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Abstract

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1 Introduction

Public goods are usually provided either by voluntary contributions, government interventions or both. There are several ways governments can increase the supply of public goods. They can for example supply some quantity directly or incentivise private provision by matching or tax break schemes. Each approach can interact with private provision. Prominent examples are the crowding out of private contributions by government subsidies (Warr 1982, Bergstrom et al. 1986) and the importance of the design of schemes intended to stimulate private contributions (Eckel and Grossman 2003).

Models of 'warm glow' giving (Andreoni 1989, 1990) or moral motivation (Brekke et al. 2003) allow to bridge the gap between theoretical predictions and empirical observations, namely that crowding-out is usually incomplete and that private provisions tend to be substantially larger than predicted by models of pure altruism, regardless of group size.[1] This is achieved by taking into account that people might not only care about the aggregate level of provision but also about their individual contribution to the public good. This effectively converts a pure public good into an impure one.[2] Intrinsic motivation to contribute to the public good has been used as an alternative label of warm glow.

This paper is relevant for both types of altruism but the effects described are larger for intrinsically motivated agents. We investigate how a particular form of government intervention - the introduction of a cap-and-trade scheme - affects private provision of a public good like the reduction of greenhouse gas (GHG) emissions or the reduction of overfishing that are mainly affected by negative contributions. Both examples have in common that they involve large group sizes (in terms of consumers, billions in the former and often millions in the latter), that there is some evidence of intrinsic motivation and that they are subject to cap-and-trade type regulation at least in parts of the world. The most prominent cap-and-trade scheme is the EU Emission Trading System (EU ETS) that covers almost half of all GHG emissions in participating countries. Australia will convert its recently introduced emissions tax into a cap-and-trade scheme in 2015 and other governments, including those

[1]Andreoni (1988) shows that in a model of pure altruism private contributions converge to zero in very large groups.

[2]For models of private provision of impure public goods see e.g. Cornes and Sandler (1984a, 1994).

of the U.S. and California, consider introducing one or have done so in the recent past. Total allowable catches (TAC) and individual transferable quota (ITQ) type regulations are cap-and-trade schemes applied to fisheries in order to reduce over-fishing and are employed in Australia, Canada, Iceland, New Zealand, the U.S. and other countries.

Cap-and-trade schemes have an innate feature that is of particular relevance in the context of private provision of public goods. The government sets a binding upper bound on negative contributions to the public good, allocates them in the form of tradable permits or quotas and allows trading. This mechanism at the very heart of any cap-and-trade scheme effectively converts a public good or externality problem into one of cost minimisation. The immediate implication of cap-and-trade is therefore that any change in emissions by one regulated source is perfectly offset by oneor more other regulated sources. The Nash conjecture that contributions by all other parties are given is no longer tenable.[3] The very institution of cap-and-trade makes the aggregate cap on say GHG emissions of regulated sources exogenous, but renders the response by other parties participating in the scheme endogenous and perfectly predictable in the aggregate. This holds as long as the aggregate cap is indeed binding.

Institutionalised offsetting under a cap-and-trade scheme renders efforts to privately improve the provision of the public good futile if these contributions take place within the scheme. To illustrate this point consider a trip within Europe. The decission to fly or not no longer has any substantial impact on total GHG emissions because emissions from aviation within the EU are included in the EU ETS. Any additional emissions caused have to be reduced elsewhere and vice versa.

A cap-and-trade scheme with full coverage would therefore make private contributions to the public good via consumption or life-style choices (green consumerism) impossible. However, none of the real world incarnations of cap-and-trade are anywhere near full coverage. The EU ETS for example focuses on aviation and big stationary sources such as electricity production and energy intensive industries. All other sectors including road transport, agriculture and all with a low energy intensity are not covered. The latter make up more than

[3]For a discussion of non-Nash conjectures in the early literature on private provision of public goods see Cornes and Sandler (1984b) and Sugden (1985).

half of GHG emissions in participating countries.

Incomplete coverage requires that intrinsically motivated citizens are aware of the offsetting effect and which emissions are covered by the cap-and-trade scheme and which are not. Otherwise they will misallocate their efforts to contribute to the public good. Consider again the example of aviation. A green consumer might opt to travel by bus instead of by plane in order to reduce the GHG emissions of her trip. This has the desired effect if that trip takes place in the US. However, in the EU, taking the bus is likely to increase total GHG emissions compared to the flight. The simple reason being that any additional emissions caused by the flight are fully offset (potentially even twice if the individual chooses to buy additional offsets offered by most airlines when buying tickets) while those of a bus journey are not.

Many recommendations by government agencies[4] and NGOs[5] on how to reduce one's carbon footprint are inappropriate in the EU. Reducing the number of flights, installing energy efficient light bulbs and many other recommended actions have no or a much lower impact on total GHG emissions and depending on the alternatives chosen might actually have the exact opposite effect. The same holds for carbon footprint labels like those used by the UK Carbon Trust or calculated based on Publicly Available Specification (PAS) 2050.[6] They report life-cycle emissions of products and do not differentiate between emissions covered by the EU ETS and those that are not. Consumption decisions influenced by those labels are very likely to be misguided.[7] Consumers caring about either total GHG emissions or their

[4]Examples are the 'a world you like' campaign by the EU ($http : //world - you - like.europa.eu/en/explore/$, accessed 15.01.2013) and the 'What can I do?' website of the UK Department of Energy & Climate Change ($http : //www.decc.gov.uk/en/content/cms/tackling/saving_{e}nergy/individual/individual.aspx$, accessed 15.01.2013)

[5]Examples include advice by the Carbon Trust's Empower Savings Calculator ($http : //www.carbontrust.com/resources/tools/empower - savings - calculator$, accessed 15.01.2013), the National Energy Foundation ($http : //www.nef.org.uk/actonCO2/ecotravelling.asp$, accessed 15.01.2013) and Climate Care ($https : //www.climatecare.org/climate/low - carbon - living/$, accessed 15.01.2013)

[6]PAS 2050 can be downloaded at $http : //shop.bsigroup.com/en/forms/PASs/PAS - 2050$ (accessed 15.01.2013).

[7]Perino et al. (2013) provide evidence from a field experiment that a significant share of UK grocery shoppers take the UK Carbon Trusts carbon footprint label into account.

own contribution to total GHG emissions should only take emissions not covered by the EU ETS into account. There are still very good reasons to buy energy efficient light bulbs. But reducing GHG emissions is not one of them. This has absolutely nothing to do with any of its technical characteristics but is exclusively due to the regulatory framework. Also note that this effect does not require any preferences to change and that it is neither a response to the public provision itself nor to the fact that emissions are priced. It merely assumes that consumers understand how a cap-and-trade scheme works, i.e. that there is a cap on regulated emissions that is unaffected by their shopping and lifestyle choices.[8]

This paper studies the crowding-out effect of cap-and-trade schemes on private contributions in a world were regulation is second-best due to incomplete coverage and potentially a lack of stringency. Section 3 makes comparisons with taxes of the same coverage and stringency. There is no offsetting under a tax scheme and hence no crowding out. The level of private contributions and their distribution over sectors in the economy differs between instruments. Heyes and Kapur (2011) have recently compared price and quantity based regulation with altruistic agents but they focus on uniform emission standards that are not transferable between individuals. They therefore do not capture the crowding-out effect caused by institutionalised offsetting which is at the heart of this paper.[9] Section 4 shows that the failure to understand how a cap-and-trade scheme works or equivalently basing decisions on both regulated and unregulated emissions as recommended by government agencies, NGOs and established carbon footprint labels unambiguously increases total emissions.

2 Green consumerism and second-best regulation

There is a continuum of consumers with mass one who derive utility from the consumption of two private goods x and y and experience disutility from pollution. Emissions are caused in the production or consumption of both private goods where $\alpha \in [0, 1]$ is the emission

[8]The cap is of course not truly exogenous as consumers can also influence the political process as citizens. This is not explicitly modelled here in order to focus on the impact of cap-and-trade schemes on private provision of the public good and green consumerism.

[9]There is an extensive literature comparing price and quantity based regulation including e.g Weitzman (1974), Montero (2002), Requate and Unold (2003), Krysiak (2008).

intensity of good x and y causes one unit of emissions per unit of output. Hence, x is the cleaner good.

The utility function is assumed to be

$$u^i = v(x^i, y^i) - m^i l^i - d^i E^{ex}, \tag{1}$$

where v is the utility derived from consumption (with $v(0,0) = 0$, $v_k > 0$, $v_k \leq 0$ with $k = \{x^i, y^i\}$ and $v_{xy} \geq 0$), $l^i = \alpha x^i + y^i$ are the emissions controlled by individual i and E^{ex} is the level of emissions exogenously given. Total emissions are therefore $E = E^{ex} + l^i$. The marginal damage from general emissions is $d^i > 0$. Emissions under the direct control of individual i cause a disutility of $m^i \geq d^i$ per unit. Both d^i and m^i are exogenously given. If $m^i = d^i$ the consumer is a 'pure' altruist in that she only cares about the absolute level of the public good.[10] However, if $m^i > d^i$ there is an extra warm glow associated with emissions controlled by individual i.[11] One could also call this intrinsic motivation to contribute to the common good, or in the context of climate change, green consumerism. All of the results derived below hold regardless of whether there is a warm glow. However, the magnitude of any effect is increasing in m and hence the results are especially relevant for intrinsically motivated consumers.

The share β of consumers internalises at least part of the externality associated with pollution ($m^{green} = m > 0$) while the remaining share $1 - \beta$ does not take the externality into account ($m^{white} = 0$). For simplicity consumers are assumed to be identical in all other aspects.

The assumption that both m and d are constants seems warranted with the climate change application in mind. While on a larger scale damages from emissions are most certainly increasing, this is not the case for the scales relevant for an individual consumer's decision making. In 2011 annual per capita emissions of CO_2 were 7.5t in the EU, 7.2t in China and 17.3t in the US, which is negligible compared to global annual emissions of 34 billion tons in the same year.[12] This again is dwarfed by the stock of CO_2 in the atmosphere (which is the part that matters for global warming) estimated at 730 billion tons, which of

[10] See Bergstrom et al. (1986), Warr (1983), Andreoni (1988).

[11] Andreoni (1989, 1990).

[12] Olivier et al. (2012).

course is only one part of the much bigger global carbon cycle.

In the absence of any regulatory intervention to restrict pollution, the budget constraint is given by

$$x^i + py^i = w, \tag{2}$$

where w is the consumer's income and p the (relative) price of good y.. In what follows the focus is on cases where the budget constraint is binding for all consumers and at all times. This cannot be taken for granted as green consumers naturally restrict consumption by internalising at least part of the pollution externality and at least if $\alpha > 0$ all consumption causes pollution. The condition for consumption to be constrained by budget is $v_x(x^{green*}, y^{green*}) - \alpha m > 0$ where x^{green*} and y^{green*} are the quantities consumed by green consumers in equilibrium. The larger m, the less likely that the budget constraint is binding.

If there is no regulatory intervention to restrict emissions, the provision of the public good relies entirely on private provision by green consumers. Demand for goods x and y by consumer of type $i = \{white, green\}$ is given by maximising (1) subject to (2) and $l^i = \alpha x^i + y^i$. The familiar conditions determining $x^{i,un}$ and $y^{i,un}$ are

$$p = \frac{v_y - m^i}{v_x - \alpha m^i}, \tag{3}$$

$$w = x^i + py^i, \qquad i = \{white, green\}. \tag{4}$$

Note that $m^{white} = 0$.

2.1 Cap-and-trade

While cap-and-trade schemes are in theory able to fully solve the externality problem, all real world examples both implemented and proposed are clearly second-best policies. They tend to focus on large, stationary sources but exclude emissions from e.g. road transport and agriculture. The EU Emission Trading System (EU ETS) is the most prominent example covering about half of GHG emissions in participating countries. The key sectors included in the trading scheme are large scale electricity and heat generation, energy intensive industries like aluminium and steel production and inner-European flights. Even if the emission cap would be second-best optimal for regulated sectors, private provision of GHG abatement still has substantial scope to improve welfare in unregulated sectors. Moreover, at least in the past the EU ETS has been plagued by over-provision of allowances, even leading to an effective collapse of the scheme toward the end of Phase I (2005 - 2007). One might therefore conclude that even in regulated sectors a bit of green consumerism might do good.

Green consumerism within regulated sectors is futile. To understand how a cap-and-trade scheme like the EU ETS affects the private provision of GHG abatement it is important to highlight a basic - by design - feature of these schemes: They impose a binding upper bound of emissions by regulated sources. This has an important implication, i.e. that any abatement conducted in regulated sectors have no (direct) impact on aggregate emissions. Cap-and-trade schemes are all about allocating a given amount of emissions such as to minimise abatement costs. The environmental impact is decided ex-ante by the stringency of the cap and all decisions at the micro-level, whether by firms or consumers, are irrelevant for total emissions from regulated sources. This relies on the assumption that the cap is indeed binding.

Consider flying. It emits more GHG emissions per kilometre than any other common form of transport and it is therefore a tenet among environmental NGOs and government agencies alike that flying less is an important step to reduce GHG emissions. At least within Europe, this is no longer true. Whether or not I fly from London to Rome and back has effectively no impact on aggregate GHG emissions from regulated sectors which include aviation within participating countries. Staying at home might even increase overall emissions if the trip means that I don't use my car for a week and don't need (gas or oil powered) central heating. The same holds if I take the bus instead. Since emissions from road transport are not covered by the EU ETS, the bus trip actually causes emissions to rise compared to a flight.

Next we formalise these features of a second-best cap-and-trade scheme into our model. Partial coverage is captured by assuming that only emissions associated with the production of good y are captured by the cap-and-trade scheme. Emissions from production of x are not included. Remember that x is the cleaner good and thereby this is in line with the fact that the EU ETS only covers emission intensive sectors.

The aggregate cap on emissions C is assumed to be exogenous. Any emissions arising as part of the cap-and-trade scheme are hence summarised in the E^{ex}. The emissions controlled by an individual are therefore

$$l^{c\&t} = \alpha x^{green}. \tag{5}$$

If the cap is binding, emission allowances are traded at a positive price. The budget constraint becomes

$$x^i + (p + \gamma)y^i = w, \qquad i = \{green, white\} \tag{6}$$

where γ is the cost for purchasing allowances for one unit of emissions. The permit constraint is

$$(1 - \beta)y^{white} + \beta y^{green} \leq C, \tag{7}$$

and we restrict attention to cases where (7) is binding.

Demand for goods x and y by consumer of type $i = \{white, green\}$ is given by maximising (1) subject to (5) - (7). The familiar conditions determining $x^{i,c\&t}$ and $y^{i,c\&t}$ under cap-and-trade are

$$\begin{aligned} p + \gamma &= \frac{v_y}{v_x - \alpha m^i}, && (8) \\ w &= x^i + (p + \gamma)y^i, \qquad i = \{white, green\} && (9) \\ C &\geq (1 - \beta)y^{white} + \beta y^{green}, && (10) \end{aligned}$$

which is a system of five equations and five unkowns. Note that again $m^{white} = 0$.

2.2 Emissions taxes

A second instrument available to reduce GHG emissions is a tax charged on emissions. Australia has recently introduced a tax on carbon emissions (which will be converted into a cap-and-trade scheme in 2015), Germany taxes petrol and electricity based on associated GHG emissions and the UK is about to impose a tax (binding price floor) on GHG in electricity production. Again, coverage of these schemes is limited and the appropriateness of their stringency debatable. By and large they suffer from the same imperfections as cap-and-trade schemes as they can only cover emissions that can be easily measured and verified. However, in contrast to cap-and-trade schemes, taxes do not pre-determine aggregate emissions in regulated sectors but set a pre-determined price for a unit of emissions instead. Hence, green consumerism affects aggregate emissions in the standard way so that $l^{tax} = \alpha x^{green} + y^{green}$. The consumer's budget constraint is $x^i + (p+\gamma) y^i = w$, i.e. the same as with a cap-and-trade scheme, where γ is now the tax rate.

Demand for goods x and y by consumer of type $i = \{white, green\}$ under taxes is given by the following conditions

$$
\begin{aligned}
p + \gamma &= \frac{v_y - m^i}{v_x - \alpha m^i}, && (11)\\
w &= x^i + (p+\gamma) y^i, \qquad i = \{white, green\}. && (12)
\end{aligned}
$$

Note that $m^{white} = 0$. There are two differences between the conditions under taxes and permits. The first is that in (11) but not in (8) green consumerism is relevant for good y. The second difference is the permit constraint (10) which is only relevant in the cap-and-trade scheme, as the price of emissions is set exogenously under an emissions tax. In the tax case consumption choices by individual consumers are independent of each other as they are only linked through prices which here are treated as exogenous. In the cap-and-trade scheme, however, the permit constraint reflects the offsetting aspect of this regulatory approach directly linking choices by individuals and rendering the Nash conjecture untenable.

3 Comparison of instruments

This section compares consumption and emission levels under cap-and-trade to those under an emissions tax. For that purpose the emissions tax is set equal to the equilibrium price of permits. This makes sure that consumers face the same set of prices and that any difference can be attributed to the impact of the cap-and-trade scheme on private provision of the public good by green consumers. White consumers' consumption choices are the same under both instruments as they only care about relative prices and by assumption they are held constant. The difference in consumption levels for green consumers is driven by them caring about the impact of their consumption choices on total emissions and the fact that an individual's emissions associated with good y are fully offset under a cap-and-trade scheme but not under an emissions tax. This is reflected by the absence of m in the numerator of (8) while m appears in the numerator of (11). Since $v_{xx} < 0$, $v_{yy} < 0$ and $m > 0$ it follows that

Proposition 1 *(Demand by green consumers) Green consumers consume less of the relatively clean good ($x^{green,c\&t}(\gamma) < x^{green,tax}(\gamma)$) and more of the relatively dirty good ($y^{green,c\&t}(\gamma) > y^{green,tax}(\gamma)$) under a cap-and-trade scheme than under an emissions tax. This holds for all γ and hence for all levels of the aggregate cap on emissions C.*

The proof is given in the appendix. Figure 1 illustrates Proposition 1. Consumption by green consumers under a cap-and-trade scheme is given by the black line. Consumption by green consumers under an emissions tax are represented by the grey line.

Note that Figure 1 is drawn in a way that the equilibrium permit price approaches zero at the right end of each panel and is strictly positive and strictly increasing as one moves towards the left. Not surprisingly consumption under taxes converges to the unregulated level (shown as a horizontal grey dashed line) when the price of emissions approaches zero. This is not the case under a cap-and-trade scheme. While the budget constraint converges towards the one in the unregulated case, an individual's emissions in sector y are still fully offset and hence green consumers ignore them in their consumption choices. As derived above demand for the dirty good by green consumers y is higher under cap-and-trade than under an equivalent emissions tax. This implies that

Proposition 2 *(Permit price with cap at unregulated level) The permit price is strictly positive when the cap imposed on the dirty sector is equal to unregulated emissions in that sector.*

The proof is given in the appendix but the intuition for this result is straightforward. Because private provision of reduction of greenhouse gas emissions is crowded-out by a cap-and-trade scheme in the regulated sector, the demand for dirty goods increases when such a scheme is introduced (Proposition 1). With an emission cap at the unregulated level of emissions (represented by 1.0 on the horizontal axis in Figure 1), the permit constraint is binding because demand for dirty goods y with a cap-and-trade scheme is higher than without. Permits are hence a scarce resource with a strictly positive value. The permit price drops to zero only when the cap on emissions exceeds the unregulated level significantly.

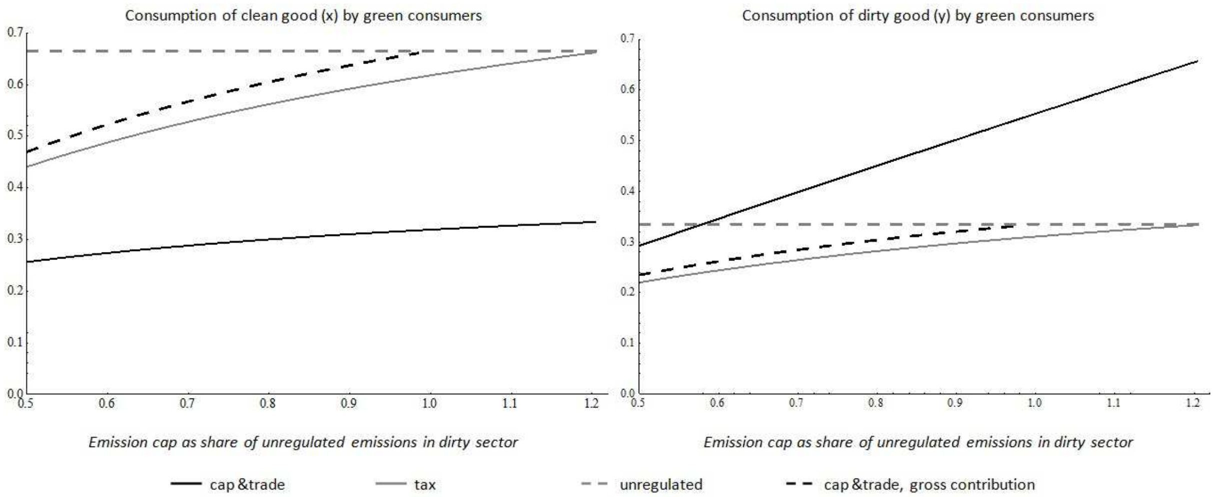

Figure 1: Consumption of goods x (left panel) and y (right panel) by green consumers as a function of the stringency of the cap-and-trade scheme.

The crowding out of private contributions to the public good affects the aggregate level of emissions (see Figure 2). To highlight this we focus again on the case where the price of emissions converges to zero. All equilibrium conditions and hence consumption choices and emissions under a tax converge to that without regulation. Under a cap-and-trade scheme, the budget constraint again converges to the unregulated case, but green (not white) consumers choose a different point (one with a higher y and a lower x) on that line as they ignore emissions associated with y (see Proposition 1). Such a movement along a given budget line implies that

Proposition 3 *(Total emissions) Total emissions are higher under a cap-and-trade scheme than under an emission tax if the price of emissions is close to zero and if the dirty good is sufficiently cheap* ($p < \frac{1}{\alpha} \geq 1$).

The proof is given in the appendix.

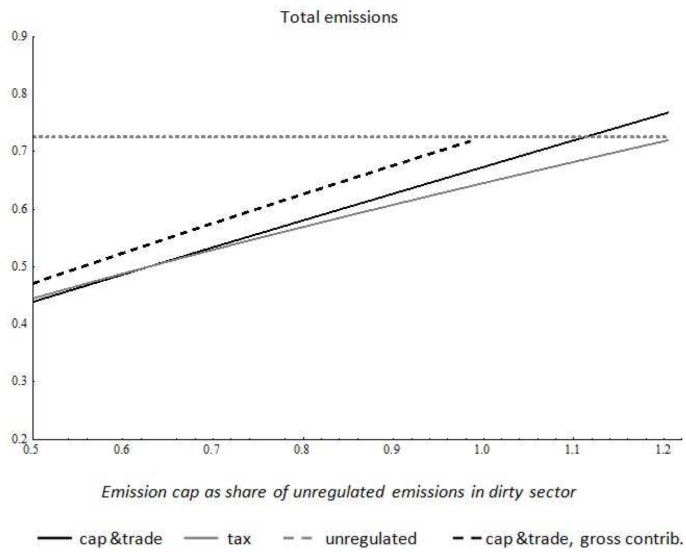

Figure 2: Total emissions as a function of the stringency of the cap-and-trade scheme.

4 Consumers caring about gross contribution

Now let us briefly consider what happens if green consumers base decisions on their gross rather than their net contribution in a cap-and-trade scheme. Gross contributions would be all emissions physically associated with consumption (i.e. $l = \alpha x + y$) ignoring any offsets occuring within a cap-and-trade scheme. This is the case if they care about their net contribution but are unaware - as is arguably the case at the moment - that marginal emissions in a cap-and-trade scheme such as the EU ETS are completely offset. Alternatively, consumers might fully understand the regulatory framework, but their preferences are defined over full carbon footprints of their consumption choices rather than the actual change in total GHG emissions. In both cases they effectively follow advise by governments and NGOs on how to reduce carbon footprints and in their shopping choices consider carbon footprint labels based on life-cycle GHG emissions (such as those based on PAS 2050 and used by the UK supermarket chain Tesco and Coca-Cola).

In this case (8) needs to be replaced by (11). This has a number of implications. The first is that the permit price is zero at a cap equal to the unregulated level of emissions. The black dashed lines in Figure 1 both stop at 1.0 and quantities consumed coincide with the unregulated levels as at this point the cap-and-trade scheme has neither an impact on how consumers trade-off goods nor on the budget constraint. It is also straightforward to show that consumption by green consumers of the dirtier (cleaner) good is decreasing (increasing) in the m in the numerator of (11) while holding the m in the denominator constant. Hence, green consumers buy more of the cleaner good if they base their consumption choices on gross rather than net contributions under a cap-and-trade scheme. By doing this they increase their unregulated emissions, and decrease regulated emissions - inducing white consumers to buy more of the dirty good as the price of emissions is lower.

Proposition 4 *(Emissions when consumers consider gross contributions) If green consumers take all emissions instead of only those outside a cap-and-trade scheme into account total emissions increase compared to the case where they only consider unregulated emissions. This only ceases to hold if the unregulated sector x is perfectly clean ($\alpha = 0$) and coverage of the cap-and-trade scheme therefore complete.*

The proof is given in the appendix. Figure 2 illustrates the increase in total emissions.

Cap-and-trade schemes crowd-out private provision of GHG control when green consumers realise that the emission their consumption causes in regulated sectors are fully offset. This results in higher aggregate emissions than under an equivalent tax if the dirtier good is sufficiently cheap and the cap on dirty sector emissions sufficiently lenient. However, if green consumers are oblivious to or disregard the offsetting effects of the cap-and-trade scheme this makes matters even worse. Emissions in this case are always higher than under full crowding-out because green consumers misallocate their restraint between sectors and cause too many unregulated emissions which in contrast to regulated emissions are not offset.

5 Conclusions

Cap-and-trade schemes fundamentally change what is a reasonable conjecture about the response by others to a change in an individual's private contribution to a public good. By imposing a binding upper bound on (negative) contributions to the public good and allowing contributors to trade the rights for these, it is no longer consistent to believe that one's own decisions will not affect contributions by others. Cap-and-trade schemes institutionalise perfect offsetting of marginal contributions. Someone caring either about the total level of the public good (pure altruism) or her individual contribution to the total level (impure altruism) should therefore disregard any contribution made within a cap-and-trade scheme. A cap-and-trade scheme fully crowds out voluntary contributions within the system.

The EU Emission Trading System (EU ETS) is the most prominent - but not the only - example of a cap-and-trade scheme. Within this system marginal GHG emissions, i.e. those caused by electricity production, energy intensive industries and inner-European aviation, are fully offset. Carbon footprint labels such as those calculated based on PAS 2050 that include both regulated and unregulated emissions are misleading. Green consumers that base their consumption decisions on these labels unwittingly emit more than if they would only consider emissions not covered by the EU ETS. The same holds for following advise by both governments and environmental NGOs on how to reduce carbon footprints as they so far do not differentiate between emissions occurring within or outside the EU ETS.

With a cap-and-trade scheme in place, green consumers are left with three options to reduce total GHG emissions. First, they can reduce emissions not captured by the EU ETS, e.g. by driving less or by eating less red meat. Second, they can influence the political process via voting and lobbying to reduce the cap on regulated emissions. Third, they can buy EU ETS allowances (or other types of offsets) and retire them and thereby have a direct impact on total GHG emissions.[13]

But it is not only green consumers that are vulnerable to failing to understand the full implications of a cap-and-trade scheme. The European Commission - the same institution that governs the EU ETS - claims that its recent ban of incandescent light bulbs "will reduce emissions of carbon dioxide by 15 million tons each year."[14] This is wrong. Any emissions saved in electricity production will be emitted by another sector participating in the EU ETS - or the electricity will be used to do other things.

The crowding out effect is also not limited to the particular way private contributions are modelled in this paper. Using alternative specifications like reciprocity (Sugden 1984) would have very similar effects. Reciprocity is impossible within a cap-and-trade system, unless voluntary sacrifices are so large as to render the cap non-binding. But this is also true

[13]For models of demand for offsets in the presence of impure public goods see Kotchen (2005, 2006, 2009).

[14]$http://ec.europa.eu/news/energy/090901_en.htm$, accessed on 15.01.2013.

under the specification used in this paper.

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A Appendix

A.1 Proof of Proposition 1

The equilibrium conditions for the emissions tax (11) and (12) consist of two 2x2 systems of equations. One for white and one for green consumers with no interaction between them, because all prices are fixed. To allow comparison between the two regulatory schemes the price for emissions is assumed to be the equilibrium permit price under the cap-and-trade scheme. Note that the conditions for white consumers is the same as those under a cap-and-trade scheme. Hence the equilibrium quantities are the same under a tax and cap-and-trade if all prices are the same. For green consumers the budget constraint remains unaltered but the marginal rate of substitution has changed due as emissions of the dirty good were not considered under cap-and-trade but have a internalised marginal cost m under an emissions tax. The equilibrium quantities under tradable permits hence do not satisfy (11) and (12) for green consumers. Rewriting the two conditions by adding an exogenous parameter ρ in front of the m in the numerator one obtains a generalised version that contains both the cap-and-trade conditions ($\rho = 0$) and those for the emissions tax ($\rho = 1$).

$$p + \gamma = \frac{v_y - \rho m^i}{v_x - \alpha m^i}, \tag{A.1}$$

$$w = x^i + (p + \gamma)y^i, \qquad i = \{white, green\}. \tag{A.2}$$

Using the implicit function theorem and Cramer's rule it is straightforward to show that

$$\frac{\partial x^{green}}{\partial \rho} = -\frac{m(p+\gamma)}{(p+\gamma)^2 v_{xx} - 2(p+\gamma)v_{xy} + v_{yy}} > 0 \tag{A.3}$$

$$\frac{\partial y^{green}}{\partial \rho} = \frac{m}{(p+\gamma)^2 v_{xx} - 2(p+\gamma)v_{xy} + v_{yy}} < 0 \tag{A.4}$$

Hence $x^{green,c\&t}(\gamma) < x^{green,tax}(\gamma)$ and $y^{green,c\&t}(\gamma) > y^{green,tax}(\gamma)$.

A.2 Proof of Proposition 2

If the price of emissions approaches zero (from above) the equilibrium conditions under a tax (11) and (12) and the unregulated case (3) and (4) converge. Hence quantities consumed and sector emissions converge as well. Using Proposition 1 shows that as the permit price converges to zero, the total quantity consumed of the dirty good and hence dirty sector emissions are always strictly higher under a cap-and-trade scheme than under a tax. The price for permits is therefore strictly positive at the unregulated level of dirty sector emissions and drops to zero only at a cap strictly above the unregulated level of dirty sector emissions.

A.3 Proof of Proposition 3

Moving along the budget constraint requires that $\frac{\partial x}{\partial y} = -(p+\gamma)$. The effect on individual emissions e are $\frac{\partial e}{\partial y} = \alpha \frac{\partial x}{\partial y} + 1 = 1 - \alpha(p+\gamma)$. With γ approaching zero this is positive if $p < \frac{1}{\alpha} \geq 1$.

A.4 Proof of Proposition 4

To assess the impact on emissions when green consumers care about gross contributions in a cap-and-trade scheme we re-write the system (8) - (10) by again adding the parameter ρ. This is different from the proof for Proposition 1 as we are looking now at the 5x5 cap-and-trade system of equations and not at the 2x2 tax one.

$$p+\gamma = \frac{v_y^g - \rho m}{v_x^g - \alpha m}, \tag{A.5}$$

$$p+\gamma = \frac{v_y^w}{v_x^w}, \tag{A.6}$$

$$w = x^g + (p+\gamma)y^g, \tag{A.7}$$

$$w = x^w + (p+\gamma)y^w, \tag{A.8}$$

$$C \geq (1-\beta)y^{white} + \beta y^{green}, \tag{A.9}$$

where $v_j^i = v_j(x^i, y^i)$ and $v_{jk}^i = v_{jk}(x^i, y^i)$. Using the implicit function theorem, Cramer's rule and the fact that emissions in the dirty sector are capped at C the effect of a change in ρ on total emissions E is

$$\begin{aligned}\frac{\partial E}{\partial \rho} &= \alpha \left[\frac{\partial x^{white}}{\partial \rho} + \frac{\partial x^{green}}{\partial \rho} \right] \\ &= \alpha m \frac{(p+\gamma)A^w C - \beta[(p+\gamma)y^g + y^w]B^w - (p+\gamma)(1-2\beta)v_x^w}{\Omega}\end{aligned} \tag{A.10}$$

where $\Omega = -(1-\beta)B^g[v_x^w - A^w y^w] + \beta(v_x^g - \alpha m)[(p+\gamma)A^w - B^w] + A^g[B^w y^g \beta + (p+\gamma)[v_x^w(1-\beta) - A^w[(1-\beta)y^w + \beta y^g]]] < 0$, $A^i = (p+\gamma)v_{xx}^i - v_{xy}^i < 0$ and $B^i = (p+\gamma)v_{xy}^i - v_{yy}^i > 0$. If $\beta \leq 0.5$ then (A.10) is strictly positive. If $\beta > 0.5$ then the last term in the nominator of (A.10) becomes positive and the sign of the entire expression potentially ambiguous. The conditions for the nominator to be strictly positive are

$$\beta > \frac{(p+\gamma)v_x^w - (p+\gamma)A^w C}{2(p+\gamma)v_x^w - [(p+\gamma)y^g + y^w]B^w} > \frac{1}{2} \tag{A.11}$$

or

$$\beta < \frac{(p+\gamma)v_x^w - (p+\gamma)A^w C}{2(p+\gamma)v_x^w - [(p+\gamma)y^g + y^w]B^w} < 0 \tag{A.12}$$

The latter is irrelevant since $\beta \geq 0$. We therefore check the sign for the extreme case when $\beta = 1$, i.e. all consumers are green. In this case the system (A.5) - (A.9) collapses to

$$p + \gamma = \frac{v_y^g - \rho m}{v_x^g - \alpha m}, \tag{A.13}$$

$$w = x^g + (p+\gamma)y^g, \tag{A.14}$$

$$C \geq y^{green}, \tag{A.15}$$

which yields $y^g = C$, $x^g = w - (p+\gamma)C$ and γ implicitly defined by $p + \gamma = \frac{v_y(w-(p+\gamma)C,C)-\rho m}{v_x(w-(p+\gamma)C,C)-\alpha m}$. Differentiating the latter w.r.t. γ and ρ yields

$$\frac{d\gamma}{d\rho} = -\frac{m}{v_{xy}C + v_x - \alpha m - C(p+\gamma)v_{xx}} < 0. \tag{A.16}$$

Hence, for $\beta = 1$ it holds that

$$\frac{\partial E}{\partial \rho} = \alpha \frac{\partial x}{\partial \rho} = \alpha \frac{\partial x}{\partial \gamma}\frac{\partial \gamma}{\partial \rho} = \alpha \frac{Cm}{v_{xy}C + v_x - \alpha m - C(p+\gamma)v_{xx}} \geq 0. \tag{A.17}$$

The expression in (A.10) is therefore always positive (strictly if $\alpha > 0$) and total emissions higher when green consumers are unaware of or ignore the offsetting induced by a cap-and-trade scheme if production of x is not perfectly clean $\alpha > 0$.