimal emissions tax for a monopoly should generally be less than the marginal damages.6 These theoretical concerns are important as many polluting industries are likely subject to market power.7 Since the inefficiency from market power arises due to insufficient output, an intensity standard's implicit output subsidy may reduce the inefficiency of environmental regulation of firms with market power. In a related working paper, Holland [22] shows that the second-best intensity standard can dominate the second-best emissions tax when the externality producing firms have market power.

Section 2 discusses several policies which regulate emissions intensities. The policies are all quite different. However, a common feature of the policies is that they do not regulate the level of the externality but regulate the intensity of the externality, which is the definition of an intensity standard.

Section 3 presents the basic model with the externality as the sole market failure and illustrates the implicit emissions tax and output subsidy from an intensity standard. In the absence of leakage, the implicit output subsidy causes the intensity standard to be inefficient. Showing that this inefficiency is corrected by a consumption tax (even with heterogeneous firms) illustrates that this inefficiency arises from the implicit output subsidy rather than from mispricing of the externality.

Section 4 extends the model to analyze leakage from a covered (domestic) sector to an uncovered (foreign) sector. I characterize the second-best emissions tax and intensity standard and show that neither policy can attain efficiency unless uncovered emissions are also taxed at marginal damages. The main result of the paper (the second proposition) shows that an intensity standard can dominate the second-best emissions tax and derives a sufficient condition for this dominance. I then address combining the policies with a consumption tax applied to both covered and uncovered production. This additional instrument is useful since it can allow the intensity standard to attain the first-best even though an emissions tax/consumption tax combination cannot. Extending the model to output-based updating shows the similarity of the two policies and the superiority of output-based updating if the output subsidy is sufficiently flexible. Section 5 concludes.

2. Intensity standards in environmental regulation

As used in this paper, an intensity standard refers to a policy which regulates an externality per unit of output. In contrast, a Pigouvian tax or a cap-and-trade program would simply regulate the level of the externality. There are several policies which have been adopted or proposed which regulate an externality per unit of output either at the firm level or at the market level through trading. This section describes five such policies: the Low Carbon Fuel Standard (LCFS), the Renewable Portfolio Standard (RPS), the Renewable Fuel Standard (RFS), several aspects of the Clean Air Act Amendments (CAAAs), and indexed regulation. These policies all differ in their definition of emissions and output and in whether or not trading is allowed. Note that trading transforms an intensity standard from a firm- to a market-level policy (Holland et al.).

The Low Carbon Fuel Standard was launched in California by Governor Arnold Schwarzenegger on January 18, 2007 ([1] and [6], and Holland et al.). The LCFS was intended to reduce California's carbon emissions by regulating the carbon intensity of motor fuel. Probably due to political expediency, California's LCFS was quickly adopted into law despite a lack of careful evaluation and despite economists' recommendations for a carbon fee or cap-and-trade program.

Defining emissions was particularly difficult for the LCFS since tailpipe carbon emissions from gasoline and from advanced biofuels are equal although their lifecycle emissions may be dramatically different. California chose to define emissions based on lifecycle analysis, which has proved highly controversial [10] and [30].

Defining output also entailed several options each with different advantages and disadvantages. The simplest measure, gallons of fuel, would not account for the differences in energy content of fuels. For example, a gallon of ethanol (E85) has 65% of the energy content of a gallon of gasoline, but diesel fuel has slightly more energy per gallon. Miles traveled is a better measure of output, but mileage depends on many factors not controlled by the regulated entities. Ultimately California measured output as energy equivalent gallons of fuel with slight adjustments for differential drivetrain efficiencies.

California's LCFS regulated the fuel blenders (e.g. Chevron). However, the aim of the policy was to reduce California's carbon intensity from motor fuel which did not necessarily require every blender to reduce its carbon intensity. Thus the LCFS instituted trading of “LCFS credits” which allows a blender to meet its obligation by purchasing credits from another blender who had produced enough low-carbon fuel to exceed the standard. Holland et al. show that trading transforms the LCFS into a market-level policy instead of a firm-level policy.

A LCFS was included in several national bills to address climate change including in early versions of H.R. 2454 (known as Waxman–Markey) although a LCFS was not included in the version which passed the House. LCFSs have also been proposed in other regions and countries including: British Columbia, Washington, Oregon, Arizona, New Mexico, Minnesota, Illinois, the United Kingdom and the European Union (Holland et al.).

Another intensity standard, a Renewable Portfolio Standard (RPS) requires electricity providers to obtain a minimum percentage of their power from renewables. In the language of this paper, an RPS is an intensity standard regulating the nonrenewable intensity of electricity. There is no national RPS, but currently 24 states plus the District of Columbia have RPSs requiring from 15% to 40% renewable power by various dates.8 There is substantial variation in the policies across states. Most variation arises in the definition of renewable, perhaps due to the ambiguity of the externality associated with nonrenewable electricity. For example, some states classify "waste tires" and "energy efficiency" as renewable, but no states classify nuclear as renewable despite its negligible emissions. The state-level RPSs are similar in that most allow trading and define output as MWs (capacity) or MWh (production) of electricity.

The Renewable Fuels Standard (RFS) regulates the share of "renewable" fuel in motor fuel. A national RFS was adopted as part of the Energy Policy Act of 2005 and was expanded under the Energy Independence and Security Act (EISA) of 2007. The RFS adopted in EISA actually specifies the minimum levels of renewables rather than the minimum percentages.9 However, in implementing the law, the US EPA requires each blender to procure a specified percentage of renewable fuel (with trading allowed). Thus the RFS is quite similar to an intensity standard as used in this paper.

Some regulations under the CAAAs specify performance standards (technology standards) for new equipment. For example, the regulations may require a NOx emissions rate measured in lbs/MW below some threshold, which may vary by region. Performance standards regulate the emissions intensity of equipment and hence are like smokestack-level intensity standards. The incentive effects of such performance standards have been criticized (e.g. see Helfand). However, the adverse effects are mitigated by the lack of trading since the implicit output subsidy is reduced.

Newell and Pizer [27] and Pizer [28] analyze indexed regulations where the emissions cap is indexed, e.g. a carbon cap indexed to GDP. While conceptually similar to the intensity standard in this paper, an indexed carbon cap would not have an implicit output subsidy if the regulated firm views GDP as exogenous. However, if freely allocated permits were linked to each firm's output, the incentives under indexed regulation would be quite similar to an intensity standard.

3. Regulation with no leakage

To introduce the model and solution methods, I first analyze intensity standards combined with a consumption tax where the sole market failure arises from the externality. The consumption tax helps to illustrate the output subsidy implicit with the intensity standard and also illustrates that the inefficiency of the intensity standard arises primarily from this output subsidy rather than from mispricing the externality.

Assume a (representative) firm produces output, q, with a concave production function $f(k,e)$ with non-negative marginal products ($f_k \geq 0$ and $f_e \geq 0$) where k is a vector of market inputs (*e.g.* labor, capital, fuel, etc.) and e is an unpriced input (*e.g.* emissions).[10] Let w be the price vector for the market inputs, and let the ith market input, market input price, and marginal product be represented by k_i, w_i, and f_{k_i}. Let U be the benefit from consumption, where $U'>0$ and $U''<0$, and let damages from emissions e be τe.[11]

Suppose the firm is subject to two policies: an intensity standard σ such that e/q must be no greater than σ and a consumption tax tc per unit of output. I first characterize the perfectly competitive equilibrium using the cost function. I then derive the optimal policy for the regulator who recognizes that its policy choices affect the resulting equilibrium.

The firm's cost function depends on the intensity standard and is given by $c(q;w,\sigma)=\min_{k,e} wk+\lambda[q-f(k,e)]+\gamma[e-\sigma q]$ where λ and γ are Lagrange multipliers. Cost minimization implies that $w=\lambda f_k(k,e)$, *i.e.* $\lambda=w_i/f_{k_i}$ for every i, and $\gamma=\lambda f_e(k,e)$ which implies that $\gamma=w_i f_e(k,e)/f_{k_i}(k,e)$ for every i. Note that the envelope theorem implies that $\partial c/\partial\sigma=-\gamma q=-q w_i f_e(k,e)/f_{k_i}(k,e)$, so that increasing σ (relaxing the regulation) decreases costs.

The envelope theorem further implies that the marginal cost is $c_q(q;w,\sigma)=\lambda-\gamma\sigma=w_i/f_{k_i}\cdot(1-f_e\sigma)$. This condition describes the output subsidy effect. With no unpriced inputs, the cost of increasing output by one (marginal) unit is the cost of the additional input required, $1/f_{k_i}$, times it price, w_i. Cost minimization requires that the firm equates this cost across all market inputs. With an unpriced input and an intensity standard, the cost of increasing output by one (marginal) unit is reduced. Increasing output by one unit relaxes the standard which allows σ additional units of the unpriced input (emissions) and $f_e\sigma$ additional units of free output. Thus increasing output requires additional market inputs for only the proportion $1-f_e\sigma$ of additional output.

An intensity standard does not distort the relative prices faced by market inputs. The condition $w=\lambda fk(k,e)$implies that the marginal rate of technical substitution (MRTS) equals the market input price ratio,*i.e.*$fki/fkj=wi/wj$, for all market inputs i and j. Thus the intensity standard does not distort the relative prices faced by market inputs, but potentially distorts the price faced by emissions relative to market inputs if $\gamma\neq\tau$.

The five endogenous variables in the equilibrium - q, λ, k, e, and γ - are completely determined by the two first-order conditions from cost minimization; the production function; the market clearing condition, $U'(q)-tc=\lambda-\gamma\sigma$; and the binding intensity standard, $e=\sigma q$. This completely characterizes the perfectly competitive equilibrium.

Conditional on this equilibrium, the regulator can choose the consumption tax and intensity standard to maximize net social benefits

$$\max_{t_c,\sigma} U(q)-c(q;w,\sigma)-\tau e,$$

where by assumption, the regulator receives no benefit from the tax revenue. The first order condition for tc is

$$[U'(q)-c_q]\frac{\partial q}{\partial t_c}=\tau\frac{\partial e}{\partial t_c},$$

and for σ is

$$[U'(q)-c_q]\frac{\partial q}{\partial \sigma}-\frac{\partial c}{\partial \sigma}=\tau\frac{\partial e}{\partial \sigma}.$$

As usual, each of these conditions can be interpreted as equating marginal cost and marginal benefit of strengthening the regulation. In Eq. (2) increasing the consumption tax results in costs from lost consumption (the left-hand side) but a benefit from reduced emissions. Similarly, in Eq. (3), tightening the intensity standard (reducing σ) has costs from lost consumption and higher production costs but a benefit from reduced emissions.12

The appendix shows that the first-order condition for σ in Eq. (3) can be written

$$(t_c-\tau\sigma)\frac{\partial q}{\partial \sigma}=q\tau\left[1-\frac{w_i}{\tau}\frac{f_e}{f_{k_i}}\right].$$

This equation has two implications. First, if tc=τσ, then the optimal σ implies productive efficiency, i.e. the MRTS between each market input and pollution equals the social price ratio. If tc is chosen by the regulator, this suggests that the regulator can choose the consumption tax to attain productive efficiency. Second, if the consumption tax is not set optimally, e.g. if tc=0, then

production is not efficient with the optimal σ unless the elasticity of output with respect to the intensity standard is zero. The actual result is somewhat stronger[13]:

Proposition 1

. (i) An intensity standard coupled with a consumption tax can attain the efficient level of emissions, input usage, and consumption. (ii) An intensity standard alone cannot attain efficiency if$(tc-\tau\sigma)(\partial q/\partial tc)\neq 0(tc-\tau\sigma)(\partial q/\partial tc)\neq 0$.

Although a consumption tax cannot in general correct an externality if emissions rates are heterogeneous or endogenous, part (i) shows that a consumption tax combined with an intensity standard can be efficient. This follows since the optimal intensity standard can induce productive efficiency if $tc=\tau\sigma tc=\tau\sigma$. Since the optimal consumption tax is $tc=\tau\sigma$, the optimal tax induces productive efficiency and exactly offsets the implicit output subsidy leading to efficiency. This result is analogous to, but more general than, a result in Holland et al. which showed that an LCFS combined with a gasoline tax could be efficient.14

Since the optimal consumption tax depends on the intensity standard, it is not obvious that part i should hold with heterogeneous firms. An online appendix demonstrates that part (i) does indeed hold with heterogeneous firms, i.e. the optimal combined policy is efficient, if trading is allowed.15 Intuitively, trading puts a price on emissions. Since emissions of each firm face the same price, production is at least cost. By adjusting the stringency of the intensity standard, the regulator can set the price of emissions at marginal damages, so production is efficient. Adjusting the consumption tax then leads to efficiency, even with heterogeneous firms.

The inefficiency of an intensity standard in part (ii) is analogous to results in Fischer [11], Holland et al. and in Helfand. The result illustrates in two ways that the inefficiency of the intensity standard arises from the implicit output subsidy. First, the inefficiency is corrected by the consumption tax as shown in part (i). Second, the condition shows that if $\partial q/\partial tc=0$, the intensity standard can attain efficiency. Intuitively, if demand is perfectly inelastic, so that $\partial q/\partial tc=0$, an intensity standard can attain the first best since there is no output distortion and the standard leads to the efficient emissions. Similarly the inefficiency in Holland et al. requires elastic demand.

4. Regulation with leakage

To extend the model to analyze leakage, consider a covered (regulated or domestic) firm, which produces qC, and an uncovered (unregulated or foreign) firm, which produces qU. It is well-

known (and is demonstrated in the online appendix) that an emissions tax equal to marginal damages can be efficient in the absence of leakage. However, with leakage it is no longer clear that an emissions tax can be efficient or should equal marginal damages. This section first characterizes the perfectly competitive equilibrium with leakage for an emissions tax and for an intensity standard. The optimal regulations conditional on the equilibria are then compared.

For simplicity, assume both the covered and uncovered firm have access to the same production technology described by the concave production function f(kj,ej) for j∈{C,U} where kj is a vector of market inputs (e.g. labor, capital, fuel, etc.) with prices w, and ej is an unpriced input (e.g. emissions). Let U(Q) be the benefit from consumption of the two perfect substitutes, i.e.Q=qC+qU, where, as before, U′>0 and U″<0.16 Let damages from pollution be τ(eC+eU).17

Assume throughout that emissions of the uncovered firm are subject to an *uncovered emissions charge*, *tU*, (possibly zero), so its cost function is given by $cU(qU;w,tU)=mink,ewkU+tUeU+\lambda U[qU-f(kU,eU)]$ where λU is the Lagrange multiplier.[18] Cost minimization implies the two first order conditions: $w=\lambda Ufk(kU,eU)$ and $tU=\lambda Ufe(kU,eU)$. The envelope theorem implies that the marginal cost is $c_q^U(q^U;w)=\lambda^U$.

4.1. Second-best emissions tax

If the covered firm is subject to an emissions tax, *t*, its cost function is $cC(qC;w,t)$; cost minimization implies that $w=\lambda Cfk(kC,eC)$ and $t=\lambda Cfe(kC,eC)$ where λC is the Lagrange multiplier; and the envelope theorem implies that $c_q^C(q^C;w,t)=\lambda^C$. The eight endogenous variables in the equilibrium - *qj*, *λj*, *kj*, and *ej*- are completely determined by the four first-order conditions from cost minimization; the two production functions; and the two market clearing conditions: $U'(Q)=\lambda C=\lambda U$.

Conditional on this perfectly competitive equilibrium, the regulator can choose the emissions tax on the covered sector to maximize net social benefits[19]

$$\max_t U(Q)-c^C(q^C;w,t)-c^U(q^U;w,t_U)-\tau(e^C+e^U)+te^C+t_Ue^U.$$

Note that the emissions tax revenue is counted as a cost for the firms and thus must be added to the objective.[20] The FOC is then

$$[U'(Q)-c_q^C]\frac{\partial q^C}{\partial t}+[U'(Q)-c_q^U]\frac{\partial q^U}{\partial t}-\frac{\partial c^C}{\partial t}+e^C-(\tau-t)\frac{\partial e^C}{\partial t}-(\tau-t_U)\frac{\partial e^U}{\partial t}=0.$$

Since the first two terms are zero by the market clearing conditions and the third and fourth terms are additive inverses by applying the envelope theorem to the covered firm's cost function, the FOC implies that

Equation (5)

$$t=\tau+(\tau-t_U)\frac{\partial e^U/\partial t}{\partial e^C/\partial t}.$$

To interpret this optimal emissions tax, consider two extremes.[21] If the uncovered emissions charge is equal to marginal damages, *i.e.* if $tU=\tau$, then the optimal emissions tax is equal to marginal damages and the first-best is attained. At the other extreme, if $tU=0$, the best tax is less than social damages if the tax decreases covered emissions and increases uncovered emissions, *i.e.* causes leakage. In this case, the MRTS of the covered firm is less than the input price ratio τ/wi, and covered emissions are too high relative to control technology, *i.e.* efficiency is not attained.

4.2. Second-best intensity standard

If the covered firm is subject to an intensity standard σ, the firm's cost function is $cC(qC;w,\sigma)$; cost minimization implies $w=\lambda Cfk(kC,eC)$ and $\gamma=\lambda Cfe(kC,eC)$ where λC and γ are Lagrange multipliers; and the envelope theorem implies that $c_q^C(q^C;w,\sigma)=\lambda^C-\gamma\sigma$. The nine endogenous variables in the equilibrium - qj, λj, kj, ej, and γ - are completely determined by the four first-order conditions from cost minimization; the two production functions; the two market clearing conditions: $U'(Q)=\lambda C-\gamma\sigma=\lambda U$; and the binding intensity standard: $eC=\sigma qC$.

Conditional on this equilibrium, the regulator chooses the intensity standard to maximize net social benefits

$$\max_{\sigma} U(Q)-c^C(q^C;w,\sigma)-c^U(q^U;w,t_U)-\tau(e^C+e^U)+t_U e^U.$$

The first order condition is then

$$[U'(Q)-c_q^C]\frac{\partial q^C}{\partial\sigma}+[U'(Q)-c_q^U]\frac{\partial q^U}{\partial\sigma}-\frac{\partial c^C}{\partial\sigma}-\tau\frac{\partial e^C}{\partial\sigma}-(\tau-t_U)\frac{\partial e^U}{\partial\sigma}=0.$$

Since the first two terms are zero by the market clearing conditions and since $-\partial cC/\partial\sigma=\gamma qC=wiqCfe(kC,eC)/fki(kC,eC)$, this FOC implies that

equation(6)

$$\frac{f_e(k^C,e^C)}{f_{k_i}(k^C,e^C)}=\frac{\tau}{w_i}\left(1+\frac{\partial q^C}{\partial\sigma}\frac{\sigma}{q^C}\right)+\frac{\tau-t_U}{w_i}\left(\frac{\partial e^U}{\partial\sigma}\frac{\sigma}{e^C}\right).$$

Note that the optimal intensity standard does not equate the MRTS with the social input price ratio $\tau/wi$and the deviation is greater (i) for a larger magnitude elasticity of output with respect to the standard; (ii) for a greater responsiveness of uncovered emissions with respect to the standard; and (iii) for greater deviation of the uncovered emissions charge from marginal damages. Also, note that even if the uncovered emissions charge is equal to marginal damages, the optimal standard does not attain the first best. In summary, efficiency is not attained.

4.3. Comparing optimal emissions taxes and intensity standards

Since 4.1 and 4.2 show that with leakage neither an emissions tax nor an intensity standard will generally attain the first best, either may dominate. Although the second-best net social benefits are difficult to compare analytically, the main result simply compares the possibilities and is easy to state and prove.[22]

Proposition 2

. (i) *If the uncovered emissions charge equals marginal damages, i.e. if*$tU=\tau$*, then the optimal emissions tax attains the first best, but the optimal intensity standard does not.* (ii) *If*$tU<\tau$*, an intensity standard can dominate the second-best emissions tax.*

The result in Proposition 2 (i) follows from Proposition 1 and the well-known efficiency of Pigouvian taxes. If$tU=\tau$, the optimal emissions tax simply mimics the uncovered emissions charge and emissions are correctly priced. The earlier analysis in Section 3 showed that the intensity standard does not generally attain the first best.[23]

The result in Proposition 2 (ii) is a possibility result. If $tU<\tau$, the analysis in Section 4.1 showed that the optimal emissions tax is less than τ and thus does not attain the first best. Although the intensity standard does not attain the first best either, the proof and numerical simulations in Table 1 show a number of examples where an intensity standard dominates the best emissions tax.

Table 1. Single policies under incomplete regulation: comparing optimal emissions taxes with intensity standards under Cobb‑Douglas and constant returns to scale.

β	Emissions tax ($t=tU$)	Intensity standard	DWL	Output	Emissions	Standard dominates?
Panel A. Lax uncovered emissions charge. tU=0.01						
0.8	0.01	–	1.54	1.96	5.67	Yes
	–	1.93	0.66	1.96	3.79	
0.5	0.01	–	5.21	1.86	13.14	Yes

β	Emissions tax ($t=tU$)	Intensity standard	DWL	Output	Emissions	Standard dominates?
	–	3.54	2.06	1.86	6.57	
0.2	0.01	–	5.37	1.62	12.24	Yes
	–	3.09	1.88	1.62	5.01	
Panel B. Stringent uncovered emissions charge. tU=0.25						
0.8	0.25	–	0.10	1.53	2.31	No
	–	1.01	0.30	1.53	1.55	
	–	1.21	0.20	1.77	2.15	
0.5	0.25	–	0.12	1.29	1.83	Yes
	–	0.71	0.12	1.29	0.91	
	–	0.84	0.10	1.40	1.18	
0.2	0.25	–	0.05	1.28	0.74	Yes
	–	0.24	0.02	1.28	0.30	
	–	0.30	0.01	1.32	0.40	

Notes: Parameterization: $U'(q)=2-q$; $f(k,e)=k^{1-\beta}e^{\beta}$; $\tau=0.5$; and $w=0.5$. Efficient social surplus (quantity, emissions) is 0.69 (1.18, 1.55); 0.5 (1, 1); and 0.69 (1.18, 0.39).

With a Cobb-Douglas production function and constant returns to scale, *i.e.* with $f(k,e)=K\prod_i k_i^{\alpha_i}e^{\beta}$ and $\sum_i \alpha_i=1-\beta$, a sufficient condition can be derived under which the intensity standard dominates.

Corollary 1

. *With a Cobb-Douglas production function and constant returns to scale, the optimal intensity standard dominates the second-best emissions tax if the uncovered emissions charge is low, i.e. if* $tU/\tau \leq 1-(1-\beta)^{(1-\beta)/\beta}$.

Corollary 1 derives a sufficient condition for an intensity standard to dominate the best emissions tax. Intuitively, the intensity standard dominates if the uncovered emissions charge is sufficiently below marginal damages.[24] The online appendix on international leakage derives an analogous condition showing that an intensity standard dominates if the second-best emissions tax is sufficiently below marginal damages, *i.e.* if the import price is sufficiently below the price that would result from a domestic emissions tax τ.

The intuition of Proposition 2 can be illustrated with the special case involving constant returns to scale production functions. It is well known that with constant returns to scale, the marginal cost function is constant. In this case, leakage is extreme: any attempt to tax emissions leads to an increase in the marginal cost of covered firms and production shifts entirely to uncovered firms. Thus the second-best emissions tax is equal to tU, *i.e.* simply matches the uncovered emissions charge, and has no effect.

Can an intensity standard do better? The online appendix shows that the marginal cost function with an intensity standard is also constant for constant returns to scale. Moreover, the marginal cost function is decreasing in σ.[25] Thus, the regulator can adjust the intensity standard such that the marginal cost of the covered firm does not exceed the marginal cost of the uncovered firm, thereby preventing leakage and mimicking the marginal cost (and output level) of an emissions tax. This intensity standard will result in different inputs for producing the same level of output and may have lower social costs. The sufficient condition, $tU/\tau \leq 1-(1-\beta)^{(1-\beta)/\beta}$, insures that this intensity standard has lower social costs and hence dominates the optimal emissions tax.

The right-hand side of the sufficient condition, $1-(1-\beta)^{(1-\beta)/\beta}$, is decreasing in β. Thus it is more likely that the intensity standard dominates an emissions tax if β is smaller. For example, if $\beta=0.1$, the intensity standard dominates if $tU<0.6\tau$. However, if $\beta=0.9$, the intensity standard only dominates if the uncovered emissions charge is much more lax, *i.e.* if $tU<0.2\tau$. Since Cobb-Douglas assumes that all inputs are substitutes, simply estimating β from the expenditure share of emissions would be misleading. A more accurate estimate of β might come from the expenditure share of all inputs which are complements to emissions.

Table 1 illustrates Proposition 2 for a simple numerical example. Panel A illustrates the case where the uncovered emissions charge is lax. The assumption of constant returns to scale implies that the best emissions tax matches the uncovered emissions charge. This tax is ineffective, and it is dominated by an intensity standard which leads to the same level of output but at lower social costs. Panel B illustrates a more stringent uncovered emissions charge and shows that the optimal emissions tax is not necessarily dominated. For $\beta=0.8$, the sufficient condition fails and the optimal intensity standard ($\sigma=1.21$) is dominated. For $\beta=0.5$, the sufficient condition holds with equality, so the intensity standard that mimics the best emissions tax does not reduce deadweight loss. However, the optimal intensity standard, which is slightly more lax, does dominate the optimal emissions tax. For $\beta=0.2$, the optimal emissions tax is dominated. Likewise, Online Appendix Table 1 shows that an intensity standard can dominate with decreasing returns to scale, and Online Appendix Table 2 illustrates a constant elasticity of substitution production function.

4.4. Comparing the policies combined with consumption taxes

The intensity standard and consumption tax combination seems quite promising especially given the result in Proposition 1. The following proposition shows that with leakage the intensity

standard can still dominate an emissions tax even if both instruments are combined with a consumption tax.

Proposition 3

. *If* $tU<\tau$, *a combined intensity standard and consumption tax can dominate the second-best combination of an emissions tax and a consumption tax.*

This proposition is not surprising given the result in Proposition 2. However, the following corollary shows that an even stronger result can obtain, namely

Corollary 2

. *With Cobb-Douglas technology and constant returns to scale, a combined intensity standard and consumption tax attain the first best if* $tU/\tau \geq (1-\beta)^{1/}\beta$.

With complete regulation, the intensity standard corrects the relative price of inputs, the consumption tax corrects the relative price of output, and the combined policy attains the first best. However, with incomplete regulation the stringency of the intensity standard may be constrained by the marginal cost of the uncovered firm. If the uncovered emissions charge is lax, the regulator would like to make the intensity standard more stringent but cannot since this would raise the marginal cost of the covered firm above the marginal cost of the uncovered firm (causing leakage). In this case, the intensity standard would be too lax and the consumption tax, given by $tc=\tau\sigma$ would be too high to attain the first best.

If the uncovered emissions charge is not lax, *e.g.* if $tU/\tau \geq (1-\beta)^{1/}\beta$, the constraint does not bind, so the regulator can set the intensity standard and consumption tax at their optimal levels and can attain the first best.[26] Note that attainment of the first best requires constant returns to scale. With increasing marginal costs, some uncovered production should occur, but since the uncovered production is undertaxed, the first best is not attained.

Table 2 illustrates Proposition 3. Notice that the addition of the consumption tax reduces deadweight loss for all policies relative to Table 1 primarily by reducing output. In fact, for the emissions tax in Panel A, the optimal consumption tax simply stops production for β=0.5 and β=0.2. Note that the dominance of the intensity standard is maintained in Panel A with a lax uncovered emissions charge although efficiency is not attained. In Panel B the advantage of the emissions tax from Table 1 disappears, and the intensity standard/consumption tax combination attains the first best, even though the emissions tax/consumption tax combination does not. Note that the necessary and sufficient condition does not hold in Panel A but holds in Panel B.

Table 2. Combined policies under incomplete regulation: comparing consumption taxes with emissions taxes or intensity standards under Cobb‑Douglas and constant returns to scale.

β	Emissions tax (t=tU)	Intensity standard	Consumption tax	DWL	Output	Emissions	Standard dominates?
Panel A. Lax uncovered emissions charge. tU=0.01							
0.8	0.01	–	1.41	0.54	0.55	1.59	Yes
	–	1.93	0.96	0.19	1.00	1.93	
0.5	0.01	–	1.86	0.500	0	0	Yes
	–	3.54	1.77	0.496	0.09	0.32	
0.2	0.01	–	1.62	0.691	0	0	Yes
	–	3.09	1.54	0.688	0.08	0.24	
Panel B. Stringent uncovered emissions charge. tU=0.25							
0.8	0.25	–	0.38	0.03	1.15	1.74	Yes/first best
	–	1.32	0.66	0	1.18	1.55	
0.5	0.25	–	0.35	0.06	0.94	1.33	Yes/first best
	–	1.00	0.50	0	1.00	1.00	
0.2	0.25	–	0.14	0.04	1.14	0.65	Yes/first best
	–	0.33	0.16	0	1.18	0.39	

Notes: Parameterization: $U'(q)=2-q$; $f(k,e)=k^{1-\beta}e^{\beta}$; t=0.5; and w=0.5. Efficient social surplus (quantity, emissions) is 0.69 (1.18, 1.55); 0.5 (1, 1); and 0.69 (1.18, 0.39).

4.5. Comparing intensity standards and output-based updating

With incomplete regulation, the advantage of the intensity standard is that it implicitly subsidizes production while taxing emissions. Similarly, output-based updating of emissions permits implicitly subsidizes production while capping emissions.

To illustrate the implicit subsidy with output-based updating, suppose the regulator gives the firm $\eta\bar{e}R$ free permits where $\eta\in(0,1)$ is the fraction of freely allocated permits, $\bar{e}$ is the emissions cap, and R depends on the firm's output. For example, if updating is based on the share of total output then $R=qC/Q$. Although the regulator could use a variety of rules to update allocations,

this definition of R is similar to that in Fischer[11], Fischer and Fox [13] and [14], and Bushnell and Chen.

If pe is the price of emissions permits, the regulated firm's cost minimization is $c(q^C,w,p_e,\eta)=\min_{k^C,e^C} wk^C+p_e e^C+\lambda^C[q^C-f(k^C,e^C)]-p_e\eta\bar{e}R$. Note that the firm must purchase permits to cover its emissions at cost $peeC$, but receives a free allocation of permits with value $p_e\eta\bar{e}R$. The cost minimization conditions are that $w=\lambda Cfk(kC,eC)$ and $pe=\lambda Cfe(kC,eC)$. Applying the envelope theorem to the cost function implies that $\partial c/\partial\eta=-p_e\bar{e}R$ and that $\partial c/\partial\bar{e}=-p_e\eta R$. Since both of these derivatives are negative, increasing the generosity of output-based updating, η, or the emissions cap, $\bar{e}$, decreases costs.

The envelope theorem also implies that the marginal cost of the regulated firm is $c_q^C=\lambda^C-p_e\eta\bar{e}(\partial R/\partial q^C)$. This equation illustrates the implicit output subsidy when $\partial R/\partial qC>0$, *i.e.* if the firm recognizes that increasing its output increases its allocation.

Assuming a representative firm implies that $e^C=\bar{e}$ and that the equilibrium permit price is determined by $p_e=\lambda^C f_e(k^C,\bar{e})$. The equilibrium is then completely described by the cost minimization conditions; the production functions; the two market clearing conditions, $U'(Q)=\lambda^C-p_e\eta\bar{e}(\partial R/\partial q^C)=\lambda^U$; and market clearing in the permit market $e^C=\bar{e}$ and $p_e=\lambda^C f_e(k^C,\bar{e})$.

The implicit output subsidy depends on the number of permits, $\bar{e}$, the generosity of the updating, η, and how the firm's output increases its allocation, dR/dqC. The first two of these are policy parameters which the regulator can use to influence the strength of the implicit subsidy. The final factor depends on policy choices,*e.g.* the precise rule used, as well as other factors such as the amount of leakage and the amount of market power. For example, if $R=qC/Q$, then $dR/dqC=1/Q-qC/Q^2$. This implies that as $qC\to Q$, *e.g.* a monopoly with minimal leakage, this derivative (and hence the output subsidy) goes to zero. However, if the firm is small relative to the market, its contribution to total output may be negligible so that $dR/dq_j^C=(Q-q_j^C)/Q^2\to 1/Q$. This assumption is used in Fischer and Fox and Bushnell and Chen.

Since output-based updating has considerable flexibility in the strength of the implicit output subsidy, a useful approximation is to compare the optimal intensity standard with a combined emissions tax and output subsidy to the covered firm. Intuitively, the combination of two instruments is likely to dominate the single instrument. This intuition is correct.

Proposition 4

. *The second-best combination of an emissions tax and an output subsidy for covered firms dominates the second-best intensity standard.*

This result suggests that output-based updating is superior to an intensity standard if the subsidy inherent in the output-based updating is sufficiently flexible to mimic the optimal output subsidy. This may or may not be the case. Assuming that $dR/dq_j^C = 1/Q$, some calculations based on the parameterization in Table 1 Panel B show that the optimal emissions cap with output-based updating and η=1 dominates the optimal intensity standard for β=0.8 (DWL is reduced from 0.20 to 0.08) but not for β=0.5 or β=0.2 (DWL increases from 0.10 to 0.12 and from 0.01 to 0.02). Thus the superiority of output-based updating depends on the details of its implementation.

The result also suggests that simply subsidizing output (combined with an emissions tax) might be superior to output-based updating since it clearly dominates an intensity standard and does not suffer from some of the other problems of output-based updating such as permit price "inflation" and the unclear linkage between a firm's output and its subsidy. Of course, the analysis in Section 4.4 suggests that combining these policies with a consumption tax could increase efficiency further.

4.6. Extending the model

Global climate change from greenhouse gas emissions is arguably the most important externality currently requiring additional regulation. Since leakage is a potential concern with carbon regulation, intensity standards might be a useful tool for policy makers. However, greenhouse gas emissions are a stock pollutant so it is important to extend the current static framework to include the dynamic aspects of carbon regulation.

Extending the current framework to model damages from a stock pollutant is relatively straightforward. Throughout the analysis, damages are simply assumed to be τe. With a stock pollutant, damages are a function of the stock of pollution. Since emitting a ton of pollution today affects the current stock of pollution as well as the stock of pollution in all subsequent years, the marginal damages from a ton of pollution today is the sum of the marginal damages of all future years weighted by a decay factor. For a persistent stock pollutant like carbon, this makes the marginal damages for any year quite flat, so they are reasonably approximated by constant marginal damages.

Intertemporal cost minimization is more complicated. Kling and Rubin [24] first showed that intertemporal trading of emissions permits can be inefficient if it allows firms to inefficiently delay abatement. A similar inefficiency would likely arise if an intensity standard allowed intertemporal trading through banking and/or borrowing of credits. On the other hand, Yates and Cronshaw [35] showed that intertemporal trading can smooth abatement cost shocks. Whether or

not credits for an intensity standard should be banked or borrowed likely depends on the details of the program and the externality.

Finally, the framework in this paper does not model the uncertainty inherent in damages and abatement costs. Weitzman [33] first showed that an emissions tax might be preferred to an emissions cap if marginal damages are flat relative to marginal abatement costs and information about abatement costs is asymmetric. Since an intensity standard offers more flexibility than an emissions cap, it might dominate an emissions cap if marginal damages are relatively flat. However, a more complete analysis of asymmetric information is beyond the scope of this paper.

5. Conclusion

This paper demonstrates that an emissions tax (or equivalently an emissions cap) may not be the best instrument for correcting an environmental externality in the presence of incomplete regulation (leakage). In fact, since I analyze the second-best policies, the results show that any emissions tax may be dominated by an intensity standard. A sufficient condition shows that the dominance is more likely if the second-best emissions tax is sufficiently below marginal damages.

An intensity standard implicitly subsidizes output while implicitly taxing the externality. This output subsidy is the source of the inefficiency of an intensity standard, and the analysis shows that it can be corrected by a consumption tax. However, the output subsidy is an advantage for the policy maker when confronted with the potential for leakage. The implicit output subsidy prevents leakage and can lead an intensity standard to dominate an emissions tax. Combining an intensity standard with a consumption tax further increases the advantage of the intensity standard and may even attain the first best.

With multiple market failures the policy choice is whether to use a potentially inferior instrument hoping other market failures can be addressed with other instruments or to use a superior instrument and accept the second-best world. This paper provides a framework for analyzing these policy instruments and suggests that an intensity standard should not be neglected.

Acknowledgments

Thanks to seminar participants at the University of North Carolina at Greensboro, Appalachian State University and the University of California Energy Institute (UCEI) and to Severin Borenstein, Carolyn Fischer, Don Fullerton, Garth Heutel, Jonathan Hughes, Mark Jacobsen, and Chris Knittel.

Appendix A.

A.1. Proof of Proposition 1

To derive Eq. (4), note that Eq. (3) can be written

$$t_c \frac{\partial q}{\partial \sigma} + q w_i \frac{f_e}{f_{k_i}} = \tau \left[q + \sigma \frac{\partial q}{\partial \sigma} \right],$$

where the first term follows from the market clearing condition $U'(q)-cq=tc$, the second term follows from applying the envelope theorem, and the last term follows since $\partial e/\partial \sigma = q + \sigma \partial q/\partial \sigma$. Eq. (4)

$$(t_c - \tau\sigma) \frac{\partial q}{\partial \sigma} = q\tau \left[1 - \frac{w_i}{\tau} \frac{f_e}{f_{k_i}} \right]$$

follows by algebra.

Eq. (2) implies that

equation(7)

$$t_c \frac{\partial q}{\partial t_c} = \tau \frac{\partial e}{\partial t_c} = \tau\sigma \frac{\partial q}{\partial t_c},$$

where the last equality follows since $e=\sigma q$. Eq. (7) then implies that $tc=\tau\sigma$. Note that this condition combined with Eq. (4) shows that production is efficient when the intensity standard and consumption tax are optimally chosen.

To show that consumption is efficient, note that $tc=\tau\sigma$, Eq. (4), and cost minimization imply that$\tau=wife/fki=\gamma$. Thus $U'(q)=tc+\lambda-\gamma\sigma=\tau\sigma+\lambda-\tau\sigma=\lambda$. So $U'(q)=wi/fki$ for every i and $U'(q)=\tau/fe$,*i.e.* the allocation is efficient.

To prove part (ii), note that if the regulator cannot set tc, the optimal intensity standard is determined by Eq.(4). If W is the regulator's objective function from Eq. (1), then

equation(8)

$$\frac{dW}{dt_c} = [t_c - \tau\sigma]\frac{\partial q}{\partial t_c}.$$

The RHS of Eq. (8) will be positive if tc is less than $\tau\sigma$, so increasing tc would increase social surplus,*i.e.* an intensity standard is not efficient.

A.2. Proof of Proposition 2

The result in (i) is proved in the text. The possibility result (ii) is proved by the example that follows in the proof of Corollary 1, as well as by the numerical examples that appear in the text and in the online appendices.

A.3. Proof of Corollary 1

With constant returns to scale, the marginal cost functions under both an emissions tax and intensity standard are constant as shown in Online Appendix Lemma 1. Since an emissions tax greater than tU would increase the covered firm's marginal cost and cause complete spillovers, the second-best emissions tax istU.

A binding intensity standard can mimic the second-best emissions tax. To prove the sufficient condition, let the equilibrium with the second-best emissions tax be given by $eC^{\square}$, $kC^{\square}$, $eU^{\square}=0$, and $kU^{\square}=0$.[27] Note that this equilibrium is characterized by $U'(Q^{\square})=M^{\square}$ where $M^{\square}$ is defined in (13) for $t=tU$. Thus$eC^{\square}=M^{\square}\beta Q^{\square}/tU$ and $k_i^{C*} = M^* \alpha_i Q^* / w_i$. Let eC', kC' define the binding intensity standard which mimics the second-best emissions tax. This equilibrium is characterized by $M^* = w_i/f_{k_i} \cdot (1-\sigma f_e) = w_i k_i^{C'}/(\alpha_i Q^*) \cdot (1-\beta)$ which implies that $(1-\beta)k_i^{C'} = k_i^{C*}$. Furthermore $e^{C'} = e^{C*}\prod_i (k_i^{C*}/k_i^{C'})^{\alpha_i/\beta} = e^{C*}(1-\beta)^{(1-\beta)/\beta}$ since output must be equal. Now compare the social costs. Note that $wkC'+\tau eC' \leq wkC^{\square}+\tau eC^{\square}$ iff $M^{\square}Q^{\square}\sum i\alpha i/(1-\beta)+\tau M^{\square}\beta Q^{\square}/tU\cdot(1-\beta)^{(1-\beta)/\beta} \leq M^{\square}Q^{\square}\sum i\alpha i+\tau M^{\square}\beta Q^{\square}/tU$ iff $tU/\tau \leq 1-(1-\beta)^{(1-\beta)/\beta}$. If this sufficient condition holds, mimicking the second-best emissions tax with an intensity standard reduces (does not increase) social costs, so the second-best emissions tax is dominated.[28]

A.4. Proof of Proposition 3

The possibility result is proved by the example that follows in the proof of Corollary 2 as well as by numerical examples in the text.

A.5. Proof of Corollary 2

Consider an intensity standard consumption tax combination which would attain the first best in the absence an uncovered firm. In particular, let $\sigma=1/K\cdot\prod i(\beta wi/\tau\alpha i)\alpha i$ and let $tc=\tau\sigma$. Since the production function implies that $\sigma=e/q=1/K\cdot\prod i(e/ki)\alpha i$, equilibrium will have $\beta wi/\tau\alpha i=e/ki$ for

every i which implies $f_e/f_{k_i}=\tau/w_i$, *i.e.* MRTSs are equal to the social price ratios.[29] Now note that the marginal cost is

equation(9)

$$c_q(q;w,\sigma)=\frac{w_i}{f_{k_i}}(1-\sigma f_e)=\frac{w_i k_i}{\alpha_i q}(1-\beta)=\frac{\tau\sigma}{\beta}(1-\beta)=\frac{1-\beta}{K}\left(\frac{\tau}{\beta}\right)^{\beta}\prod_i\left(\frac{w_i}{\alpha_i}\right)^{\alpha_i},$$

where the first equality follows from cost minimization, the second equality from substitution of the marginal products, the third since MRTSs are correct, and the fourth by substitution for σ.[30] If this marginal cost is less than the marginal cost of the uncovered firm then there is no leakage, and this policy combination attains the first best. The uncovered marginal cost is given by $M^{\square}$ which is defined in (13) for $t=t_U$. Comparing (13) and (9), shows that $c_q(q;w,\sigma)\leq M^{\square}$ iff $(1-\beta)\tau^{\beta}\leq t_U^{\beta}$ iff $t_U/\tau\geq(1-\beta)^{1/\beta}$.

A.6. Proof of Proposition 4

Consider the second-best intensity standard, $\sigma^{\square}$ under incomplete regulation. Denote the resulting equilibrium values by $e_C^{\square}$, $k_C^{\square}$, $e_U^{\square}$, and $k_U^{\square}$.[31] Note that this equilibrium is completely characterized by $e_C^{\square}=\sigma^{\square}q_C^{\square}$ and the equations

$$U'(Q^*)=\frac{w_i}{f_{k_i}(k^{C*},e^{C*})}-\frac{w_i f_e(k^{C*}e^{C*})\sigma^*}{f_{k_i}(k^{C*},e^{C*})}=\frac{w_i}{f_{k_i}(k^{U*},e^{U*})}=\frac{t_U}{f_e(k^{U*},e^{U*})}$$

Now consider the emissions tax t and output subsidy s to the covered firm where $t=w_i f_e(k_C^{\square},e_C^{\square})/f_{k_i}(k_C^{\square},e_C^{\square})$ and $s=t\sigma^{\square}$.[32] Note that this equilibrium is characterized by the equations

equation(10)

$$U'(Q)=\frac{w_i}{f_{k_i}(k^C,e^C)}-s=\frac{t}{f_e(k^C,e^C)}-s=\frac{w_i}{f_{k_i}(k^U,e^U)}=\frac{t_U}{f_e(k^U,e^U)}.$$

It is straightforward to verify that $e_C^{\square}$, $k_C^{\square}e_U^{\square}$, and $k_U^{\square}$ are equilibrium values for this t and s, *i.e.* the equilibria are identical. First, the second equation of (10) implies that $w_i f_e(k_C,e_C)/f_{k_i}(k_C,e_C)=t=w_i f_e(k_C^{\square},e_C^{\square})/f_{k_i}(k_C^{\square},e_C^{\square})$, so the MRTSs of the covered firm are identical for all inputs. Second, the first equation of (10) shows that $Q^{\square}$ is the equilibrium output level. Since output and the uncovered and covered MRTSs are identical, the equilibria are identical.

To complete the proof, note that the equilibrium with the second-best intensity standard is mimicked by the equilibrium with this *t* and *s*. Since the second-best emissions tax and output subsidy to the covered firm can do no worse, the second-best intensity standard is dominated.

References

S.M. Arons, A.R. Brandt, M.A. Delucchi, A. Eggert, A.E. Farrell, B.K. Haya, J. Hughes, B.M. Jenkins, A.D. Jones, D.M. Kammen, S.R. Kaffka, C.R. Knittel, D.M. Lemoine, E.W. Martin, M.W. Melaina, J.M. Ogden, R.J. Plevin, D. Sperling, B.T. Turner, R.B. Williams, C. Yang, A Low-Carbon Fuel Standard for California. Part 1. Technical Analysis, 2007. Available Online: 〈http://www.lcfs.ucdavis.edu〉.

A.H. Barnett. The Pigouvian tax rule under monopoly. American Economic Review, 70 (5) (1980), pp. 1037–1041

W.J. Baumol, W.E. Oates. The Theory of Environmental Policy. (second ed.)Cambridge University Press, Oakleigh, Victoria, Australia (1993)

J. Bluestein, Upstream regulation of CO2, Presentation to the National Commission on Energy Policy Workshop, Washington, DC, 2005.

A.L. Bovenberg, L.H. Goulder, M.R. Jacobsen. Costs of alternative environmental policy instruments in the presence of industry compensation requirements. Journal of Public Economics, 92 (2008), pp. 1236–1253

A.R. Brandt, A.E. Farrell, B.K. Haya, J. Hughes, B.M. Jenkins, A.D. Jones, D.M. Kammen, C.R. Knittel, M.W. Melaina, M. O'Hare, R.J. Plevin, D. Sperling, A Low-Carbon Fuel Standard for California. Part 2. Policy Analysis, 2007. Available Online: 〈http://www.lcfs.ucdavis.edu〉.

J.M. Buchanan. External diseconomies, corrective taxes, and market structures. American Economic Review, 59 (1969), pp. 174–177

J. Bushnell, Y. Chen, Regulation, Allocation, and Leakage in Cap-and-Trade Markets for CO2, CSEM WP-183, 2009.

J. Bushnell, C. Peterman, C. Wolfram. Local solutions to global problems: climate change policies and regulatory jurisdiction. Review of Environmental Economics and Policy, 2 (2) (2008), pp. 175–193 http://dx.doi.org/10.1093/reep/ren007

A.E. Farrell, R.J. Plevin, B.T. Turner, A.D. Jones, M. O'Hare, D.M. Kammen. Ethanol can contribute to energy and environmental goals. Science, 311 (5760) (2006), pp. 506–508

C. Fischer, Rebating Environmental Policy Revenues: Output-Based Allocations and Tradable Performance Standards, RFF Discussion Paper 01-22, 2001.

C. Fischer, Output-Based Allocation of Environmental Policy Revenues and Imperfect Competition, RFF Discussion Paper 02-60, 2003.

C. Fischer, A.K. Fox. Output-based allocation of emissions permits for mitigating tax and trade interactions. Land Economics, 83 (4) (2007), pp. 575–599

C. Fischer, A.K. Fox, Comparing Policies to Combat Emissions Leakage: Border Tax Adjustments versus Rebates, RFF Discussion Paper 09-02, 2009.

M. Fowlie. Incomplete environmental regulation, imperfect competition and emissions leakage. American Economic Journal: Economic Policy, 1 (2) (2009), pp. 72–112

D. Fullerton. Environmental levies and distortionary taxation: comment. American Economic Review, 87 (1) (1997), pp. 245–251

D. Fullerton, G. Heutel, The General Equilibrium Incidence of Environmental Mandates, NBER Working Paper No. 13645, 2007.

D. Fullerton, R. Mohr. Suggested subsidies are sub-optimal unless combined with an output tax. Contributions to Economic Analysis & Policy, 2 (1) (2003), pp. 1–20

L.H. Goulder, I.W.H. Parry, R.C. Williams III, D. Burtraw. The cost-effectiveness of alternative instruments for environmental protection in a second-best setting. Journal of Public Economics, 72 (1999), pp. 329–360

G.E. Helfand. Standards versus standards: the effects of different pollution restrictions. American Economic Review, 81 (3) (1991), pp. 622–634

S.P. Holland, Taxes and Trading Versus Intensity Standards: Second-Best Environmental Policies with Incomplete Regulation (Leakage) or Market Power, NBER WP 15262, 2009.

S.P. Holland, J.E. Hughes, C. Knittel. Greenhouse gas reductions under low carbon fuel standards? American Economic Journal: Economic Policy, 1 (1) (2009), pp. 106–146

C. Kling, J. Rubin. Bankable permits for the control of environmental pollution. Journal of Public Economics, 64 (1) (1997), pp. 101–115

E.T. Mansur, Prices vs. Quantities: Environmental Regulation and Imperfect Competition, NBER Working Paper 13510, 2007.

G. Metcalf, Designing A Carbon Tax to Reduce U.S. Greenhouse Gas Emissions, NBER Working Paper No. 14375, 2008.

R.G. Newell, W.A. Pizer. Indexed regulation. Journal of Environmental Economics and Management, 56 (3) (2008), pp. 221–233

W. Pizer, The Case for Intensity Targets, Discussion Paper 05-02, Resources for the Future, 2005.

RGGI Emissions Leakage Multi-State Staff Working Group, Potential Emissions Leakage and the Regional Greenhouse Gas Initiative (RGGI): Evaluating Market Dynamics, Monitoring Options, and Possible Mitigation Mechanisms, Initial Report of the RGGI Emissions Leakage Multi-State Staff Working Group to the RGGI Agency Heads New York, NY, March 14, 2007.

T. Searchinger et al. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. Science, 319 (2008), pp. 1238–1240

R.N. Stavins, A U.S. Cap-and-Trade System to Address Global Climate Change, The Brookings Institution, Discussion Paper 2007-13, 2007.

R.N. Stavins. Addressing climate change with a comprehensive US cap-and-trade system. Oxford Review of Economic Policy, 24 (2) (2008), pp. 298–321

M.L. Weitzman, Prices vs. quantities, Review of Economic Studies 41, 477–479.

N. Winchester, S. Paltsev, J.M. Reilly, Will border carbon adjustments work? The B.E. Journal of Economic Analysis & Policy, 11(1)Topics, Article 7, 2011. Available at: 〈 http://www.bepress.com/bejeap/vol11/iss1/art7 〉 .

A.J. Yates, M.B. Cronshaw. Pollution permit markets with intertemporal trading and asymmetric information. Journal of Environmental Economics and Management, 42 (2001), pp. 104–118\

Notes

1 Fullerton and Heutel [17] analyze the incidence of intensity standards.
Fischer [12] characterizes the imperfect competition equilibrium with intensity standards.

2 The cost-effectiveness of a variety of policy instruments, including intensity standards, has been analyzed in the presence of pre-existing distortionary taxes [19] and in the presence of industry compensation requirements [5].

3 See also Fullerton [16] and Fullerton and Mohr [18] on similar combined instruments.

4 Output-based updating is included in the House version of Waxman‐Markey.

5 Stavins [31] argues instead for requiring that imports of carbon-intensive products ‐ such as iron and steel, aluminum, cement, bulk glass, and paper, and possibly a very limited set of other particularly CO_2emissions-intensive goods ‐ carry with them CO_2 allowances. This scheme may conflict with trade law.

6 Mansur [25] compares taxes and emissions trading in concentrated industries.

7 For example, electricity is usually provided by regulated monopolies, world oil markets are affected by the OPEC cartel, and petroleum refining, coal mines, railroad transport of coal and ethanol, and cement and steel production are highly concentrated.

8 See http://apps1.eere.energy.gov/states/maps/renewable_portfolio_states.cfm and http://www.epa.gov/chp/state-policy/renewable.html.

9 See pp. 14670-904 of Federal Register, vol. 75, No. 58, Friday, March 26, 2010, Rules and Regulations.

10 Similarly, Baumol and Oates [3] and Fullerton and Heutel [17] model emissions as an input.

11 Marginal damages are assumed constant, but the results are easily extended to increasing marginal damages by letting damages be an increasing function of e and replacing τ throughout by the derivative of this function.

12 Since the regulator's objective may not be globally concave in tc and σ, the optimal policy may be a corner solution. Holland et al. show that the optimal LCFS is non-binding under certain conditions.

13 All proofs are in the appendices.

14 See also Fullerton and Mohr [18].

15 The Journal's repository of online supplemental material can be accessed at http://aere.org/journals.

16 The model is readily extended to imperfect substitutes. If the goods are not substitutable (*i.e.* are additively separable), then there is no leakage, and the emissions tax dominates. As goods become closer substitutes, leakage increases, and the emissions tax may be dominated.

17 Marginal damages, which capture whatever damages the regulator is concerned about, are assumed independent of the source as is the case with carbon emissions. The results are easily extended to different transfer coefficients.

18 If tU=0 and fe>0, demand for emissions is infinite. If tU>0, emissions are finite. Note that tU could model an implicit or implied tax on emissions.

19 This objective is quite general and can model leakage within and across political jurisdictions depending on who "the regulator" is and on what benefits/costs enter the objective. An online appendix explicitly models international leakage where the regulator is concerned solely with domestic benefits. As above, the revenue from the emissions tax or the uncovered emissions charge provides no benefit as explained in footnote 20.

20 The regulator does not receive any benefit from the tax revenue. To see this, note that the objective is equivalent to $U(Q)-wkC-wkU-\tau(eC+eU)$. To model a benefit (cost) from tax revenue (for example, from off-setting other distortionary taxes) a multiplier could be included on the te term.

21 Two other cases deserve note. If the goods are not substitutable (*i.e.* are additively separable), [5] is unchanged but $\partial eU/\partial t=0$, *i.e.* there is no leakage, so the optimal emissions tax is τ. Alternatively, if the pollutant is local, $\tau-tU$ in [5] is zero or negative, so the optimal emission tax is τ or greater.

22 The difficulty lies in deriving the optimal second-best policy, since it generally depends on how emissions change with the policy, *i.e.*$\partial e/\partial t$ in [5] and $\partial e/\partial\sigma$ in [6]. On the other hand, it is quite easy to solve for the equilibrium for a given tax or intensity standard. Rather than using [5] or [6] directly, the numerical examples derive equilibrium net social benefits for a given policy and then choose the policy to optimize net social benefits.

23 Under constant returns to scale where $tU=\tau$, an intensity standard can attain the first best by setting$\sigma=0$, so all production leaks to uncovered firms where emissions are correctly priced.

24 The condition is not necessary since it only demonstrates that the intensity standard which mimics the second-best emissions tax has lower social costs. Even if this intensity standard has higher social costs, the optimal intensity standard can have lower deadweight loss.

25 Total costs are decreasing in σ, hence marginal cost (equal to average cost) is also decreasing.

26 The right hand side of the necessary and sufficient condition is decreasing in β. Thus as β increases it is more likely that the intensity standard/consumption tax combination attains the first best.

27 Note "□" and "′" are defined only for this proof.

28 A sufficient condition can be similarly derived for decreasing returns to scale by a slight modification of the proof. The more general sufficient condition, which depends on the endogenous t□ is$t$□$/\tau\leq 1-(1-\beta)^{\sum}\alpha i^{j}\beta\cdot(1-\beta)/\sum\alpha i$.

29 For this σ, an equilibrium exists with efficient MRTSs. If other equilibria exist, this may not hold.

30 Note that $U'(q)-tc=cq=\tau\sigma/\beta-\tau\sigma$ so $U'(q)=\tau/fe$, *i.e.* output is correct as in Proposition 1.

31 Note "□′" and "′" are defined only for this proof.

32 t is well-defined since $wi/fki\cdot(1-fe\sigma)=wj/fkj\cdot(1-fe\sigma)$ implies $wi/fki=wj/fkj$.