SUBSIDIES FOR THE PRODUCTION OF CLEANER ENERGY: DO THEY CAUSE EMISSIONS TO RISE?

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ABSTRACT

A production subsidy to low-carbon energy can have a perverse effect on emissions. The subsidy causes a shift in the composition of production towards the cleaner energy, but it also causes an offsetting consumption effect: energy consumption rises because the subsidy causes the equilibrium price of energy to fall. The net effect on emissions can be *positive* if the low-carbon energy is not significantly cleaner than the high-carbon energy it displaces. We derive a necessary and sufficient condition for this perverse effect in the context of a competitive energy market. Our calibrated example for an ethanol subsidy in the U.S. suggests that this policy is likely to cause an *increase* in carbon emissions for most plausible parameter values.

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1. INTRODUCTION

Subsidies for the production of low-carbon energy have been widely adopted in response to concerns over climate change. For example, the U.S., Canada, and many European countries use either direct production subsidies or preferential excise taxes to promote the expansion of cleaner energy sources. Expenditures on such programs in the U.S. will be around $35b for the period 2007 – 2011 [Metcalf (2006)]. Subsidies for alcohol-blended fuels such as ethanol and biodiesel will account for over one-third of that total.

The wisdom of these subsidies as a climate policy is increasingly being questioned. Subsidies to ethanol in particular have attracted much recent criticism, primarily because its climate-friendly credentials – when the full production cycle is accounted for – are dubious. An ethanol-blended fuel may be cleaner than gasoline but it still produces significant carbon emissions. This raises the possibility of a perverse effect from the policy: if a low-carbon fuel is not perfectly clean in terms of its carbon emissions then a subsidy-induced expansion in the use of that fuel may actually cause overall emissions to *rise*; the market displacement of the higher-carbon fuel may be more than offset by the increase in overall fuel consumption associated with a subsidized price.

The potential for perverse effects from ill-considered subsidies has been observed previously in the literature. For example, Fullerton and Mohr (2003) show that a technology subsidy that reduces abatement costs can cause an increase in production large enough to more-than-offset a lower emissions-intensity, and thereby cause emissions to rise. Holland *et. al.* (2009) show that low-carbon fuel standards – which act much like a subsidy – can in principle reduce the market price of fuel to the extent that the associated increase in fuel consumption causes overall emissions to rise. A number of other papers have compared “clean energy” production subsidies with alternative policies, whose performance is typically superior; for example see Fischer and Newell (2008), Fischer and Toman (2000), Gerlagh and van der Zwaan (2006), and Palmer and Burtraw (2006).

In this paper we derive a necessary and sufficient condition for when a production subsidy to an imperfectly clean alternative fuel will have a perverse effect on emissions. We then calibrate the model for an ethanol subsidy in the U.S. and show that a perverse increase in emissions is likely for a wide range of plausible estimates for supply and demand elasticities.

2. THE MODEL

We examine a setting with two sources of energy: a high-carbon source and a low-carbon source. Emissions from the high-carbon source are normalized to be one unit per unit of energy produced. The low-carbon source creates $\rho \in [0,1)$ units of emissions per unit of energy produced.

Demand for energy is given by $Q(p)$, where p is the price of energy. Consumers of energy are indifferent between sources. Both high-carbon and low-carbon energy are supplied by competitive firms with increasing marginal costs. The market supplies of high-carbon and low-carbon energy are denoted $q_H(p)$ and $q_L(p)$ respectively. We assume that the marginal cost of low-carbon energy production is everywhere higher than the marginal cost of high-carbon energy production; that is, $q_L(p) < q_H(p)$ at any given price, *p*.

Equilibrium price in the absence of a subsidy is given by p^0 such that $Q(p^0) = q_H(p^0) + q_L(p^0)$. Aggregate emissions at that price, denoted $Z(p^0)$, are given by $Z(p^0) = q_H(p^0) + \rho q_L(p^0)$.

3. CONSUMPTION AND COMPOSITION EFFECTS

Suppose a per unit subsidy s is paid to low-carbon energy producers. The new equilibrium price is p^S such that $Q(p^S) = q_H(p^S) + q_L(p^S + s)$. This subsidy has four key effects: (i) production of low-carbon energy expands; (ii) production of high-carbon energy contracts; (iii) the market price of energy falls; and (iv) overall energy consumption rises. The usual motivation for subsidies to cleaner energy production stems from effects (i) and (ii). In particular, if cleaner energy simply displaces dirty energy – a shift in the *composition* of energy supply towards low-carbon energy – then emissions will fall. However, the subsidy also causes a *consumption effect*: overall energy consumption rises because the equilibrium market price falls. If the low-carbon energy is not perfectly clean – that is, if $\rho > 0$ – then the consumption effect of the subsidy can outweigh the composition effect such that equilibrium emissions rise.

It is straightforward to derive a necessary and sufficient condition for an increase in emissions in this context. This condition is stated as Proposition 1.

PROPOSITION 1. Let $\varepsilon(p) \equiv -pQ'(p)/Q(p)$ denote the absolute value of the elasticity of energy demand, and let $\eta_H(p) \equiv pq'_H(p)/q_H(p)$ denote the elasticity of high-carbon energy supply. Let $\sigma_H(p) \equiv q_H(p)/Q(p)$ denote the market share of high-carbon energy. Then

$$\frac{dZ}{ds} > 0 \text{ if and only if } \rho\varepsilon(p) > (1-\rho)\sigma_H(p)\eta_H(p).$$

Proof. See the Appendix.

The condition in Proposition1 can be interpreted in terms of the aforementioned consumption and composition effects of the subsidy. The left-hand side term, $\rho\varepsilon(p)$, reflects the consumption effect: the increase in emissions associated with the increase in total energy consumption as price falls (all of which is supplied by low-carbon energy, with emissions intensity ρ). The right-hand side term, $(1-\rho)\sigma_H(p)\eta_H(p)$, reflects the composition effect of the subsidy: the net reduction in emissions associated with the switch from high-carbon energy to low-carbon energy. Note that if the low-carbon energy is perfectly clean, that is, if $\rho = 0$, then the consumption effect vanishes, and the subsidy unambiguously reduces emissions. All other cases have the potential for emissions to increase.[1]

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[1] Note that the elasticity of low-carbon energy supply does not enter the condition in Proposition 1. This reflects the fact that the cleaner source supplies all additional consumption (as determined by the elasticity of demand) and substitutes for all contraction in the supply of high-carbon energy (as determined by the elasticity of supply for high-carbon energy). Thus, the expansion of low-carbon energy is implicitly determined by energy demand and high-carbon energy supply, for any given price change. (See equation (A6) of the proof).

4. THE EFFECT OF A SUBSIDY WHEN ELASTICITIES ARE CONSTANT

It is important to recognize that Proposition 1 relates only to the *marginal* effect of a subsidy; the result does not tell us what effect a large subsidy might have on emissions. To explore this question further it is useful to place some additional restrictions on our model. In particular, suppose that the elasticity of demand and the elasticity of high-carbon energy supply are both constant, and denoted $-\varepsilon$ and η_H respectively. We can then write Proposition 1 as

$$(1) \qquad \frac{dZ}{ds} > 0 \text{ if and only if } \sigma_H < \left(\frac{\rho}{1-\rho}\right)\frac{\varepsilon}{\eta_H} \equiv \sigma_H^* .$$

Since σ_H is declining in *s*, we can delineate two distinct cases of interest depending on the initial market share of the high-carbon fuel, σ_H^0. In Case 1, $\sigma_H^0 < \sigma_H^*$. In this case, aggregate emissions rise *monotonically* with the subsidy. That is, a subsidy of *any* size will have a perverse effect on emissions. In Case 2, $\sigma_H^0 > \sigma_H^*$. In this case aggregate emissions initially fall in response to the subsidy, but must eventually rise again as the subsidy grows and the market share for high-carbon energy falls below σ_H^*.

5. A CALIBRATED EXAMPLE: U.S. ETHANOL SUBSIDIES

In this section we calibrate our model for the case of ethanol subsidies in the U.S. The most significant subsidies for ethanol were introduced after 2004 so we use market data for that year from the Energy Information Administration (EIA) to construct the relevant market share values. In 2004 conventional gasoline accounted for 97.5% of the gasoline market (EIA 2007). Thus, in the context of our model, $\sigma_H^0 = 0.975$.

Our estimate for ρ is subject to more uncertainty. Many studies have estimated the lifecycle carbon intensity of ethanol relative to gasoline; for example, see recent work by Department of Transport (2008) in the U.K. and California Environmental Protection Agency (2009).[2] Results typically differ across ethanol sources, and some studies have even suggested that ethanol from U.S.-sourced corn may actually produce *more* emissions than gasoline once indirect land-use effects are considered; for example,

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[2] The latter paper is just one of many studies on the subject by the California Environmental Protection Agency. These are currently available at *http://www.arb.ca.gov/fuels/lcfs/lcfs.htm*.

see Searchinger *et. al.* (2008) and Yeh *et. al.* (2008). Based on the balance of evidence, our benchmark estimate for ρ is 0.75. This particular value comes from Holland *et. al.* (2009). However, in view of the uncertainty surrounding this parameter we also consider values 20% above and 20% below our benchmark value.

Based on these estimates for σ_H^0 and ρ we can calculate from condition (1) the critical ratio ε / η_H above which a subsidy of any size will have a perverse effect on emissions. Let r^* denote that critical ratio:

$$r^* = \left(\frac{1-\rho}{\rho}\right)\sigma_H^0 \tag{2}$$

For our benchmark value of ρ, $r^* = 0.33$. Figure 1 depicts this as the solid ray, which partitions the (η_H, ε) space into two regions, corresponding to Case 1 (above the ray), and Case 2 (below the ray). The higher, dashed ray corresponds to a ρ value 20% below our benchmark estimate (with a critical ratio of $r^* = 0.66$), while the lower, dashed ray corresponds to a ρ value 20% above our benchmark value (with a critical ratio of $r^* = 0.11$).

Estimates of the supply elasticity for gasoline vary widely. Dahl and Duggan (1996) survey studies available at the time and cite a range of 0.5 to 2.0. More recent estimates by Austin and Dinan (2005) and de Gorter and Just (2009) also fall within that range. We have illustrated this “consensus” range on Figure 1 and highlighted the (η_H, ε) region within that range in which a subsidy will have a perverse effect, based on our benchmark value for ρ (the shaded area in the figure). We have also depicted in Figure 1 a variety of estimates for the long-run elasticity of demand for vehicle transportation fuel (marked on the figure at the mid-point of the “consensus” range for the supply elasticity). These estimates range from 0.39 reported in Austin and Dinan (2005) to a range of 0.72 to 1.13 reported in Schmalensee and Stoker (1995). Where a single study reports a range of demand elasticity estimates, we have marked the mid-point of that range.

The information in Figure 1 should be interpreted as follows. If a particular demand elasticity estimate lies within the shaded region, then a subsidy to ethanol will cause emissions to rise for *any* gasoline supply elasticity in the "consensus" range, based on our benchmark estimate of ρ. Of the eight demand elasticity estimates available, only one falls outside the shaded region.

For a value of ρ lower than our benchmark, the case against an ethanol subsidy is not as clear. Three demand elasticity estimates fall below the upper dashed ray, corresponding to $\rho = 0.6$ (20% below our benchmark value). However, even the most positive portrayals of current ethanol production typically produce relative carbon intensities above that value. Thus, the upper dashed ray should be viewed as a generous best case for ethanol. In contrast, the lower dashed ray, corresponding to $\rho = 0.9$ (20% above our benchmark estimate), is well within the realm of possibility, especially for U.S.-sourced corn ethanol, and under that scenario all reasonable demand elasticity estimates are well above the critical threshold for a perverse effect. On balance, the weight of evidence here suggests that a subsidy to ethanol production will likely cause a long run *increase* in emissions.

6. CONCLUSION

The central message of our paper is that a production subsidy to low-carbon energy can have a perverse effect on emissions. The subsidy causes a shift in the composition of production towards the cleaner energy, but it also causes an offsetting consumption effect: energy consumption rises because the subsidy causes the equilibrium price of energy to fall. The net effect on emissions can be *positive* if the low-carbon energy is not significantly cleaner than the high-carbon energy it displaces. We have derived a necessary and sufficient condition for this perverse effect in the context of a competitive energy market. Our calibrated example for an ethanol subsidy in the U.S. suggests that this policy is likely to cause an *increase* in carbon emissions for most plausible parameter values.

APPENDIX: PROOF OF PROPOSITION 1

First consider the change in price due to the subsidy. In equilibrium,

(A1) $$Q(p) = q_L(p+s) + q_H(p)$$

Differentiating with respect to *p* and *s* yields:

(A2) $$Q'(p)dp = q_L'(p)[dp + ds] + q_H'(p)dp$$

Upon rearrangement, we have

(A3) $$\frac{dp}{ds} = \left(\frac{q_L'(p)}{Q'(p) - q_L'(p) - q_H'(p)} \right) < 0$$

This can be expressed in elasticity form by multiplying and dividing throughout by $p / Q(p)$, $q_H(p)$ and $q_L(p)$ to obtain:

(A4) $$\frac{dp}{ds} = \frac{\sigma_L(p)\eta_L(p)}{-\varepsilon(p) - \sigma_L(p)(p)\eta_L - \sigma_H(p)\eta_H(p)} < 0$$

where $-\varepsilon(p)$ is the elasticity of demand, $\eta_i(p)$ is the elasticity of supply for energy type *i*, and $\sigma_i(p)$ is the market share for energy type *i*.

Now consider the change in aggregate emissions:

(A5) $$dZ = \rho dq_L + dq_H$$

In equilibrium, $dq_L = dQ - dq_H$. Thus, we can write

(A6) $$dZ = \rho[dQ - dq_H] + dq_H = \rho dQ + (1-\rho)dq_H$$

Differentiating with respect to *s*, we obtain

(A7) $$\frac{dZ}{ds} = [\rho Q'(p) + (1-\rho)q_H'(p)]\frac{dp}{ds}$$

This too can be expressed in elasticity form by multiplying and dividing throughout by $p / Q(p)$ and $q_H(p)$ to obtain:

(A8) $$\frac{dZ}{ds} = [-\rho\varepsilon(p) + (1-\rho)\sigma_H(p)\eta_H(p)]\frac{Q(p)}{p}\frac{dp}{ds}$$

Recall from (A4) above that $\frac{dp}{ds} < 0$. It follows that $\frac{dZ}{ds} > 0$ if and only if $\rho\varepsilon(p) > (1-\rho)\sigma_H(p)\eta_H(p)$.

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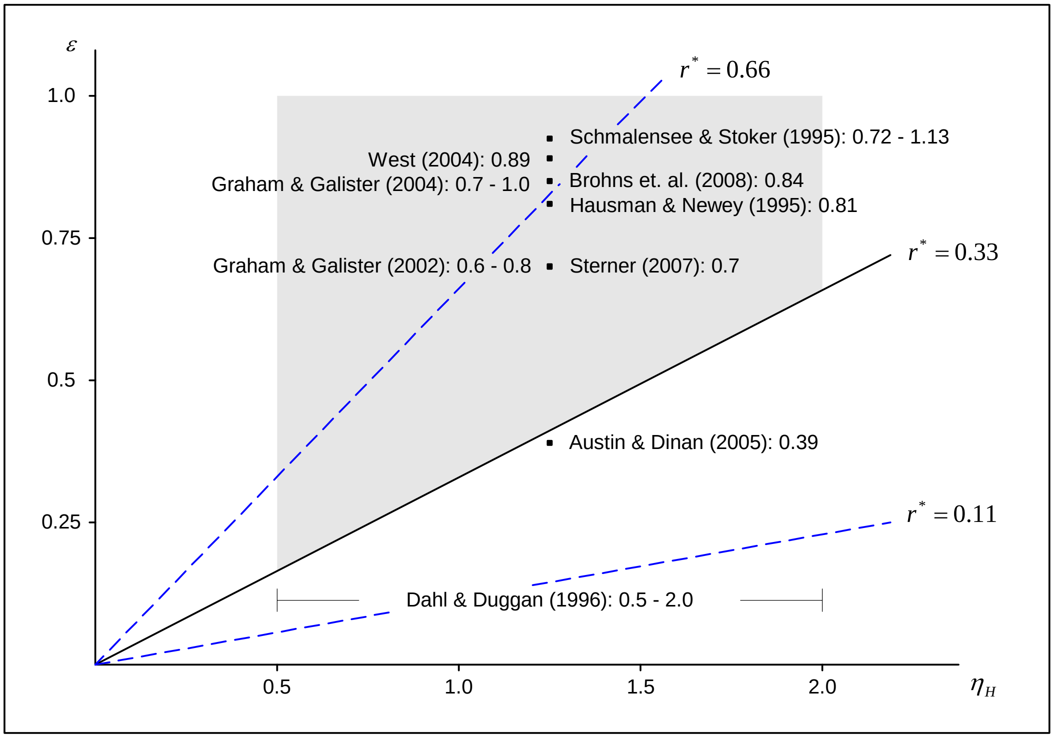

ε
1.0
0.75
0.5
0.25
0.5
1.0
1.5
2.0
η_H
$r^* = 0.66$
$r^* = 0.33$
$r^* = 0.11$
Schmalensee & Stoker (1995): 0.72 - 1.13
West (2004): 0.89
Graham & Galister (2004): 0.7 - 1.0
Brohns et. al. (2008): 0.84
Hausman & Newey (1995): 0.81
Graham & Galister (2002): 0.6 - 0.8
Sterner (2007): 0.7
Austin & Dinan (2005): 0.39
Dahl & Duggan (1996): 0.5 - 2.0

FIGURE 1