DIW Berlin

German Institute
for Economic Research

Discussion Papers

341

Susanne Dröge and
Philipp J.H. Schröder

How to Turn an Industry Green: Taxes versus Subsidies

Berlin, April 2003

Opinions expressed in this paper are those of the author and do not necessarily reflect views of the Institute.

DIW Berlin

German Institute
for Economic Research

Königin-Luise-Str. 5
14195 Berlin,
Germany

Phone +49-30-897 89-0
Fax +49-30-897 89-200

www.diw.de

ISSN 1619-4535

How to Turn an Industry Green: Taxes versus Subsidies

Susanne Dröge* Philipp J.H. Schröder†

February 2003

Abstract

Environmental policies frequently target the ratio of dirty to green output within the same industry. To achieve such targets the green sector may be subsidised or the dirty sector be taxed. This paper shows that in a monopolistic competition setting the two policy instruments have different welfare effects. For a strong green policy (a severe reduction of the dirty sector) a tax is the dominant instrument. For moderate policy targets, a subsidy will be superior (inferior) if the initial situation features a large (small) share of dirty output. These findings have implications for policies such as the Californian Zero Emission Bill or the EU Action Plan for Renewable Energy Sources.

Key Words: Environmental policy; Monopolistic competition; Taxes; Subsidies; Welfare; Zero Emission Bill

JEL: H2, L13, Q28

*Corresponding author: DIW Berlin – German Institute for Economic Research, Königin-Luise-Straße 5, 14195 Berlin, Germany, Tel.: +49 30 89789-689 (Fax: -113), E-mail: sdroege@diw.de.

†DIW Berlin – German Institute for Economic Research.

1 Introduction

Environmental policies frequently aim at greening particular industries by improving their ratio of clean to polluted production or consumption. The California Air Resources Board in its Low-Emission Vehicle regulation of 1991 required that by 2003 10% of all newly registered cars be zero-emission vehicles (ZEV); see CARB (1998) and Kazimi (1997). Similarly, the European Union Action Plan for Renewable Energy Sources states that by 2010 the share of renewable energies in gross domestic energy consumption in the EU shall reach 12% (European Commission, 1997). Also, in Germany a law from 1991 sets a minimum quota of 72% for beverages being sold in reusable containers (Verpackungsverordnung, 1998). In order to achieve these type of ratio targets (green quotas), it is necessary to make producers and consumers substitute environmentally friendly variants for dirty products from the same industry. Apart from command and control measures, such as prohibitions and standards, or voluntary agreements, which in fact anticipate quota-enforcement by decree, the main tools for changing production and consumption patterns are market-based instruments like taxes and subsidies. The reasoning is that the prices of green and dirty goods can be modified to induce producers and consumers to alter their supply and demand decisions, which in turn will eventually change the ratio of dirty to green output.

We analyse how these tools help to implement a green quota most efficiently in terms of welfare.[1] In principle, any targeted quota or ratio between dirty and green products can be achieved either by taxing the dirty sector or by subsidising the green sector of the industry in question. Yet, the two policy instruments will have different impacts on tax income, and they will affect industry profits as well as firm entry and the number of green and dirty variants if there is imperfect competition, product differentiation and endogenous market structures. One way of modelling these various forces – and the approach taken here – is Dixit-Stiglitz (1977) type monopolistic competition. It provides a consistent framework where consumers value product variety and where product differentiation, economies of scale and market entry exist. Furthermore, since it is inherently a general equilibrium approach, the full consequences of redistributing or collecting taxes (the latter in order to pay a subsidy) can be studied, and, not least, there is a clear measure of welfare, because it takes its starting point in the consumer utility function. This approach, though widely used in industrial and international economics,

[1]This means that the paper is not concerned with the rationale underlying a policy that sets fixed target ratios of green to dirty output; instead we focus on the welfare implications of obtaining such ratio targets.

has found relatively little application in environmental economics.[2]

It is well-known that market-based tools like taxes and subsidies are, compared to other measures, superior in terms of economic efficiency if they address environmental externalities and if markets feature perfect competition (e.g. Baumol and Oates, 1988). Moreover, comparison of taxes and subsidies under different market structures show that the effectiveness of instruments can deteriorate due to monopoly power of producers (see the seminal work of Buchanan, 1969). Another strand of literature discusses second-best environmental policy instruments under the presence of product market distortions and international trade (Carraro et al., 1996).[3] In contrast to the usual Pigouvian-style environmental taxes versus subsidies comparisons, which depart from an externality problem, we assume that policy-makers – no matter how they define environmental quality – decide exogenously on a production or consumption ratio between green and dirty substitutes for the industry in question. Thus, because the environmental target is given and achieved in either policy scenario, environmental damage from the dirty sector need not enter explicitly consumers' utility. Therefore, we abstract from the externality issue to obtain a clear analysis of how best to enforce politically determined quotas in terms of welfare by using taxes or subsidies.[4]

The paper finds that welfare depends on the choice of instrument and on the 'strictness' of the policy target. As utility crucially depends on substitution elasticities between the dirty and green sector, i.e. the inter-sectoral elasticity of substitution, and on consumers' love of variety within one sector, i.e. the intra-sectoral elasticity of substitution, these parameters also determine the policy level at which taxes dominate subsidies and vice versa. If the green quota target aims at a severe reduction of the dirty sector, then a tax is the welfare dominant instrument for all parameter constellations.

[2]Other authors that use Dixit-Stiglitz (1977) type monopolistic competition settings to study environmental policy issues and instruments include Heijdra and van der Ploeg (1995), Haupt (2000) and Vetter (2001). These papers address optimality when inducing abatement or reducing an externality. In contrast, the present paper takes the broader view of welfare optimality when implementing a certain – exogeneously given – environmental policy target, i.e. the ratio of dirty to green.

[3]See also Conrad and Wang (1993) who show the interaction between environmental policy choices and imperfect competitive markets. Ulph (1999) presents an overview of strategic environmental policy. Pflüger (2001) applies a monopolistic competition model to ecological dumping.

[4]It is widely recognised in the environmental economics literature that the choice of an environmental target can be made on various grounds. For example in a political economy context, the choice of a certain quota can be motivated by maximisation of a political support function including green voters and industry lobbyists (See Schulze and Ursprung, 1998).

Yet, for a wide range of moderate policy targets, a subsidy will be superior if the initial situation features a large share of dirty output and consumption. These results help explain current policy approaches which implement quotas for specific sectors. In particular, policy-makers should choose a subsidy for green variants as long as their policy target (the share of green output for the industry) is relatively lax and as long as consumers have strong preferences for polluting products and have a high love of variety. Subsidies are the actual instrument of choice in several prominent policy settings, e.g. in the case of Californian ZEV policy or in European approaches to foster electricity generation from renewable sources. The model also yields implications for other scenarios. If, for example, consumers initially have a very green bias, but change their preferences from green to dirty variants over time, then the initial green share in consumption and production can be sustained in a welfare optimal manner by adjusting policy instruments over time, starting with a tax on the dirty goods and eventually switching to a subsidy for green variants.

The following section introduces the model. Section 3 derives the welfare ranking between the two policy instruments. Section 4 concludes.

2 The Model

Consider an industry with two sectors – green (indicated by $\hat{}$) and dirty – where market conditions are characterised by increasing returns to scale in production and by differentiated goods.[5] We take a general approach to environmental damage by assuming that it can be associated either with the consumption or the production of goods, thus depending solely on output volume. The industry has a large number of potential product variants (firms) in both sectors, $\hat{N}$ and N, which enter symmetrically into demand. The number of variants actually produced are $\hat{n} < \hat{N}$ and $n < N$. Consumers demand both green and dirty products. In particular, utility – identical for all individuals – is assumed to be

$$U = \left(\sum_{j=1}^{\hat{n}} \hat{c}_j^{\theta} \right)^{1-\alpha} \left(\sum_{i=1}^{n} c_i^{\theta} \right)^{\alpha} , \tag{1}$$

[5]This section presents a straightforward application of Dixit and Stiglitz (1977) to the issue at hand.

where $0 < \theta < 1$ is the love of variety parameter and $\hat{c}_j$ is the consumption of green good j, while c_i is the consumption of dirty good i.[6] Maximisation of (1) yields that consumers will spend a constant share $1-\alpha$ and α of their income on green and dirty products respectively. Furthermore, the inter-sectoral elasticity of substitution between green and dirty products is 1, while the intra-sectoral elasticity of substitution within each sector turns out to be $\frac{1}{1-\theta}$. In terms of the example introduced above, this would imply that, even though gasoline and ZEV cars are substitutes, varieties of zero emission cars from different producers are closer substitutes than gasoline and ZEV cars are.

The inverse demand functions, $P(\hat{x}_i)$ and $P(x_i)$ are calculated by maximising the utility stemming from each sector. Focusing on the dirty sector, and realising that without any policy, the results for the two sectors are identical, we have max $\left(\sum c_i^\theta\right)^\alpha - \lambda(p_1c_1 + \cdots + p_ic_i + \cdots + p_nc_n - \alpha(w+R)$, where p_i is the price of good i, w is the economy wide wage rate and R is either redistributed green tax revenue ($R > 0$) or taxes raised in order to pay the green subsidy ($R < 0$). Due to the large number of firms assumed, individual firms do not realise the impact of their price on overall sales. The first order conditions are of the form

$$P(x_i) = \frac{\theta c_i^{\theta-1}}{\lambda\xi}\,, \tag{2}$$

where $\xi = \alpha\left(\sum c_i^\theta\right)^{-\alpha}$ is assumed to be constant, and x_i is the single firm's output.

Finally, goods market clearing requires $c_i = \frac{x_i}{L}$ and similarly $\hat{c}_i = \frac{\hat{x}_i}{L}$, where L is the total number of consumers assumed identical to the total labour force.

The cost function is identical for all firms in both sectors, $l_i(x_i) = (f + \beta x_i)$, where l_i is labour, the only factor of production; where f is the fixed costs of production; and where β is marginal costs. It is straightforward to use f and $\hat{f}$ for the two sectors throughout the analysis. However, analytical solutions for the utility comparisons would become cumbersome and thus we ignore this possibility here. Labour market clearing requires $\sum l_i + \sum \hat{l}_j = L$.

Equilibrium is characterised by prices, per firm output and the number of firms. Due to symmetry we can restrict our analysis to one variant (firm),

[6] As explained in Section 1, the specification of U contains no explicit treatment of pollution or environmental quality. Yet, including a level parameter of the environmental state, which depends on the ratio of green to dirty output and which is targeted exogenously by the government, does not affect our results, as long as it constitutes a monotone transformation of utility.

hence, omitting the subscripts i and j for the two sectors respectively. In the absence of any policy instrument, the profit of a firm in the dirty sector is[7]

$$\pi = P(x)x - (f + \beta x)\, w \; . \tag{3}$$

Using the fact that $c = \frac{x}{L}$, plugging (2) into (3) and maximising yields the profit-maximising price

$$p = \frac{\beta w}{\theta} \; . \tag{4}$$

Under free entry and exit of firms, equating the profit-maximising price with the price implied by zero profits, $p_0 = \frac{(f+\beta x)w}{x}$, gives the per firm output:

$$x = \frac{\theta f}{(1-\theta)\beta} \; . \tag{5}$$

Finally, the number of firms actually producing in equilibrium can be deduced via market clearing using the x and p just derived. In particular, $pxn = \alpha(wL + R)$ must hold. With an absence of policy $R = 0$ and hence

$$n = \frac{\alpha L(1-\theta)}{f} \; . \tag{6}$$

Similarly, for the green sector $\hat{p}\hat{x}\hat{n} = (1-\alpha)(wL+R)$ must hold, which yields

$$\hat{n} = \frac{(1-\alpha)L(1-\theta)}{f} \; . \tag{7}$$

Accordingly, the percentage of dirty products produced/consumed[8] is given by $\chi = \frac{xn}{\hat{x}\hat{n}+xn}$, which, after setting in the above values – and in accordance with intuition – turns out as $\chi = \alpha$. Now an environmental policy target, in the sense of the cases discussed in the introduction, is a restriction, $\bar{\chi}$, on the share of dirty products which can be defined as

$$\bar{\chi} = \gamma\chi = \gamma\alpha \; , \tag{8}$$

where $\gamma \in (0, 1]$ measures how tough the policy target is.

[7]Parallel to footnote 6 pollution is not explicit in production (or consumption) and thus neither is there abatement, nor are there innovation activities by firms. Yet entry, exit and scale decisions of firms constitute the switch from dirty to green production.

[8]It does not matter whether the environmentally harmful effect is associated with the consumption or production of the products of the dirty sector.

Taxing the dirty sector

Once a tax, t, is imposed in order to reduce consumption/production of products from the dirty sector, the profit function reads $\pi_t = (1-t)P(x)x_t - (f+\beta x_t)\,w$, with the subscript t indicating the taxation case. Maximisation yields the price for products in the dirty sector

$$p_t = \frac{\beta w}{\theta(1-t)} \; . \tag{9}$$

Hence a tax of dirty products raises the price, and producers shift the entire tax to consumers, such that the realised producer prices $((1-t)p_t)$, remain unaffected. Equating the new profit-maximising price with the zero profits price (driven by entry and exit), defines per-firm output:

$$x_t = \frac{\theta f}{(1-\theta)\beta} \; , \tag{10}$$

which turns out to be unchanged compared to the base case (5) . Yet as prices have risen, some firms must be driven out of business. The number of firms actually producing is deduced via the market clearing condition $p_t x_t n_t = \alpha(wL + R_t)$, where R_t is the tax revenue, that is redistributed in a lump-sum fashion. In particular, since all dirty variants behave identically and since all dirty variants are taxed, we can write $R_t = t p_t x_t n_t$. Solving the market clearing condition gives

$$n_t = \frac{\alpha L(1-t)(1-\theta)}{(1-\alpha t)f} \; , \tag{11}$$

which turns out to be less than the number of dirty sector firms in the base case, i.e. $n_t < n$, since $\frac{1-t}{1-\alpha t} < 1$. Also, the actual tax revenue can be calculated as $R_t = \frac{tw\alpha L}{1-\alpha t}$. For the green sector, even though there is no effect on prices and per-firm quantity from a taxation of the dirty sector $(\hat{p}_t = \hat{p}, \hat{x}_t = \hat{x})$, there is still a spillover via the raised and redistributed tax revenue. The market clearing condition reads $\hat{p}_t \hat{x}_t \hat{n}_t = (1-\alpha)(wL + R_t)$, where R_t has the value just derived. Hence,

$$\hat{n}_t = \frac{(1-\alpha)L(1-\theta)}{(1-\alpha t)f} \; , \tag{12}$$

which is greater than $\hat{n}$. Thus taxing the dirty sector promotes entry into the green sector via the redistributed tax revenue.

Finally, the tax level, $\bar{t}$, that obtains the mix between dirty and green products aimed at by policy target (8) can be calculated from $\chi_{\bar{t}} = \frac{x_t n_t}{\hat{x}_t \hat{n}_t + x_t n_t} = \bar{\chi} = \gamma\alpha$. Setting in the values from above gives

$$\bar{t} = \frac{1-\gamma}{1-\alpha\gamma} \ . \tag{13}$$

Thus, with an absence of policy ($\gamma = 1$) the tax becomes zero, while with a very strict policy ($\gamma \to 0$) the tax becomes one, i.e. the upper feasible limit of an ad valorem tax.

Subsidising the green sector

Now assume that a subsidy, s, is imposed in order to boost the green sector, still maintaining the ultimate policy target of achieving a mix between dirty and green sector of $\bar{\chi}$. With a subsidy the profit in the green sector becomes $\hat{\pi}_s = \hat{p}_s\hat{x}_s - (f + \beta\hat{x}_s)\, w + s\hat{x}_t$, whereby the subscript s indicates that we are in the subsidy case.[9] Maximisation yields the price for green products

$$\hat{p}_s = \frac{\beta w - s}{\theta} \ . \tag{14}$$

Hence the subsidy reduces the price for consumers. In fact, firms, since they act in a sense as monopolists and since the subsidy decreases marginal costs, have passed the subsidy on to consumers with a factor $\frac{1}{\theta}$. Thus the operating surplus of firms in the green sector must have decreased. Accordingly, since each firm still has to recover its fixed production costs, f, product runs must increase. Setting the price derived in (14) equal to the price implied by zero profits verifies this point. In particular,

$$\hat{x}_s = \frac{\theta w f}{(1-\theta)(\beta w - s)} \ , \tag{15}$$

which is larger than $\hat{x}$ given implicitly in (5). The number of firms actually producing is deduced via the market clearing condition $\hat{p}_s\hat{x}_s\hat{n}_s = (1-\alpha)(wL + R_s)$, where $R_s = -s\hat{x}_s\hat{n}_s$ is the tax revenue that must be raised with a lump sum tax in order to be able to pay the subsidy to the green sector. Solving the market clearing condition gives

$$\hat{n}_s = \frac{(1-\alpha)L(1-\theta)(\beta w - s)}{f\,(\beta w - s(1-(1-\alpha)\theta))} \ , \tag{16}$$

which can be shown to be less than the number of green sector firms in the base case, i.e. $\hat{n}_s < \hat{n}$. The actual tax revenue that has to be raised in order

[9] Notice that in line with commonly implemented policies, we compare an ad valorem tax to a unit subsidy. See Delipalla and Keen (1992) for a general comparison of unit versus ad valorem instruments under imperfect competition.

to pay the subsidies is $R_s = \frac{-s(1-\alpha)L\theta w}{\beta w - s(1-(1-\alpha)\theta)}$. So the subsidy – contrary to common intuition – does not generate any entry to the green sector, instead firms produce a larger output run each. In addition, since tax revenue must be raised to pay the subsidy, consumer spending power is reduced, and hence there are even fewer firms than in the benchmark case. Furthermore, in the dirty sector, even though prices and per firm output are unaffected by a subsidy of the green sector, the number of firms is not. Since the revenue demand for the subsidy affects income spent on dirty products as well, after solving $p_s x_s n_s = \alpha(wL + R_s)$, one has

$$n_s = \frac{\alpha L(1-\theta)(\beta w - s)}{f(\beta w - s(1-(1-\alpha)\theta))} , \tag{17}$$

which is, apart from the factor α, identical to (16). This means that the reduction of firms in the dirty sector occurs solely because of the lump-sum tax on income, which affects both sectors. Or put differently, under the – admittedly unrealistic – assumption that the subsidy to the green sector was collected exogenous to the model, then a subsidy policy would leave the number of firms in both sectors unaffected, but would only boost the output of green firms compared to dirty firms by cutting the price of green goods.

Finally, the subsidy, $\bar{s}$, that leads to the mix between dirty and green products aimed at by policy target (8), is calculated from $\chi_{\bar{s}} = \frac{x_s n_s}{\hat{x}_s \hat{n}_s + x_s n_s} = \bar{\chi} = \gamma\alpha$. Setting in the values from above gives

$$\bar{s} = \beta w \frac{1-\gamma}{1-\alpha\gamma} , \tag{18}$$

thus with no policy ($\gamma = 1$) the subsidy becomes zero, while for a very strict policy ($\gamma \to 0$) the subsidy becomes so large that it completely compensates the marginal cost of producers.

3 Results

Before actual utility levels can be calculated, the tax rate $\bar{t}$ defined in (13) has to be set into the expressions for the number of firms (11) and (12). Similarly, the subsidy $\bar{s}$ defined in (18) has to be set into the per firm quantity expression (15) and the number of firms expressions (16) and (17). Utilising market clearing, i.e. the fact that $c = \frac{x}{L}$, the resulting values can be set directly into utility function (1). The utility levels under the two different policy instruments are:

$$U_{\bar{t}} = \left(\frac{L(1-\theta)(1-\alpha\gamma)}{f} \left(\frac{\theta f}{L(1-\theta)\beta} \right)^{\theta} \right)^{1-\alpha} \left(\frac{\alpha L\gamma(1-\theta)}{f} \left(\frac{\theta f}{L(1-\theta)\beta} \right)^{\theta} \right)^{\alpha} \tag{19}$$

$$U_{\bar{s}} = \left(\frac{L(1-\theta)\gamma(1-\alpha)}{f(\gamma+\theta(1-\gamma))} \left(\frac{\theta f(1-\gamma\alpha)}{L(1-\theta)\beta\gamma(1-\alpha)} \right)^{\theta} \right)^{1-\alpha} \left(\frac{\alpha L\gamma(1-\theta)}{f(\gamma+\theta(1-\gamma))} \left(\frac{\theta f}{L(1-\theta)\beta} \right)^{\theta} \right)^{\alpha} \quad (20)$$

The terms in (19) and (20) show the utility portions stemming from the consumption of green and dirty goods respectively; as well as the various n and x applied. Recall that both expressions are derived under the same policy constraint, i.e. under the condition that they result in exactly the same target level of dirty to green products in consumption/production, namely $\bar{\chi}$. Yet the resulting utility levels differ. Figure 1 illustrates two numerical examples of (19) and (20). In Figure 1a the initial share of dirty product variants in consumption/production is relatively low ($\alpha = 0.3$). In this case, taxation of the dirty sector is welfare superior to a subsidy of the green sector for the whole range of policy targets γ. In Figure 1b, the situation is characterised by a relatively large α. In this case the taxation of the dirty sector is only welfare superior if the policy target is strict, i.e. γ is small, otherwise a subsidisation of the green varieties is welfare superior. From (19) and (20) a number of results can be stated.

Proposition 1. *For a sufficiently tough green policy target, taxing the dirty sector is welfare superior to subsidising the green sector. In particular,*

$$\lim_{\gamma \to 0} U_{\bar{t}} > \lim_{\gamma \to 0} U_{\bar{s}} \ .$$

Proof is given in Appendix A.1. Proposition 1 establishes that for very strict policy targets, that is, small γ, the taxation of the dirty sector is preferable to a subsidy for the green sector. The reason is that a close to complete removal of the dirty sector in the subsidy case can only be driven by a very harsh lump-sum tax requirement on income. Under a taxation of the dirty sector, however, consumption/production of the dirty output can be eliminated relatively efficiently via the price increase.

Proposition 2. *If the initial situation features a small share of dirty production/consumption, then taxing the dirty sector is welfare superior to subsidising the green sector for the entire policy range. In particular,*

$$\alpha < \frac{\theta}{1+\theta} \ \Rightarrow \ U_{\bar{t}} > U_{\bar{s}} \ \forall \ \gamma \in (0,1) \ .$$

Proof is given in appendix A.2. Proposition 2 establishes that if the role of dirty products in production/consumption is relatively unimportant in the initial (no policy) situation, then a further reduction of dirty products is best achieved via taxation of the dirty sector.

Figure 1: Utility under a tax and a subsidy

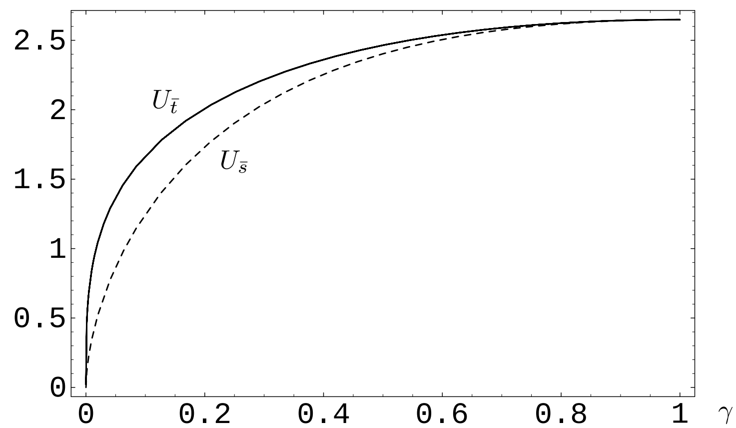

Figure 1a: $L = 100$, $f = 1$, $\beta = 0.5$, $\alpha = 0.3$, $\theta = 0.6$

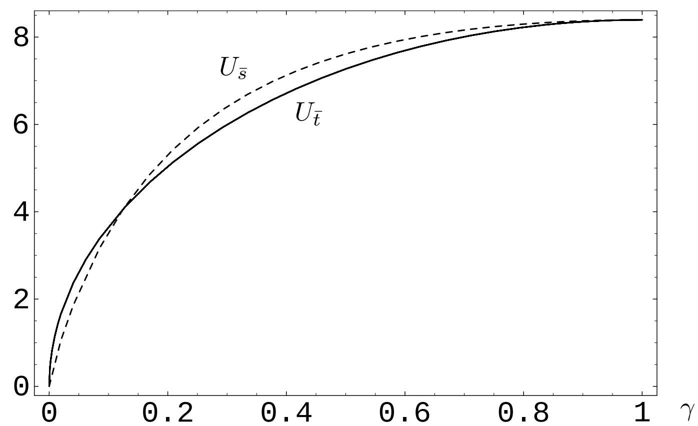

Figure 1b: $L = 100$, $f = 1$, $\beta = 0.5$, $\alpha = 0.5$, $\theta = 0.3$

Proposition 3. *If the initial situation features a large share of dirty production/consumption, then there exists a critical level of policy, γ^c, such that for policies tougher than γ^c taxing the dirty sector is welfare superior and for policies softer than γ^c, subsidising the green sector is welfare superior. In particular,*

$$\alpha > \frac{\theta}{1+\theta} \;\Rightarrow\; \exists\, \gamma^c \in (0,1), \; \begin{cases} U_{\bar{t}} > U_{\bar{s}}\,, & \gamma \in (0,\gamma^c) \\ U_{\bar{t}} = U_{\bar{s}}\,, & \gamma = \gamma^c \\ U_{\bar{t}} < U_{\bar{s}}\,, & \gamma \in (\gamma^c,1)\,. \end{cases}$$

Proof is given in Appendix A.3. Proposition 3 establishes that if the share of dirty variants, α, is greater than the critical value $\frac{\theta}{1+\theta}$ the superior policy tool depends on how strict a quota is chosen.

Figure 1 illustrates propositions 2 and 3. Figure 1a shows a Proposition 2 situation (a situation where $\alpha < \frac{\theta}{1+\theta}$), while Figure 1b features a Proposition 3 situation. In particular, in figure 1b a taxation of the dirty sector is only welfare superior if the policy target is very strict, i.e. if γ is small. The two curves intersect at γ^c.

The critical value $\frac{\theta}{1+\theta}$ in propositions 2 and 3 lies between 0 and $\frac{1}{2}$ and is determined by the love of variety parameter, $\theta \in (0,1)$, or alternatively the intra-sectoral elasticity of substitution, $\frac{1}{1-\theta}$. In particular, for θ close to zero, products are strongly differentiated, i.e. love of variety matters significantly. In the extreme case, higher quantities do not contribute any utility. The critical value $\frac{\theta}{1+\theta}$ becomes zero. Then, any share of income, α, consumers spend on the dirty variants, will be sufficiently large to fulfill Proposition 3. In such a situation, the subsidy is the welfare-superior instrument for moderate green targets. What brings about this result? Within the model, when θ is close to zero, only a comparison of the number of firms $n_{\bar{t}}$, $\hat{n}_{\bar{t}}$, $n_{\bar{s}}$ and $\hat{n}_{\bar{s}}$ matters, because this is what determines variety. Now, the tax instrument has the disadvantage that – even though revenues are redistributed – it results in a severe reduction in the number of dirty variants, compensated for by only a slight increase in the number of green variants. In contrast, a subsidy policy results in only a moderate (and equal) reduction in the number of variants in both sectors, driven only by the lump-sum tax requirement.

Similarly consider the case of θ close to 1. Now, there is little love of variety, products are close substitutes and quantities matter. In this case, if $\alpha < \frac{1}{2}$, we are in Proposition 2 (taxes are always welfare superior) and if $\alpha > \frac{1}{2}$, Proposition 3 applies. The intuition is as follows: when consumption of dirty products is relatively unimportant ($\alpha < \frac{1}{2}$), the tax instrument is always preferred, since it shrinks the dirty sector relatively effectively, i.e. the number of dirty variants/firms decreases and prices increase. And it allows consumers to spend the redistributed revenue on green products instead. In contrast, if consumer preferences are such that dirty output is relatively important ($\alpha > \frac{1}{2}$), then the subsidy is preferable for moderate policy targets (Proposition 3), because it leaves prices and quantities of the dirty variants unaffected and leads to an increase in quantities of the green products. Variety in both sectors decreases, but due to θ being close to 1, this hardly affects welfare.

Policy Implications

Before we highlight some of the policy implications of these results, recall once more the limitations of the model. In our setting major real world phenomena are ignored, including for example the possibility of a second industry which may be superior in terms of environmental quality compared to the so-called green sector, say public transport compared to cars. Also, second-best effects from/on other taxes or subsides are ignored. Furthermore, the import and export of product variants and international spill-overs of environmental effects have not been dealt with. Thus, our findings are a first step in analysing environmental policy that targets the ratio of dirty to green products, and as such capture some developments observable in the real world.

Our results show that welfare under a green policy target depends on the choice of instruments, on the strictness of the policy target, and on consumers' preferences. Preferences are reflected in the substitution elasticities between dirty and green varieties and in the intra-sectoral substitution elasticity, i.e. consumers' love of variety.

The model, on the one hand, offers an explanation for current policy approaches which target green quotas for specific sectors. One of our results is that policy-makers should choose subsidies for green variants in cases where consumers prefer polluting products, have a high love of variety and where the target is not strict. All these factors can be observed in the Californian ZEV policy (CARB, 2002) and, as a matter of fact, subsidies are the actual tool chosen by Californian policy-makers. This is in contrast to standard economic reasoning, which would typically favor the direct policy tool, i.e. tax the item you want less of. Put differently, our model shows that subsidies, which in political economy settings – or in fact the debate surrounding the ZEV policy – could have been regarded as vote-buying tools, turn out to be justified from a consumer utility point of view.

Furthermore, programmes to foster electric power generation from renewable sources in Europe also rely on subsidies, e.g. the price supports of the German Renewable Energies Act, in order to achieve a green quota target. Markets for electricity, however, are rather oligopolistic and their analysis would therefore need a different competitive outset.

On the other hand, we can also state policy implications for other scenarios. If, for example, policy-makers want to tighten their quota targets over time, but the inherent bias towards the dirty varieties in consumers' utility does not change, then a very strict policy target is best – in terms of welfare – obtained by taxing the dirty variants. Another possible scenario is a change in consumer preferences from green to dirty, as is e.g. revealed in Germany for reusable beverage containers.[10] Then a high green policy target can only

[10] According to the Federal Environmental Ministry (BMU), the actual quota of reusable out of total beverage containers declined from 71.69% in 1991 to 63.81% in 2001. See Federal Environmental Ministry (2002).

be sustained in a welfare optimal manner by adjusting policy instruments over time and in parallel to consumers behavior, starting with taxing the dirty variants and then switching to a subsidy for the green products.

4 Conclusions

This paper compares subsidies and taxes as instruments to achieve a green quota target. Such quotas are frequently designed as the production or consumption ratio between environmentally friendly and polluting products within one industry. We examine such policy in a monopolistic competition setting, where we assume that the green quota target is set exogenously by policy-makers. We find that welfare depends on the choice of policy instruments, on the strictness of the policy target, and on consumers' preferences. If the green quota is very strict, meaning that dirty variants should be nearly banned from the market, then a tax is the welfare-dominant tool, regardless of substitution elasticities in consumers' utility. For a wide range of moderate policy targets, however, a subsidy will be superior as long as consumers prefer dirty over green variants. A tax is only superior for achieving a moderate quota if the initial consumption of dirty goods is low.

These results help interpret some of the current environmental policy measures and their implementation, e.g. the Californian Zero Emission Bill for cars or the European Action Plan for Renewable Energy Sources. It also gives some valuable hints for the taxes-versus-subsidies choice, if product differentiation, entry of firms and love of variety determine market equilibria. Certainly there are also other policy tools applicable for achieving green quotas, e.g. voluntary agreements or price supports, and moreover, other strategic choices are available to firms. We leave the investigation of these issues to future research.

A Appendix[11]

A.1 Proof of Proposition 1

Proof. $\lim_{\gamma\to 0} U_{\bar{t}} > \lim_{\gamma\to 0} U_{\bar{s}}$.
Dividing the utility levels under a tax and subsidy given in (19) and (20) by the common factor $\left(\left(\frac{L(1-\theta)}{f}\left(\frac{\theta f}{L(1-\theta)\beta}\right)^{\theta}\right)^{1-\alpha}\left(\frac{\alpha L\gamma(1-\theta)}{f}\left(\frac{\theta f}{L(1-\theta)\beta}\right)^{\theta}\right)^{\alpha}\right)$ yields the transformations $v_{\bar{t}}$ and $v_{\bar{s}}$ respectively.

$$v_{\bar{t}} = (1-\alpha\gamma)^{1-\alpha} \tag{A.1}$$

$$v_{\bar{s}} = \frac{\left(\frac{1-\alpha\gamma}{\gamma-\alpha\gamma}\right)^{\theta-\alpha\theta}(\gamma-\alpha\gamma)^{1-\alpha}}{\gamma+\theta-\gamma\theta}\,. \tag{A.2}$$

For $\gamma \to 0$ one has: $\lim_{\gamma\to 0} v_{\bar{t}} = 1\,,\ \lim_{\gamma\to 0} v_{\bar{s}} = 0$.

□

A.2 Proof of Proposition 2

Proof. $\alpha < \frac{\theta}{1+\theta} \ \Rightarrow\ U_{\bar{t}} > U_{\bar{s}}\ \forall\, \gamma \in [0,1)$.
Consider the comparison of the transformations $v_{\bar{t}}$ and $v_{\bar{s}}$ given in (A.1) and (A.2). Since $v_{\bar{t}}$ and $v_{\bar{s}}$ have the same value, $(1-\alpha)^{1-\alpha}$, and slope, $-\alpha(1-\alpha)^{1-\alpha}$, for $\gamma \to 1$ the curvature of the two function for $\gamma \to 1$ is decisive for the welfare ranking. Twice differentiating (A.1) and (A.2) with respect to γ and evaluating at $\gamma = 1$ yields:

$$\left.\frac{\partial \frac{\partial v_{\bar{t}}}{\partial\gamma}}{\partial\gamma}\right|_{\gamma=1} = -\alpha^3(1-\alpha)^{-\alpha} \tag{A.3}$$

$$\left.\frac{\partial \frac{\partial v_{\bar{s}}}{\partial\gamma}}{\partial\gamma}\right|_{\gamma=1} = -\left(\alpha^3-\alpha+(1-\theta)\theta+\alpha\theta^2\right)(1-\alpha)^{-\alpha}\,. \tag{A.4}$$

Hence, $v_{\bar{t}}$ is convex in $\gamma = 1$, and in fact for the entire parameter range (see separate appendix). Equating (A.3) and (A.4) yields the critical level of $\alpha^* =$

[11] A detailed separate appendix is available from the authors upon request.

$\frac{\theta}{1+\theta}$ for which $v_{\bar{t}}$ and $v_{\bar{s}}$ have the same curvature. Values of $\alpha < \alpha^*$ imply that $\left.\frac{\partial \frac{\partial v_{\bar{s}}}{\partial \gamma}}{\partial \gamma}\right|_{\gamma=1} < \left.\frac{\partial \frac{\partial v_{\bar{t}}}{\partial \gamma}}{\partial \gamma}\right|_{\gamma=1}$ and hence $v_{\bar{s}}$ is more convex than $v_{\bar{t}}$. Accordingly $v_{\bar{s}}$ must lie below $v_{\bar{t}}$ and hence $U_{\bar{t}} > U_{\bar{s}}$.

□

A.3 Proof of Proposition 3

Proof. $\alpha > \frac{\theta}{1+\theta} \Rightarrow \exists\ \gamma^c \in (0,1)\ :\ U_{\bar{t}} > U_{\bar{s}}, \gamma \in (0,\gamma^c)\,;\ U_{\bar{t}} = U_{\bar{s}}, \gamma = \gamma^c\,;\ U_{\bar{t}} < U_{\bar{s}}, \gamma \in (\gamma^c, 1)$.
Consider the comparison of the transformations $v_{\bar{t}}$ and $v_{\bar{s}}$ given in (A.1) and (A.2). From Appendix A.2 it follows that $\left.\frac{\partial \frac{\partial v_{\bar{s}}}{\partial \gamma}}{\partial \gamma}\right|_{\gamma=1} > \left.\frac{\partial \frac{\partial v_{\bar{t}}}{\partial \gamma}}{\partial \gamma}\right|_{\gamma=1}$ for values of $\alpha > \alpha^*$. Hence, $v_{\bar{t}}$ is more convex than $v_{\bar{s}}$ for $\gamma = 1$ and accordingly $v_{\bar{s}}$ must lie above $v_{\bar{t}}$ for $\gamma \rightarrow 1$. Since $\lim_{\gamma\rightarrow 0} v_{\bar{t}} > \lim_{\gamma \rightarrow 0} v_{\bar{s}}$ (Appendix A.1) the two functions must cross at some $\gamma^c \in (0,1)$. Accordingly, $v_{\bar{s}} > v_{\bar{t}}$, implying $U_{\bar{s}} > U_{\bar{t}}$, for $\gamma \in (\gamma^c, 1)$ and $v_{\bar{s}} < v_{\bar{t}}$, implying $U_{\bar{s}} < U_{\bar{t}}$, for $\gamma \in (0, \gamma^c)$.

□

Uniqueness of $\gamma^c \in (0,1)$ is proven in a separate appendix, available from the authors upon request.

References

Baumol, William J.; Oates, Wallace E. (1988), *The Theory of Environmental Policy*, 2nd Edition, Cambridge University Press, New York.

Buchanan, J.M. (1969), External Diseconomies, Corrective Taxes and Market Structure, *American Economic Review*, Vol 59, pp. 174-177.

Carraro, C.; Katsoulacos,Y.; Xepapadeas, A. (eds.)(1996), *Environmental Policy and Market Structure*, Kluwer, Dordrecht.

CARB – California Air Resources Board (2002), Zero Emission Vehicle Incentive Programs, http://www.arb.ca.gov

CARB – California Air Resources Board (1998), Market-Based Approach Zero Emission Vehicle Program Working for California, News Release No. 98–47, California Environmental Protection Agency.

Conrad, Klaus; Wang, Jianmin (1993), The effect of emission taxes and abatement subsidies on market structure, *International Journal of Industrial Organization*, Vol. 11(4), pp. 499-518.

Delipalla, Sofia; Keen, Michael (1992), The Comparison between Ad Valorem and Specific Taxation under Imperfect Competition, *Journal of Public Economics*, Vol.49, pp. 351-367.

Dixit, Avinash K.; Stiglitz, Joseph E. (1977), Monopolistic Competition and Optimum Product Diversity, *American Economic Review*, Vol. 67(3), pp. 297–308.

European Commission (1997), *Energy for the Future: Renewable Sources of Energy*, White Paper for a Community Strategy and Action Plan, COM(97)599 final.

Federal Environmental Ministry (BMU) (2002), Das Dosenpfand kommt zum 1. Januar 2003, Press Release No. 169/02.

Haupt, Alexander (2000), Environmental Product Standards, International Trade and Monopolistic Competition, *International Tax and Public Finance*, Vol. 7(4/5),pp. 585–608.

Heijdra, Ben; van der Ploeg, Frederick (1995), Fiscal and environmental policy under monopolistic competition, *De Economist*, Vol. 143 (2), pp. 217-248.

Kazimi, Camilla (1997), Valuing Alternative-Fuel Vehicles in Southern California, *American Economic Revue*, Vol. 87(2), pp. 265–271.

Pflüger, Michael (2001), Ecological Dumping under Monopolistic Competition, *Scandinavian Journal of Economics*, Vol. 103 (4), pp. 689–706.

Schulze, Günther G.; Ursprung, Heinrich W. (1998), Environmental Policy in an Integrated World Economy, *Nota di Lavoro Fondazione ENI Enrico Mattei*, No. 28.98, Milano.

Ulph, Alastair M. (1999), *Trade and the environment: selected essays of Alistair M. Ulph*, New horizons in environmental economics, Edward Elgar, Cheltenham.

Verpackungsverordnung (1998), Verordnung über die Vermeidung und Verwertung von Verpackungsabfällen, *Bundesgesetzblatt BGBl I 1998, 2379*, 21. August 1998.

Vetter, Henrik (2001), Environmental Taxes in Monopolistic Competition, *University of Aarhus Working Paper*, No. 2001–13.