Climate campaigns, cap-and-trade and carbon leakage: Why reducing your carbon footprint can harm the climate

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Abstract

Governments and environmental NGOs campaign for carbon footprint reductions by households. Many of the behavioral changes recommended reduce demand for goods produced by sectors covered by cap-and-trade schemes. With a binding cap, greenhouse gas emissions from those sectors do not change. I show that climate campaigns create leakage effects if coverage of cap-and-trade schemes is incomplete. Campaigns targeted at sectors subject to a cap increase aggregate emissions, as do campaigns to reduce carbon footprints generally if the capped sectors are emission intensive. However, campaigns targeting sectors not covered by a cap-and-trade scheme or propagating retiring of emission allowances reduce emissions.

Keywords: Climate campaigns; carbon leakage; cap-and-trade schemes; green consumerism

JEL codes: Q54; Q58; H31

1 Introduction

Climate change seriously challenges established governance concepts. The apparent difficulty in achieving substantial and effective emission reductions, both at the national and international level, have recently led to a more serious consideration of the potential of contributions made by individuals and households as part of their consumption and life-style choices. This is supported by evidence that a substantial share of the population is intrinsically motivated to contribute to climate change mitigation and does so when given the chance. Examples are subscriptions to 'green' electricity tariffs (Kotchen & Moore, 2007; Jacobsen et al., 2012), energy savings (Allcott, 2011; Costa & Kahn, 2013), purchases of hybrid cars (Ozaki & Sevastyanova, 2011), grocery shopping (Perino et al., 2013) and a general willingness to purchase carbon offsets (Diederich & Goeschl, 2013a,b).

Researchers (Gardner & Stern, 2008; Dietz et al., 2009; Aamaas et al., 2013), governments (EPA, 2013; European Commission, 2011) and environmental NGOs (Greenpeace, 2013) advise households on how to reduce their carbon footprint by providing specific lists of actions or carbon footprint calculators. In the context of grocery shopping, carbon footprint labels provide the information necessary for consumers to take into account the climate impacts of their consumption choices (Perino et al., 2013; Vandenbergh et al., 2011). Common standards to compute life-cycle carbon footprints exist in the UK (BSI, 2011) and are currently under development internationally as ISO 14067.

While it is clear that voluntary behavioral changes alone cannot solve the climate change problem, they are widely believed to be an important part of the solution. Ostrom (2012) advocates that actions being taken at many different levels including both national and international cap-and-trade programs and changes in household behavior and consumption and Dietz et al. (2009) regards adjustments of life-styles as complements to cap-and-trade schemes. Common recommendations for individual climate actions include saving electricity and other actions affecting the demand of industries subject to cap-and-trade programs in many parts of the world. Cap-and-trade schemes for greenhouse gas (GHG) emissions are operating in the European Union (EU) in the form of the EU Emission Trading Scheme (EU ETS) and in North America as part of the Western Climate Initiative (WCI) and the Regional Greenhouse Gas Initiative (RGGI). Australia has plans to convert what currently in effect is a carbon tax into a cap-and-trade scheme in 2015 and China has started the first of a number of city-level cap-and-trade programs for carbon emissions in June 2013 to gain experience for a future national scale program (Qui, 2013).

Given the trend to extend the use of both cap-and-trade schemes and policies stimulating voluntary behavioral change, it is important to understand how these two mechanisms interact. In this paper I make a first step in this direction. Using a general equilibrium model of an economy with intrinsically motivated consumers I investigate the short-run effects on total GHG emissions of campaigns to stimulate voluntary behavioral changes in the presence of a cap-and-trade scheme with only partial coverage of GHG emissions.

The literature has so far focused on empirical tests of the effectiveness of specific policy instruments in inducing climate friendly behavior[1], on rebound effects at the individual level (Druckman et al., 2011), on carbon leakage induced by unilateral increases in policy stringency[2] and on overlapping instruments when cap-and-trade schemes have full coverage (Böhringer & Rosendahl, 2010; Fischer & Preonas, 2010; Frankhauser et al., 2010). The key contribution of this paper is to combine the analysis of overlapping instruments with a general equilibrium framework and partial coverage of the cap-and-trade regulation similar to that used by Baylis et al. (2013) and Fullerton et al. (2013). This allows to identify leakage effects that are absent from previous studies on instruments affecting industries subject to an aggregate cap on emissions. The standard result that additional interventions have no effect is replaced by a careful analysis of the leakage occurring in sectors not covered by the cap.

Climate campaigns are found to increase aggregate emissions unless specifically targeted e.g. at sectors not covered by the cap-and-trade scheme. This holds even if at the individual level, consumers that change their behavior successfully manage to reduce their personal carbon footprint. To the best of my knowledge, the paper is also the first to study climate campaigns in a general equilibrium model with pre-existing environmental regulation.

The paper is organized as follows. The modeling framework is introduced in the next section. Section 3 derives the impact on aggregate emissions of three types of climate campaigns dubbed: "Save electricity!", "Drive less!" and "Reduce your footprint!". The basic framework is extended in several ways in section 4. The last section concludes and discusses policy implications.

2 The Model

To study the impact of climate campaigns on aggregate emissions in the presence of a cap-and-trade scheme we use a simple general equilibrium model. A general equilibrium model is required because the binding cap on emissions in a key sector such as power generation implies that any change in total emissions is caused by changes in other parts of the economy. The focus is therefore on how the capped and the non-capped parts of the economy interact, i.e. whether emissions might leak from the capped sector into the sector without a binding upper bound on emissions or vice versa.

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[1]See e.g. Abrahamse et al. (2005); Allcott & Mullainathan (2010); Allcott (2011); Bolderdijk et al. (2013); Costa & Kahn (2013); Perino et al. (2013).

[2]See e.g. Babiker (2005); Burniaux & Martins (2012); Baylis et al. (2013); Eichner & Pethig (2011); Fullerton et al. (2013).

2.1 Production

The economy has two perfectly competitive sectors, each using two inputs, L and R, to produce consumption goods x ("driving") and y ("electricity"), respectively. The corresponding aggregate output quantities are denoted X and Y. There is a representative firm in each sector that has access to a sector specific constant returns to scale technology $f_j(L_j, R_j)$, where $j \in \{x, y\}$, satisfying

- $\partial f_j / \partial L_j > 0$ and $\partial f_j / \partial R > 0$ $\forall L_j, R_j \in \mathbb{R}_+$ (positive marginal product)
- $\partial^2 f_j / \partial L_j^2 < 0$ and $\partial^2 f_j / \partial R^2 < 0$ $\forall L_j, R_j \in \mathbb{R}_+$ (decreasing marginal product)
- $\partial^2 f_j / \partial L_j \partial R_j > 0$ $\forall L_j, R_j \in \mathbb{R}_+$ (substitutability)
- $\left(\partial^2 f_j / (\partial L_j \partial R_j)\right)^2 - \partial^2 f_j / \partial L_j^2 \cdot \partial^2 f_j / \partial R_j^2 < 0$

The use of one unit of input R (fossil fuel) causes one unit of emissions, whereas there are no emissions associated with the use of input L (labor or capital). Thus, we call R the «dirty» input and L the «clean» input.

World markets provide a perfectly elastic supply of fossil fuels at an exogenous price z. Section 4 relaxes this assumption and shows that the results also hold if fossil fuels are provided at increasing marginal costs. Labor is in fixed supply and traded at a price of w. Again, this assumption is relaxed in section 4. Consumption goods x and y are traded at prices p_x and p_y, respectively.

Sector Y is regulated by a tradable permit scheme with aggregate emissions limit C, which is assumed to be binding ($R_Y = C$) such that permits are traded at a strictly positive price $\gamma > 0$.

The profit functions of representative firms are therefore

$$\pi_x = p_x X - wL_x - zR_x, \tag{1}$$

$$\pi_y = p_y Y - wL_y - (z + \gamma)C. \tag{2}$$

2.2 Consumption

There is a continuum $I = [0, 1]$ of consumers. Each consumer i experiences a consumption based utility $v_i(x_i, y_i)$, where x_i and y_i are the quantities of good x and y consumed, respectively. Consumption utility v_i has the following properties: it is non-satiated in both goods ($\partial v_i / \partial j_i > 0, \forall j_i \in \{x_i, y_i\}$), marginal utility is decreasing ($\partial^2 v_i / \partial j_i^2 < 0, \forall j_i \in \{x_i, y_i\}$), the two goods are substitutes ($\partial^2 v_i / (\partial x_i \partial y_i) > 0$), demand for both goods is strictly positive at finite prices ($\lim_{j_i \to 0} \partial v_i / \partial j_i = \infty, \forall j_i \in \{x_i, y_i\}$) and there is asymptotic satiation ($\lim_{j_i \to \infty} \partial v_i / \partial j_i = 0, \forall j_i \in \{x_i, y_i\}$).

A share $l_g \in]0, 1[$ of consumers is «green», i.e. intrinsically motivated to reduce their carbon footprints. Intrinsic motivation is modeled as a 'warm glow'

(Andreoni, 1990) that «green» consumers experience if they reduce their personal carbon footprint. Formally, the net utility of «green» consumers is

$$u_g(x_g, y_g) = v_g(x_g, y_g) - m_x x_g \frac{R_x}{X} - m_y y_g \frac{C}{Y}, \tag{3}$$

where $m_j \geq 0$ is the warm glow originating from the reduction in one unit of personal greenhouse gas (GHG) emissions associated with the production of good $j \in \{x, y\}$. $\frac{R_x}{X}$ and $\frac{C}{Y}$ are the carbon intensities of goods x and y, respectively. For simplicity all «green» consumers are assumed to be identical and are represented by a subscript g. Section 4 discusses to what extent the results are robust to alternative specifications of «green» consumers' utility functions. All other consumers are labeled «plain», identified by subscript p, and are assumed to be identical as well. Their net utility equals consumption utility $u_p(x_p, y_p) = v_p(x_p, y_p)$.

Aggregate demand is assumed to satisfy the weak axiom of revealed preferences. A sufficient condition for this to hold is that individual demand satisfies the the uncompensated law of demand property (see Mas-Colell et al., 1995). This is, for example, the case when $v_i(x_i, y_i)$ is homothetic for both types of consumers. Consumers are constrained by a budget derived from their one-unit endowment of the clean input and lump-sum transfers from permit auctions.

$$p_x x_i + p_y y_i \leq w + \gamma C, \forall i \in \{g, p\}. \tag{4}$$

Note that «green» consumers have a bliss point in each good for which $m_j > 0$. Hence, there are parameter values for which a «green» consumer's budget constraint is not binding, if and only if $m_x > 0$ and $m_y > 0$. For the main part of the analysis it is assumed that budget constraints are indeed binding for all consumers. This is considered to be the by far more plausible case since the alternative would imply that a «green» consumer does not spend all her resources in order to protect the environment. While such «radical greens» are conceivable, they are empirically rare and in a somewhat richer model with elastic labor supply, such an individual can be expected to reduce participation in the labor market to an extent that renders her budget constraint binding again. Section 4 discusses the case when «green» consumers' budget constraints cease to be binding.

2.3 Equilibria

In order to identify the effect of climate campaigns on aggregate emissions, we first need to identify the equilibrium of this stylized economy. An equilibrium of the economy is a vector of prices (p_x, p_y, w, γ) together with a vector of quantities $(X, Y, x_g, y_g, x_p, y_p, L_x, L_y, R_x)$ for which the following conditions hold simultaneously:

$$p_x \frac{\partial v_p}{\partial y_p} - p_y \frac{\partial v_p}{\partial x_p} = 0 \tag{5}$$

$$\tag{6}$$

$$p_x\left[\frac{\partial v_g}{\partial y_g}-m_y\frac{C}{Y}\right]-p_y\left[\frac{\partial v_g}{\partial x_g}-m_x\frac{R_x}{X}\right]=0 \quad (7)$$

$$p_x x_p+p_y y_p-w-\gamma C=0 \quad (8)$$

$$p_x x_g+p_y y_g-w-\gamma C=0 \quad (9)$$

$$p_x X-wL_x-zR_x=0 \quad (10)$$

$$g_x\left(\frac{L_x}{R_x}\right)-\frac{w}{z}=0 \quad (11)$$

$$p_y Y-wL_y-(z+\gamma)C=0 \quad (12)$$

$$g_y\left(\frac{L_y}{C}\right)-\frac{w}{z+\gamma}=0 \quad (13)$$

$$L_x+L_y-1=0 \quad (14)$$

$$(1-l_g)x_p+l_g x_g-X=0 \quad (15)$$

$$(1-l_g)y_p+l_g y_g-Y=0 \quad (16)$$

$$X-f_x(L_x,R_x)=0 \quad (17)$$

$$Y-f_y(L_y,C)=0 \quad (18)$$

where $g_j=\partial f_j/\partial L_j/\partial f_j/\partial R_j$ with $g_j'<0$, for all $j\in\{x,y\}$ are the marginal rates of technical substitution that map relative factor prices into factor shares. Since the technologies in both sectors exhibit constant returns to scale, these are independent of scale. The first two conditions equalize marginal rates of substitution across products for «green» and «plain» consumers, respectively. Equations (8) and (9) represent the budget constraints of the two types of consumers. (10), (11) and (12) and (13) are the zero profit and the marginal rate of technical substitution equals relative input prices conditions for sectors X and Y, respectively. The following equation is the market clearing condition for the clean input. (15) and (16) aggregate demand over «plain» and «green» consumers. The last two conditions are the market clearing conditions for goods x and y.

Good x is used as the numeraire, i.e. $p_x=1$ in what follows. This implies that the relative price of the dirty input and good x is fixed. The results would be the same if we pick labor or good y as the numeraire instead.

3 Climate Campaigns

The impact of three different climate campaigns on aggregate emissions are studied in this section. They differ in terms of the good or sector at which they are targeted. A campaign that focuses on good y and hence the sector that is subject to a cap-and-trade scheme is represented by an exogenous increase in «green» consumers' intrinsic motivation m_y to reduce their carbon footprint associated with emission in sector Y. In most real world cap-and-trade schemes this would correspond to a campaign that urges consumers to save electricity. Similarly, a campaign focusing on good x is represented by an increase in m_x and would correspond to a slogan like "Drive less!" as emissions from road transport are usually not covered by cap-and-trade schemes.

However, most climate campaigns do not focus on one sector only. Their objective is to increase climate friendly consumption in general. Hence, instead of focusing on one good or sector only, they aim at increasing intrinsic motivation to reduce carbon footprints generally. Such "Reduce your footprint!" campaigns are represented by an exogenous increase in $m = m_x = m_y$.

Regardless of the type of the campaign, the impact on aggregate GHG emissions is determined by the change in emissions by the sector not subject to the cap ($\partial R_x/\partial m_j$). Given the assumption that the cap on emissions in sector Y is binding both before and after a campaign, only sector X can affect total emissions.

3.1 Campaign on capped sector: Save electricity!

We start by analyzing the effect of a campaign focused on the good produced by the sector subject to the emission cap. Despite being (by assumption) effective in changing preferences of «green» consumers, the intervention cannot have a direct impact on the emissions of the sector it is targeted at (again, by assumption). However, in contrast to results of previous studies on instruments overlapping a cap-and-trade scheme, the effect on aggregate emissions by no means has to be zero. Because the cap only keeps the emissions of one sector fixed, the overall effect will be determined by the direction of inter-sectoral leakage, which can in principle go either way (Fullerton et al., 2013; Baylis et al., 2013).

Before we start the comparative static analysis, it is helpful to first establish which variables will not be affected by the exogenous increase in m_y. The price p_x of the numeraire x and the price of fossil fuels z will not change by assumption. However, since sector X employs a constant returns to scale technology this also implies that the price w of the clean input L and the input mix (L_x/R_x) in sector X will not change either. Only the scale can vary in response to the climate campaign. This implies that the variable we are primarily interested in, R_x, changes in the same direction as L_x as the ratio would otherwise change as well.

A campaign focusing on the good produced by sector Y shifts the demand function of good y to the left holding all prices fixed. While in a general equilibrium model this does not necessarily imply that equilibrium output of sector Y goes down, it has an unambiguous effect on p_y, given that the weak axiom of revealed preferences holds - as assumed - for aggregate excess demand. The shift in the demand function reduces the equilibrium price of y and hence also the price γ of emission allowances. From (13) it follows that a reduction in γ implies a decrease in L_y. The effective price of using the dirty input in the sector with the emission cap ($z + \gamma$) goes down as the price of emission allowances drops. This induces the firms in sector Y to substitute away from the clean input, i.e. to adjust the input mix. Because the amount of the dirty input remains constant due to the assumption that the cap remains binding, the only way by which the adjustment in the input mix can be achieved is by reducing the absolute amount of the clean input used. The reduction in L_y has two immediate consequences: sector Y contracts and sector X expands. The latter is implied by the market clearing condition of the clean input (14) and the previously established fact that relative prices faced by sector X remain unaffected. Hence, X, L_x and most importantly R_x increase. This can be summarized in the following proposition

Proposition 1 *A climate campaign successfully increasing the restraint of a share of consumers to consume the good produced by the sector subject to a cap-and-trade scheme unambiguously raises aggregate emissions. This increase is due to emission leakage into the sector not constrained by a cap.*

Saving electricity when power generation is - as e.g. in the case of the RGGI - the only sector covered by a cap-and-trade program hence has exactly the opposite effect of the one intended. Instead of reducing aggregate emissions, it increases them. A cap-and-trade scheme hence does not just make additional abatement efforts in the sectors covered ineffective as has been suggested by previous studies. It turns them upside down and makes them counter-productive.

3.2 Campaign on sector without a cap: Drive less!

Given that campaigns on reducing consumption in sector Y backfire in terms of their impact on total emissions, can campaigns targeting sector X make a contribution to GHG mitigation? Yes, they can - and it is straightforward to see how. The increase in m_x triggered by the campaign shifts, again at fixed prices, the demand curve for good x inwards and that for good y outwards. Hence, all effects derived in the previous subsection are reversed and therefore sector X has to contract. Given the constant input mix this implies a reduction in the quantities consumed of both inputs. Emissions in sector X drop as a result, as do aggregate emissions.

Proposition 2 *A climate campaign successfully increasing the restraint of a share of consumers to consume the good produced by the sector NOT subject to a cap-and-trade scheme unambiguously reduces aggregate emissions.*

Exerting restraint in the consumption of goods produced by sectors not subject to a cap-and-trade scheme such as driving less or eating less meat has the intended impact on aggregate emissions, at least in terms of the direction of the effect. However, it induces an expansion of the sector subject to the cap, which might well be the more pollution intensive one. Since emissions in that sector are capped, this expansion has no impact on total emissions. It is associated with a rise in the price of emission allowances and a reduction in the emission intensity of the capped sector.

3.3 General climate campaign: Reduce your footprint!

Instead of targeting a particular good or sector, a climate campaign can focus on reductions in personal carbon footprints generally. This is represented by an exogenous increase in the degree of intrinsic motivation by «green» consumers. For convenience we assume that «green» consumers give all GHG emissions associated with the goods they consume the same weight ($m = m_x = m_y$).

As is apparent from the analysis of targeted climate campaigns, the impact of a general campaign on aggregate emissions is determined by its effect on the demand functions of the two goods at given prices. If an increase in m induces «green» consumers to substitute away from x and into y, then aggregate emissions will go down and vice versa. Applying Cramer's rule to conditions (7) and (9) reveals that whether demand by «green» consumers at fixed prices shifts left or right depends on the sign of the following term:

$$\frac{C}{p_y Y} - \frac{R_x}{p_x X}, \tag{19}$$

and hence on the relative emission intensity per dollar worth of output of the two sectors. If (19) is positive, i.e. if the sector subject to the cap is more emission intensive than sector X, then demand for y by «green» consumers decreases when prices are fixed. Hence, we are in the same situation as when the campaign is targeted at sector Y and therefore aggregate emissions increase in response to the campaign. Unfortunately, this condition is likely to hold in the real world. Existing cap-and-trade schemes tend to focus on emission intensive sectors like power generation, steel production, airlines and others. The average emission intensity of the sectors covered is therefore higher than in sectors not bound by the cap. In such a setting a climate campaign raising the intrinsic motivation to reduce personal carbon footprints in general unambiguously increases total emissions.

Proposition 3 *The impact of a climate campaign successfully increasing the intrinsic motivation of a share of consumers to reduce their personal carbon footprint on aggregate emissions depends on the relative emission intensity of sectors.*

- *If the sector subject to a cap-and-trade scheme is the more emission intensive (measured in emissions per dollar worth of output), then the campaign raises total emissions.*
- *If the sector not covered by the cap is the more emission intensive one, then the campaign reduces total emissions.*

Given the current design of real-world cap-and-trade schemes that cover only emission intensive sectors and leave total emissions of sectors that are - on average - less polluting unconstrained, general climate campaigns will backfire. Instead of contributing to the mitigation of GHG emissions, they increase them.

Note that this result does not hinge on the specific way by which the campaign is represented. Instead of increasing the intrinsic motivation of existing «green» consumers a general climate campaign could instead increase the share of intrinsically motivated consumers. This conversion of formerly «plain» consumers has again an impact on the demand for good y, keeping prices fixed. Inspecting the relevant condition (16) reveals that what matters is whether converts increase or decrease their demand for y at given prices. Again, the term (19) determines the direction of the effect and hence the impact on aggregate emissions. Proposition 3 also holds if the campaign works at the extensive rather than the intensive margin.

4 Extensions

This section checks the robustness of the results derived above. First, the special case of «radical greens» that don't spend all their money in order to reduce their carbon footprint is considered. Second, it is discussed how important the specific representation of intrinsic motivation in the utility function is for the results. Third, a further option, namely the purchase and retirement of emission allowances by «green» consumers is considered. Fourth, the industry structure is extended to include an additional sector subject to the cap-and-trade program. The latter reflects systems like the EU ETS that covers multiple sectors but only some are usually targeted by climate campaigns. Fifth, the impact of pre-existing environmental regulation in sector X is considered. Last, the assumptions on supply elasticities of inputs are relaxed.

4.1 Burning money to save the climate

If intrinsic motivation by «green» consumers is sufficiently strong the marginal dis-utility from the emissions associated with each of the goods consumed is so large, that they stop consuming before they exhaust their budget. The bliss point of such «radical greens» lies strictly within their budget set. They do not spend all their money (i.e. they "burn" it) in order to avoid GHG emissions. As indicated above, while this case is a natural implication of the model, it is also mainly an artifact of inelastic labor supply and the one-period nature of this model (i.e. there is no saving). In a world where consumers face opportunity costs of providing the clean input to firms (e.g. forgone leisure time), such «radical greens» would reduce their supply of the green input until the budget constraint would be binding again. However, for completeness a brief analysis of this special case is provided in what follows.

If all «green» consumers are «radical greens» the equilibrium conditions have to be adjusted as follows. Conditions (7) and (9) are replaced by

$$\frac{\partial v_g}{\partial x_g} - m_x \frac{R_x}{X} = 0, \tag{20}$$

$$\frac{\partial v_g}{\partial y_g} - m_y \frac{C}{Y} = 0. \tag{21}$$

The analysis of targeted campaigns is straightforward. A campaign targeting the good produced in the sector subject to the emission cap, represented by an increase in m_y, reduces excess demand for y when prices are fixed. The relative price of y therefore drops in response to the increase in m_y, as does the allowance price γ. On the production side nothing has changed and therefore a reduction in γ is still associated with an increase in emissions in sector X.

A campaign inducing additional restraint by «green» consumers with respect to good x, represented by an increase in m_x, clearly results in a decrease in excess demand for good x at given prices. Hence, the relative price of good x has to drop in response to the exogenous shock. Since x is the numeraire, this implies that p_y increases which in turn causes an increase in γ. A rise in γ is associated with a drop in emissions in sector X. Propositions 1 and 2 therefore hold when «green» consumers are «radical».

The remaining question is therefore what will happen to aggregate emissions when a general climate campaign is launched. In contrast to the case in section 3 a rise in m does no longer shift demand by «green» consumers from the more pollution intensive sector to the cleaner one. It reduces demand by «radical greens» for both goods independently of any changes in the relative price of goods or their income. However, the effect on the relative product price and hence also on the allowance price is no longer clear. It can be shown that the pollution intensity of sectors only affects the size but no longer the direction of the comparative static effect. Whether aggregate emissions increase or decrease as a result of the campaign is determined by the interaction between «plain» consumers' and firms in the two sectors. Proposition 3 no longer holds.

4.2 Different representations of intrinsic motivation

Here I'd like to discuss briefly how sensitive the results are to the way intrinsic motivation is represented in «green» consumers' utility function. Choosing a linear "warm glow" representation of intrinsic motivation is certainly convenient - but is it also innocent? The clear answer is yes, it is perfectly innocent. The analysis in section 3 relies entirely on the effect a particular campaign has on the excess demand for good y relative to that of good x at given prices. Hence, proposition 1 holds given that a campaign targeted at the capped sector induces a reduction in demand for the good produced by that sector but not for the good produced in the other sector. The result is not affected by the specific way by which this shift is brought about. The same holds for a campaign targeting the good produced by the sector not subject to a binding upper bound on emissions. Proposition 2 holds, given that demand for good y but not x shifts outwards at given prices.

Last not least, a general campaign urges consumers to be more sensitive to personal carbon footprints. Putting more emphasis on reductions in personal carbon footprints almost naturally implies that «green» consumers substitute away from emission intensive goods. Which is all that is needed for proposition 3 to hold. The crucial part is therefore not how exactly intrinsic motivation is modeled but rather what «green» consumers are intrinsically motivated to do. If a reduction of their personal carbon footprint is what they care about, then proposition 3 seems robust. However, if they were to care about changes in aggregate emissions instead, then the effect crucially depends on whether they understand how a cap-and-trade scheme works and what it covers. If they are fully informed, then $m_y = 0$ and a general campaign becomes equivalent to a targeted campaign on sector X. If they are ignorant about the implications of a cap-and-trade scheme, then proposition 3 still holds.

4.3 Retiring of allowances

Consumers that want to reduce their personal carbon footprints or aggregate GHG emissions in the presence of a cap-and-trade scheme in practice have another option to pursue this goal. They can buy and retire emission allowances. Retiring means to permanently withholding them from the market and not using them for actual emissions. This reduces the amount of allowances available to polluting firms participating in the program and is similar in effect to a reduction in the cap. Most real world cap-and-trade schemes allow for allowances to be bought by anyone and both private individuals and environmental NGOs have used this to retire allowances.[3]

The key question is how retiring of emission allowances affects aggregate emissions. There is a clear direct effect. For each unit bought and retired, emissions in sector Y are reduced by one unit. The aggregate effect, however, needs to take into account any leakage into sector X. This is exactly what the paper by Fullerton et al. (2013) focuses on. I therefore do not repeat their analysis but just report the main findings. First, they show that leakage might be negative. In this case, a reduction in the cap in sector Y induces a reduction of emissions in sector X. The aggregate effect of retiring one unit would be a reduction of more than one unit overall. However, this is only the case if the elasticity of substitution between inputs in sector Y is relatively high compared to the elasticity of substitution of the two goods in consumption. Otherwise leakage is positive.

Positive leakage does not imply that retiring of allowances is not effective. Only that retiring one unit of emissions results in a reduction of aggregate emissions of less than one unit. However, in principle leakage could exceed 100% in which case the net effect of retiring would be counter-productive. Fullerton et al. (2013) conduct a series of simulation to gauge the size of leakage effects. They find that leakage rates are generally in the one digit range, i.e. even if positive, they are nowhere near 100%.[4] Note that Fullerton et al. (2013) consider an exogenous reduction in the cap. Compared to that retiring of allowances has an additional effect as it reduces «green» consumers' budget to be spend on purchases of consumption goods. In general the direction of this effect is ambiguous. Whether it makes it more or less likely that leakage is positive depends on how «green» con-

[3] In the UK sandbag.org offers retiring of EU ETS allowances as a service to consumers. The Acid Retirement Fund and the Clean Air Conservancy did the same for the U.S. Acid Rain Program. The Clean Air Conservancy also retires allowances from the RGGI program.

[4] In the context of international carbon leakage, there are conflicting findings in the literature, while Babiker (2005) finds that leakage rates can exceed 100%, Burniaux & Martins (2012) argue that they are unlikely to exceed 40% unless the supply of fossil fuels is highly inelastic.

sumers' relative demand for the two goods is affected by the change in income, which, among other things, depends on sectors' relative pollution intensity. But compared to the direct emission reduction this indirect effect can be expected to be relatively small. Retiring of emission allowances is therefore a feasible option for intrinsically motivated consumers to reduce emissions in sectors subject to a cap-and-trade scheme.

4.4 Extending the industry structure

Given the strong results in section 3, are there plausible and straightforward extensions of the model that could change the results? Recall that the channel by which climate campaigns increased aggregate emissions was the movement of clean inputs from the capped sector into the sector without a cap - which then attracted additional dirty inputs into the uncapped sector. This leakage could be prevented if there were a third sector Z that uses the additional clean input without causing additional pollution. This third sector could either produce by only using the clean input, or be an additional sector that is less carbon intensive than sector Y but also covered by the cap-and-trade scheme (i.e. $R_y + R_z \leq C$). Each could utilize clean input that becomes available if a climate campaign reduces demand for y. Whether this will reduce aggregate emissions depends mainly on the elasticity of substitution between goods in consumers' utility functions. If y and z are close substitutes relative to y and x, the increase in restraint on y will mainly increase demand for z.

An example could be different modes of public transport. In the EU both electricity generation and inner-European flights are covered by the EU ETS, but emissions from buses are not. Now imagine a passenger considering to make a trip from London to Paris. In principle, three modes of transport are available: the electricity-powered EuroStar train, flights and buses. Per journey, taking the plane is associated with the most emissions. If a climate campaign manages to deter some travelers from taking the plane, the impact on aggregate GHG emissions depends on whether they opt for the train or the bus and how the total number of journeys is affected by this change of transportation mode. If they opt for the bus and cause the total number of emissions from buses to increase, then total emissions will increase as well. If they opt for the train, the matter is more complicated. If the additional train journeys pull more of the clean input into the sector than has been freed up by the reduction in air trips, then total emissions would drop and vice versa.

For cap-and-trade schemes that cover several sectors differing in their emission intensities, a well targeted climate campaign on a specific sector within the scheme could hence have a positive impact on total emissions. While we have not specified the exact conditions, they are likely to be much more involved than the relatively simple rule to focus on sectors outside the cap-and-trade scheme or to retire allowances. They would need to consider emission intensities and elasticities of substitution with goods inside and outside the cap-and-trade program.

4.5 Environmental regulation in sector X

So far the implicit assumption was that the sector not covered by the cap-and-trade scheme does not face any environmental regulation. Here I briefly discuss the implications if this is not the case. First, and most obviously, all previous results break down if sector X is subject to a sector-specific and binding cap-and-trade program. In this case none of the campaigns has any effect on total emissions as they are effectively (but inefficiently due to the restriction on trading between sectors) capped as in previous studies on overlapping instruments.[5]

If sector X faces a pre-existing, linear emission tax, then aggregate emissions are, ceteris paribus, lower than without such a tax. However, qualitatively the comparative statics of climate campaigns are not affected. Propositions 1 - 3 still hold as the direction of the effects does not depend on the size of the price of the dirty input in sector X.

Another common form of climate policy is an emission rate standard such as those used in both the EU and the US for carbon emissions of cars. Again, the presence of an emission rate standard in sector X does not affect propositions 1 - 3. The emission intensity in sector X is not affected by any of the climate campaigns in the absence of such regulation. A binding emission rate standard can reduce the size of the leakage effect for any given amount of the clean input moving from sector Y to sector X but it cannot stop it from occurring unless sector X is perfectly clean.

Unless there is a cap on emissions in sector X as well, common forms of environmental regulation pre-existing in the sector not covered by the cap-and-trade scheme do not affect the results derived in section 3.

4.6 Factor elasticities

The results above are derived using starkly different assumption on the supply elasticities of the two inputs. While the dirty input is assumed to be in perfectly elastic supply, the supply of the clean input is perfectly inelastic. What happens if we relax these assumption?

A simple way to induce inelastic supply of the dirty input is to assume that one needs one unit of the clean input to produce one unit of the dirty one (see Fullerton et al., 2013). In this case condition (14) becomes

$$L_x + L_y + R_x + R_y - 1 = 0 \tag{22}$$

and the price of the dirty input is the same as the one for the clean input $z = w$. Although w is not affected by any of the climate campaigns due to the constant returns to scale technology, the opportunity costs of the dirty input are nevertheless rising in its use. Looking at a campaign targeted at sector Y, it still induces clean input to move into sector X. The latter expands, but less so than previously, as the

[5] See Böhringer & Rosendahl (2010); Fischer & Preonas (2010); Frankhauser et al. (2010).

additional clean input flowing into sector X is now split and used to increase both L_x and R_x in accordance with the sector's factor share, which remains unaffected. The size of carbon leakage is smaller when the dirty input is in inelastic supply compared to when it is perfectly elastic, however the effect itself still exists. This only changes if supply of fossil fuels becomes perfectly inelastic. But then the problem is trivial and equivalent to an aggregate cap on emissions with trading restrictions between sectors (see section 4.5 and Burniaux & Martins (2012)).

Moving back to a world with perfectly elastic supply of the dirty input but allowing consumers to decide on the amount of the clean input (labor) they supply requires to specify how this is affected by consumers' real income and the real factor price. If leisure is a normal good, then an increase in real income reduces the supply of labor and an increase in the real wage rate increases it. Let us again focus on the "save electricity" campaign targeting sector Y. With the numeraire p_x and the nominal wage rate w staying constant, the drop in p_y induced by the campaign implies that the real wage rate rises. Ceteris paribus, this increases the supply of the clean input and would therefore aggravate the increase in total emissions associated with this type of campaign. However, there is a second effect via the real income channel. Nominal income is reduced because the drop in the price for emission allowances implies that fewer revenues are raised in the allowance auctions which are redistributed lump-sum to consumers. However, each unit of income buys more goods since the campaign induces a drop in p_y. The direction of this second effect is hence ambiguous. To invalidate proposition 1, however, it would need to be sufficiently strong not only to compensate for the effect of the increase in the real wage rate, but also to fully neutralize the amount of labor freed up in sector Y to prevent it from being used to expand sector X. This seems rather unlikely.

5 Conclusion

Are climate campaigns futile? The result of this paper is that, if they manage to change consumers' behavior and are well targeted, then they are clearly not futile. However, it is also obvious that in order to ensure a reduction in aggregate emissions, they would need to be better targeted then is currently the case. So far, climate campaigns by both governments and NGOs do usually not consider the regulatory framework they are interacting with. Especially cap-and-trade programs are of relevance as their design implies that emission reductions within such a scheme merely affect who emits but not directly how much is emitted. The results above clearly show that when their coverage is limited to some sectors of an economy, that climate campaigns shifting demand (and hence resources) away from capped sectors are likely to increase total GHG emissions.

Campaigns that target goods produced by sectors not covered by a cap-and-trade scheme reduce total emissions. The same holds for those that induce consumers to buy and retire emission allowances. In principle highly targeted campaigns focusing on the most emission intensive industries within a cap-and-trade scheme can also induce reductions in aggregate emissions, but only if the elasticities of substitution between other goods within the scheme and between goods outside it are of the appropriate size.

General campaigns that induce consumers to reduce their carbon footprint would be effective in reducing aggregate emissions if the capped sectors of the economy had a below average carbon intensity. However, in the real world the exact opposite is the case with cap-and-trade schemes around the world focusing on emission intensive sectors. Hence, efforts by «green» consumers to reduce their personal carbon footprint shift demand away from sectors subject to the cap and shift it - and resources - toward sectors not subject to an upper bound on carbon emissions. Total emissions increase as a result.

For the same reason the design of carbon footprint labels such as PAS 2050 and ISO 14067 and the way carbon footprint calculators work should be reconsidered. At the moment they do not distinguish between emissions occurring within or outside a cap-and-trade scheme. Focusing on emissions not covered by cap-and-trade programs, however, would be necessary to induce intrinsically motivated consumers to have a real impact on total emissions that works in the direction desired.

One further caveat is in order. The current paper completely ignores any long-term effects that might well have important impacts on total emissions. Changes in consumers' and hence citizens' preferences can be expected to affect future policy making. Increasing the intrinsic motivation of «green» consumers or increasing their share in the population could well result in tighter environmental regulation, and tighter emission caps in particular, in the future. Moreover, climate campaigns and the (often observable) behavioral change they induce might trigger changes in social norms that result in emission reductions not accounted for in this model. Last not least, the changes in industry structure and profitability resulting from these campaigns also change the political economy of environmental policy making. These issues certainly require further attention by future research.

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A Appendix

A.1 Proof of propositions 1, 2 and 3

First we show that input mix in sector X and hence the wage rate are not affected by changes in m, m_x or m_y. The constant returns to scale technology in sector X implies that the marginal product of the dirty and clean inputs depend only on factor proportions L_x/R_x but not on scale. Because p_x is the numeraire and z the exogenous world market price for the dirty input, the first-order conditions of the representative firm's profit maximization

$$p_x \frac{\partial f_x}{\partial L_x} = w \tag{A.1}$$

$$p_x \frac{\partial f_x}{\partial R_x} = z \tag{A.2}$$

imply that L_x/R_x is constant (A.2) and hence that w is constant as well (A.1).

Equilibrium conditions 5 - 18 can be reduced to a system of eleven equations and unknowns. Here I drop conditions 17 and 18. Using the implicit function theorem and Cramer's rule to determine $\partial R_x/\partial m_y$ yields

$$\begin{aligned}\frac{\partial R_x}{\partial m_y} \quad = \quad & -\frac{p_x C y_p g_x' w[L_g - p_y(1-L_g)]}{Y R_x (z+\gamma)^2 \Phi}\left[\frac{\partial^2 v_p}{\partial x_p y_p}(p_y + l_g(1-p_y))\right. \\ & \left. + \frac{\partial v_p}{\partial x_p}\frac{(l_g(1+p_y)-p_y)}{y_p} - \frac{\partial^2 v_p}{\partial y_p^2}(1-l_g) - l_g p_y \frac{\partial^2 v_p}{\partial x_p^2}\right]\end{aligned} \tag{A.3}$$

where Φ is the determinant of the Jacobian of the system of eleven equilibrium conditions. Several of the components of (A.3), including Φ, have an ambiguous sign. However, the same procedure yields

$$\begin{aligned}\frac{\partial \gamma}{\partial m_y} \quad = \quad & -\frac{y_p L_x g_x' g_y' [L_g - p_y(1-L_g)]}{R_x^2 Y \Phi}\left[\frac{\partial^2 v_p}{\partial x_p y_p}(p_y + l_g(1-p_y))\right. \\ & \left. + \frac{\partial v_p}{\partial x_p}\frac{(l_g(1+p_y)-p_y)}{y_p} - \frac{\partial^2 v_p}{\partial y_p^2}(1-l_g) - l_g p_y \frac{\partial^2 v_p}{\partial x_p^2}\right]\end{aligned} \tag{A.4}$$

which is identical to (A.3) with the exception of a few factors that can be clearly signed. Indeed, since $g_y' < 0$, (A.3) always has the opposite sign of (A.4). However, since an increase in m_y reduces excess demand of y at constant prices, we know (Mas-Colell et al., 1995, p. 618) that $\partial p_y/\partial m_y < 0$ and due to

$$p_y \frac{\partial f_y}{\partial L_y} = w,$$

the labor intensity L_y/C drops because w is constant. Condition (13) in turn implies that $\partial \gamma/\partial m_y < 0$ as well. Hence, (A.4) is negative and (A.3) is positive. This completes the proof of proposition 1.

For the proofs of propositions 2 and 3 it is convenient to re-write (A.3) as

$$\frac{\partial R_x}{\partial m_y} = -p_x \frac{C}{Y} \cdot \Psi > 0.$$

Again using the implicit function theorem and Cramer's rule yields

$$\frac{\partial R_x}{\partial m_x} = p_y \frac{R_x}{X} \cdot \Psi < 0 \tag{A.5}$$

$$\frac{\partial R_x}{\partial m} = \left(\frac{R_x}{p_x X} - \frac{C}{p_y Y} \right) \cdot \Psi \tag{A.6}$$

which proves propositions 2 and 3.