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Climate campaigns, cap-and-trade and carbon leakage: Why trying to reduce 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 that shift demand away from 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

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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., 2014) and a general willingness to purchase carbon offsets (Diederich & Goeschl, 2013, 2014).

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, the use of carbon footprint labels that provide the information necessary for consumers to take into account the climate impacts of their consumption choices is rising (Perino et al., 2014; Vandenbergh et al., 2011). Common standards to compute life-cycle carbon footprints for consumer goods exist in the UK as PAS2050 (BSI, 2011) and internationally as ISO 14067.

While it is clear that voluntary behavioral changes alone cannot solve the climate change problem, many (though not all) scholars and practitioners believe them to be an important part of the solution. For example, 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. Kotchen (2013) provides a critical overview on voluntary- and information-based approaches. While he does not explicitly consider interactions with cap-and-trade schemes he is cautiously optimistic with regard to the potential of voluntary efforts to contribute to environmental improvements. Common recommendations by governments and NGOs 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 System (EU ETS) and in North America as part of the Regional Greenhouse Gas Initiative (RGGI) and in a linked scheme in California and Quebec. While Australia has reverted plans to introduce a cap-and-trade scheme in 2015, 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 that is scheduled to be introduced in 2016 (Qui, 2013; NYT, 2014).

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. Are they complements as Ostrom (2012) and Dietz et al. (2009) suggest or are they rather substitutes as is implied by the literature on interventions overlapping a cap-and-trade scheme (Fischer & Preonas, 2010; Böhringer, 2014; Goulder, 2013)? In this paper I focus on this interaction. Using a general equilibrium model of an economy with intrinsically motivated consumers I investigate the medium-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 and compare it to the effects under sector specific carbon taxes.

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 and the green paradox induced by unilateral increases in policy stringency[2] and on overlapping instruments when cap-and-trade schemes have full coverage[3]. The key contribution of this paper is to analyze an intervention overlapping with a cap-and-trade scheme with only partial coverage within a general equilibrium framework similar to that used by Baylis et al. (2013, 2014). They use the same basic setup to identify intra-juristictional leakage effects in response to a change in the stringency of a carbon tax or cap-and-trade scheme in one sector. Hence, they do not consider overlapping instruments or climate campaigns. Introducing campaigns into their model 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 into 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. 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.

There are also a few other papers studying the interaction between intrinsically motivated consumers and mandatory regulation. Heyes & Kapur (2011) and Delgado & Khanna (2013) focus on individual consumers' reaction to changes in regulation and identify optimal interventions in the presence of (impure) altruism. Their results are complementary to the ones presented here as they do not consider leakage.

It is important to highlight a number of caveats. The paper takes a medium term perspective that allows the economy to move from one equilibrium to another

[1]See e.g. Abrahamse et al. (2005); Allcott & Mullainathan (2010); Allcott (2011); Bolderdijk et al. (2013); Costa & Kahn (2013); Perino et al. (2014).

[2]See e.g. Babiker (2005); Burniaux & Martins (2012); Baylis et al. (2013); Fowlie (2009); Baylis et al. (2014); Carbone (2013); Goulder et al. (2012); Eichner & Pethig (2011); van der Werf & Di Maria (2012); Winchester & Rausch (2013).

[3]See e.g. (Böhringer & Rosendahl, 2010; Fischer & Preonas, 2010; Frankhauser et al., 2010; Goulder, 2013; Böhringer, 2014).

in response to an intervention but it keeps the cap of the emission trading scheme fixed. The caps of the EU ETS, the RGGI and the Californian scheme are set until 2020. In the EU ETS the following phase will fix the cap between 2021 and 2030. If longer time periods are considered, the cap clearly needs to be viewed as endogenous. Hence, the current paper ignores any effects that might arise from interactions between climate campaigns and the political process of setting future caps. Campaigns might trigger preference changes that affect future elections and might induce household or energy sector investments that make ambitious targets easier to achieve. These questions are left for future research and the results need to be read with this in mind.

The paper is organized as follows. The modeling framework is introduced in the next section. Section 3 considers campaigns targeted at a specific sector under two regulatory regimes: i) sector-specific carbon taxes and ii) a partial cap-and-trade scheme with the other sector being subject to a carbon tax and provides numerical examples to illustrate the rough size of campaign induced changes in emissions. A generic campaign increasing the weight consumers put on their desire to reduce their carbon footprint is analyzed in Section 4. Section 5 discusses several extensions of the basic framework. The last section concludes and discusses policy implications. Proofs are provided in the appendix.

2 The Model

To study the impact of climate campaigns on aggregate emissions in the presence of a cap-and-trade scheme, I draw on a simple general equilibrium model with sector specific climate policies recently introduced by Baylis et al. (2013, 2014). 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.

2.1 Production

The economy has two perfectly competitive sectors, each using two inputs, the «clean» input L and «dirty» carbon emissions C, to produce consumption goods x ("driving") and y ("electricity"), respectively. These labels are not to be taken too literally. "Electricity" represents an average consumption good produced in a sector subject to a cap-and-trade scheme and "driving" a representative consumption good from the rest of the economy that might or might not be subject to regulatory interventions targeting GHG emissions other than a cap. The corresponding aggregate output quantities are denoted X and Y. The clean input is a composite of labor and capital, is perfectly mobile between sectors and hence traded at the uniform price w and is in fixed supply ($L = \bar{L}$). This assumption will be relaxed in Section 5. There is a representative firm in each sector that has access to a sector specific constant returns-to-scale technology $f_j(L_j, C_j)$, where $j \in \{x, y\}$. Assuming constant returns-to-scale makes the analysis much more tractable by limiting adjustments in prices and factor shares to a minimum as will become clear in Section 3. However, they are not essential for the gist of the results.

Consumption goods x and y are traded at prices p_x and p_y, respectively. Good x is treated as the numeraire ($p_x = 1$).

Both sectors are subject to environmental policies that impose prices on carbon emissions. In sector X this policy is an exogenous carbon tax $t_x \geq 0$ that is expressed in units of x.[4] Note that this setup allows for the case without a carbon price in sector X (i.e. $t_x = 0$). Sector Y is either also regulated by an exogenous and fixed carbon tax $t_y > 0$ or regulated by a tradable permit scheme with aggregate emissions limit $\bar{C}_y$, which is assumed to be binding ($C_y = \bar{C}_y$) such that permits are traded at a strictly positive price $t_y > 0$. In contrast to sector X and to the setup used in Baylis et al. (2014), the price of emissions in sector Y is endogenous when subject to a cap reflecting a major difference between emission taxes and cap-and-trade schemes. The importance of whether sector Y is regulated via a price or quantity based instrument is highlighted throughout the analysis by contrasting the two cases.

The focus on exogenous environmental policies is appropriate when considering the short to medium term impact of climate campaigns on GHG emissions. NGOs take the regulatory environment as given when considering to run a campaign aiming to influence consumer behavior as do carbon footprint calculators and labels informing consumers about the GHG emissions associated with their choices. Moreover, governments and their agencies can initiate campaigns more easily than changing tax rates or tighten emission caps. While major campaigns (or the combination of several smaller ones) might well affect future policies such indirect channels are not considered in this paper.

2.2 Consumption

There is a representative consumer maximizing the utility function $u(X, Y; m)$ where m is a parameter that shifts the marginal rate of substitution between y and x up or down. This shift in the marginal rate of substitution represents the impact of a climate campaign and can be induced in several ways. The first are campaigns directly targeting specific products discouraging their consumption. Examples are campaigns to save electricity (Abrahamse et al., 2005; Allcott, 2011), fly less (Aamaas et al., 2013) or eat less meat (Stehfest et al., 2009). They are considered in Section 3. Another possibility are information campaigns that reveal the relative

[4] An emission rate standard such as those used in both the EU and the US for carbon emissions of cars would yield similar results as both policies effectively fix the input ratio in sector X given the constant returns to scale technology.

environmental impacts of goods, such as the introduction of carbon footprint labels. Last not least, a campaign could aim at increasing the intrinsic motivation of consumers to reduce their carbon footprint generally and leave it to consumers how they want to achieve this (Section 4).

Note that m is not interpreted as the size of individual damages from climate change, because simply caring about a stable climate is not enough to trigger voluntary contributions by consumers. The very large number of contributors and the stock dynamics of the carbon cycle imply that the Nash contribution is effectively zero (Andreoni, 1988).[5] Hence, the channels by which a campaign could affect the marginal rate of substitution have in common that consumers have some form of intrinsic motivation to contribute to the public good of greenhouse gas mitigation.[6]

Utility u has the following properties: it is non-satiated in both goods ($u_j = \partial u/\partial j > 0, \forall j \in \{X,Y\}$) and marginal utility is decreasing ($u_{jj} = \partial^2 u/\partial j^2 < 0, \forall j \in \{X,Y\}$), demand for both goods is strictly positive at finite prices ($\lim_{j\to 0} u_j = \infty, \forall j \in \{X,Y\}$) and there is asymptotic satiation ($\lim_{j\to\infty} u_j = 0, \forall j \in \{X,Y\}$) to ensure interior solutions. For analytical tractability we follow Baylis et al. (2013, 2014) in restricting the utility function to be homothetic. Hence the marginal rate of substitution (MRS) only depends on the ratio but not on the scale at which the two goods are consumed.

The qualitative results do not depend on this assumption and a policy-relevant case with non-homothetic utility is discussed in Section 4. Consumers are constrained by a budget derived from their endowment of the clean input and lump-sum transfers from permit auctions and carbon tax revenues $X + p_y Y \leq wL + t_x C_x + t_y C_y$.

2.3 Equilibria and basic comparative statics

In order to identify the effect of climate campaigns on aggregate emissions, we assume the economy to be in equilibrium and focus on the comparative statics induced by a climate campaign represented by a change in the utility parameter m and represent proportional changes in endogenous variables by using the "hat" notation. Note that $\hat{p}_x = 0$ since the price of good x is the numeraire. The conditions are introduced for the general case that allows regulation in sector Y to be both a tax or a cap-and-trade scheme. Additional restrictions specifying the regulatory scheme are introduced below.

Totally differentiating the resource constraint on the clean input, which by assumption is in fixed supply, yields

$$\alpha_x \hat{L}_x + \alpha_y \hat{L}_y = 0, \tag{1}$$

[5] This is also the reason why the public good aspect is not explicitly modeled in the utility function.

[6] A representative consumer is chosen for convenience. The same results hold if only a fraction of consumers are intrinsically motivated and hence are affected by changes in the parameter m, i.e. respond to a climate campaign.

where $\alpha_i = L_i/L$ is the share of the clean input used sector i ($j = x,y$). It therefore holds that $\alpha_x + \alpha_y = 1$. Totally differentiating the production functions yields

$$\hat{X} = \theta_{XL}\hat{L}_x + \theta_{XC}\hat{C}_x, \tag{2}$$
$$\hat{Y} = \theta_{YL}\hat{L}_y + \theta_{YC}\hat{C}_y, \tag{3}$$

where θ_{ij} is the share of income used on input j in the production of good i, e.g. $\theta_{YL} = wL_y/(p_yY)$. The zero-profit conditions ensure that $\theta_{iL} + \theta_{iC} = 1$. Totally differentiating the zero-profit conditions yields

$$\hat{X} = \theta_{XL}\left(\hat{L}_x + \hat{w}\right) + \theta_{XC}\left(\hat{C}_x + \hat{t}_x\right), \tag{4}$$
$$\hat{p}_y + \hat{Y} = \theta_{YL}\left(\hat{L}_y + \hat{w}\right) + \theta_{YC}\left(\hat{C}_y + \hat{t}_y\right). \tag{5}$$

Both sectors use constant returns-to-scale technologies and hence for both the respective marginal rates of technical substitution (MRTS) only depend on the relative factor shares but not on the scale of production. In equilibrium the MRTS equals the ratio of input prices faced by the respective sector, i.e.

$$MRTS\left(\frac{C_i}{L_i}\right) = \frac{w}{t_i},$$

with $MRTS' > 0$. Totally differentiating this condition yields,

$$\hat{C}_x - \hat{L}_x = \sigma_x\left(\hat{w} - \hat{t}_x\right), \tag{6}$$
$$\hat{C}_y - \hat{L}_y = \sigma_y\left(\hat{w} - \hat{t}_y\right), \tag{7}$$

where σ_i is the elasticity of substitution of the input factors in the production of good i. They are assumed to be strictly positive for both sectors.

In order to identify the impact of climate campaigns their effect on preferences is key. In equilibrium consumers equalize the marginal rate of substitution with the relative price of the goods.

$$MRS_{yx}\left(\frac{Y}{X};m\right) = \frac{1}{p_y},$$

with $\partial MRS/\partial(Y/X) > 0$ and $\partial MRS/\partial m > 0$. Totally differentiating this condition yields

$$\hat{X} - \hat{Y} = \sigma_u\left(\hat{p}_y + \frac{1}{\sigma_m}\hat{m}\right), \tag{8}$$

where σ_u is the elasticity of substitution in consumption between x and y and $\sigma_m = MRS/m \cdot (\partial MRS/\partial m)^{-1}$ is the elasticity of the MRS with respect to a change in m. For the case of the constant elasticity of substitution (CES) utility function

$$u(X,Y;m) = \left[\frac{m}{1+m}X^{-\rho} + \frac{1}{1+m}Y^{-\rho}\right]^{-\frac{1}{\rho}},$$

the marginal rate of substitution becomes $MRS = m(Y/X)^{\rho-1}$, the elasticity of substitution $\sigma_u = 1/(1+\rho)$ and condition (8) simplifies to

$$\hat{X} - \hat{Y} = \sigma_u (\hat{p}_y + \hat{m}). \quad (9)$$

For convenience the CES-specification will be used in what follows and σ_u is assumed to be strictly positive, i.e. goods are allowed to be gross substitutes or gross complements.

Conditions (1) to (7) and (9) together form a system of eight linear equations with seven unknowns that specify the general equilibrium effect of a small shock in an exogenous parameter. Note that $\hat{m}$, $\hat{t}_x$ and depending on the regulatory regime either $\hat{t}_y$ or $\hat{C}_y$ are exogenously determined (i.e. all but the first are set to zero).

3 Sector Specific Climate Campaigns and Regulatory Regimes

In this section the effect of campaigns targeting a specific sector on total emissions is considered. These campaigns are represented by an exogenous shift in the utility parameter m which shifts demand from one sector to the other. Specifically, an increase in m ($\hat{m} > 0$) represents a campaign that increases the relative weight of good x in the utility function and therefore, at constant prices, increases demand for good x and reduces demand for good y. Using the labels for goods x and y, such an increase in m could be triggered by a campaign message like "Save electricity!". On the other hand, a decrease in m has the exact opposite effect on demand curves of the two goods and would be associated with a campaign message like "Drive less!".[7] The assumption is that the purpose of such campaigns is to reduce emissions in the targeted sectors, i.e. those that experience a reduction in demand. Associated changes in emissions in the other sector are considered to be unintended carbon leakage.

The impact on net emissions will not only depend on the type of campaign message used but also on the regulatory regime the economy is subject to. To identify the interaction between campaigns and existing climate policy regimes two setups are compared. The first serves as a benchmark and has both sectors subject to a (potentially zero) carbon tax as in Baylis et al. (2014). In the second setting, sector X is regulated by a carbon tax and sector Y by a cap-and-trade scheme.

3.1 Sector specific carbon taxes

In this policy regime both sectors face exogenously fixed carbon taxes t_x and t_y. Baylis et al. (2014) use this setting to investigate the change in emissions caused by an exogenous change in the tax rate in sector Y. While using the same setting, the present analysis keeps tax rates constant but looks at how a change in preferences, e.g. induced by a campaign, affects emissions.

In this case the following lemma holds

[7] A Google search delivered more than half a million hits for each campaign message.

Lemma 1 *If both sectors are regulated by carbon taxes, then a climate campaign represented by a change in the utility parameter m has no impact on equilibrium prices (i.e.* $\hat{t}_x = \hat{t}_y = \hat{w} = \hat{p}_y = 0$*).*

The intuition for Lemma 1 is as follows. Remembering that the price of good x is the numeraire, that the price of the dirty input in sector X is fixed and that the sector-specific technology exhibits constant returns to scale, it follows that the price of the clean input cannot change either. Hence, both input prices relevant for sector Y are constant and given the constant returns to scale technology, the output price of good y cannot change. Using the terminology of Baylis et al. (2014) there is no terms-of-trade effect (TTE) as prices do not adjust.

Lemma 1 has direct implications for changes in quantities.

Lemma 2 *If both sectors are regulated by carbon taxes, then in response to a climate campaign represented by a change in the utility parameter m inputs and outputs of each sector expand or contract proportionately (*$\hat{X} = \hat{L}_x = \hat{C}_x$ *and* $\hat{Y} = \hat{L}_y = \hat{C}_y$*) and the movement of sectors is linked deterministically (*$\hat{X} = -\alpha_y/\alpha_x \hat{Y}$*).*

Again, the intuition is straightforward. With no movement in prices and constant returns to scale technologies output and input use in each sector has to adjust proportionately (scale effect), or not at all. Hence, firms do not substitute one input for another or in the words of Baylis et al. (2014), there is no abatement resource effect (ARE). Moreover, the changes in scale of the two sectors are linked through the perfectly inelastic supply of the clean input and the corresponding market clearing condition. Hence, any unit of the clean input no longer used in sector X gets employed by sector Y and vice versa.

The impact of a climate campaign can now be specified as follows.

Proposition 1 *If both sectors are regulated by carbon taxes, then a climate campaign represented by a change in the utility parameter m induces the following changes in emissions:*

- *Sector X:* $\hat{C}_x = \alpha_y \sigma_u \hat{m}$,
- *Sector Y:* $\hat{C}_y = -\alpha_x \sigma_u \hat{m}$,
- *Total emissions:* $\hat{C} = \varepsilon_x \hat{C}_x + \varepsilon_y \hat{C}_y = \sigma_u \frac{L_x L_y}{CL} \left[\frac{C_x}{L_x} - \frac{C_y}{L_y} \right] \hat{m}$, *where* $\varepsilon_i = C_i/C$.

Hence, total emissions increase (decrease) in response to an exogenous increase in m if and only if sector X (Y) is more carbon intensive than sector Y (X).

A change in preferences moves demand away from one sector and towards the other sector. This results in a contraction and hence emission reduction in the former (direct effect) and an expansion of output and emissions in the other (carbon leakage). Since there are no changes in relative prices and hence no substitution effects (Lemma 1) the net effect on total emissions depends on the relative factor intensities. If the sector that contracts is more pollution intensive, then total emissions go down and vice versa. Note that a simultaneous contraction of both sectors (i.e. negative leakage) is not possible as it would violate the assumption of non-satiated preferences. This also points at the limitations of the labeling of sectors introduced above. Of course in the real world it is possible to save electricity and drive less at the same time while holding non-satiated preferences because there are more than two goods and more than one time period. Hence, what Proposition 1 states is that one cannot simultaneously reduce consumption of all goods now and forever without adjusting the supply of labor, capital and other inputs by households. So the basic results hold if campaigns affect the composition of consumption bundles but not factor supply decisions of households. This does not imply that the latter does not occur. However, the explicit aim of most (mainstream) climate campaigns seems to be in line with this interpretation as slogans are usually of the "consume less of ..." rather than of the "work/earn less" type.

The key insight of Proposition 1, that a campaign shifting demand away from the carbon intensive sector reduces aggregate emissions, is very intuitive. In this setting it guarantees that the primary emission reducing effect dominates the secondary carbon leakage effect. The scale of the change in emissions is determined by the elasticity of substitution in consumption and the factor shares in production. The elasticity of substitution of inputs in production does not affect the size or presence of the effect since there is no substitution effect in production as all prices are unaffected by the intervention (Lemma 1).

3.2 Partial cap-and-trade scheme

In order to study the effect of preference changes in the context of cap-and-trade schemes that cover some but not all polluting sectors of an economy, sector Y is now assumed to be regulated by a binding and exogenous cap on emissions $\bar{C}_y$ and hence the price on emissions in this sector, t_y, is endogenous. Sector X continues to be regulated by a (potentially zero) carbon tax. This is the central setup of this paper.

The essence of Lemma 1 still holds for sector X but no longer for sector Y and hence,

Lemma 3 *If sector X is regulated by a carbon tax and sector Y by a binding cap-and-trade scheme, then a climate campaign represented by a change in the utility parameter m has no impact on the equilibrium price of the clean input, i.e.* $\hat{w} = 0$. *In sector Y output price and the sector specific carbon price move in the same direction (*$\hat{p}_y = \theta_{YC}\hat{t}_y$*).*

Again, for sector X the output price being the numeraire and the price of carbon emissions exogenously fixed together with the constant returns to scale technology imply that the price of the clean input does not change. However, in sector Y price of output and carbon emissions are endogenous but linked through the zero-profit condition. If the output price rises, then the willingness-to-pay to buy emission allowances increases and the carbon price t_y increases as well and vice versa. For changes in input and output quantities this implies,

Lemma 4 *If sector X is regulated by a carbon tax and sector Y by a binding cap-and-trade scheme, then in response to a climate campaign represented by a change in the utility parameter m inputs and outputs of sector X expand or contract proportionately ($\hat{X} = \hat{L}_x = \hat{C}_x$). In sector Y, output is determined by the change in the use of the clean input ($\hat{Y} = \theta_{YL}\hat{L}_y$) which also determines the change in output of sector X, i.e. $\hat{X} = -\alpha_y/\alpha_x\hat{L}_y$.*

In sector Y a proportional increase or reduction in the scale is no longer feasible since the amount of the dirty input is fixed. Carbon emissions cannot increase beyond the amount set by the sector-specific cap. In principle, emissions could drop below the cap, however, attention is restricted to cases where the drop in demand for emission allowances is not sufficiently large to render the cap non-binding. If the cap would become non-binding, the carbon price would drop to zero and the cap-and-trade scenario becomes a special case of the tax-tax scenario discussed above with $t_y = 0$. Given the fixed amount of carbon used in the production of Y, any adjustment in output is brought about by changes in the use of the clean input.

The key question is how a change in m induced by a campaign affects C_x. This is captured by the following proposition.

Proposition 2 *If sector X is regulated by a carbon tax and sector Y by a binding cap-and-trade scheme, then a climate campaign represented by a change in the utility parameter m induces the following changes in emissions:*

- *Sector X:* $\hat{C}_x = \frac{\sigma_u}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{m}$,
- *Sector Y:* $\hat{C}_y = 0$ *(by assumption),*
- *Total emissions:* $\hat{C} = \varepsilon_x\hat{C}_x = \frac{\varepsilon_x\sigma_u}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{m}$, *where* $\varepsilon_x = C_x/C$.

Hence, total emissions increase in response to an exogenous increase in m.

A campaign that shifts demand away from the capped sector ($\hat{m} > 0$) implies that its output, output price or both have to drop in response. Each would imply a reduction in the amount of the clean input used in sector Y (see Lemma 4 and condition (7)). The clean input moves to sector X which expands output and emissions proportionately. Hence, in the regulatory regime with a partial cap-and-trade scheme, the impact of a campaign on aggregate emissions no longer depends on the relative factor intensity of sectors but only on the type of campaign. If the campaigns manages to shift demand away from the capped sector Y, then sector X expands and emissions increase, even if sector Y is more emission intensive. This is in clear contrast to the result in a purely price-based regulatory regime (Proposition 1). As all currently existing and planned cap-and-trade schemes for greenhouse gas emissions target emission intensive sectors like electricity generation and heavy

Parameter	Definition	Value
α_x	$\frac{L_x}{L}$	0.855
α_x	$\frac{L_y}{L}$	0.145
ε_x	$\frac{C_x}{C}$	0.587
ε_y	$\frac{C_y}{C}$	0.413
θ_{YL}	$\frac{wL_y}{p_y Y}$	0.989
θ_{YC}	$\frac{t_y C_y}{p_y Y}$	0.011
σ_y	$\frac{MRTS}{dMRTS}\frac{L_y}{C_y}$	$[0,2]$
σ_u	$\frac{MRS}{dMRS}\frac{X}{Y}$	$[0,2]$

Table 1: Parameters used in simulation

industries, this result has important implications. In contrast to common sense, moving demand away from the emission intensive (and emission capped) sector, does not reduce but rather increase total emissions because there is no direct emission reducing effect due to the cap and the leakage effect unambiguously increases emissions. Hence, the model predicts that in regions with a cap-and-trade scheme, campaign messages like "Save electricity!" have a detrimental effect on the climate - at least as long as the cap is exogenous and binding.

So far the presence of the effects has been established. In order to gauge their policy relevance it is important to get an idea of their size. This is to what I turn next.

3.3 Numerical illustration of magnitudes

Are the leakage effects of campaigns established above only second-order effects and hence predominantly of academic interest or are they substantial and should be taken into account in policy design? In order to establish rough estimates of the scale of effects, I use a simple parametrized version of the model presented above. Parameters are calculated using data from Eurostat on sector specific GDP at the EU(28) level and from the European Environment Agency on EU ETS and non-EU ETS greenhouse gas emissions for 2011.[8] Table 1 lists all parameters used and their definitions.

The numerical part also serves to illustrate the sensitivity to changes in parameters, especially the substitution elasticities of the two goods w.r.t. consumption and of the two inputs in the production of Y. Figure 1 presents the impact of a campaign ($\hat{m} = 2\%$) on sector specific and aggregate changes in emissions for the two regulatory regimes analyzed above. Note that sector specific changes in emissions are given relative to total emissions and not relative to sector-wide emissions, i.e. they plot $\varepsilon_x \hat{C}_x$ and $\varepsilon_y \hat{C}_y$.

[8] The EU is of course not a closed economy and hence does not fully match the model. However, over sixty percent of trade by EU(28) member states were with other members in 2011 (Eurostat).

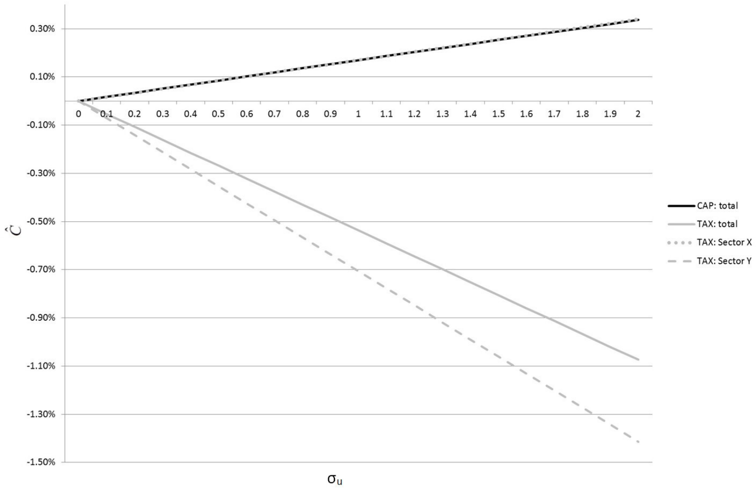

Figure 1: Changes in emissions for price-based and mixed (tax-cap) regulatory regimes as a function of the elasticity of substitution in consumption σ_u. ($\sigma_y = 1, \hat{m} = 2\%$)

Generally the impact of a campaign on emissions increases in the elasticity of substitution in consumption. If goods are perfect complements ($\sigma_u = 0$), there is no effect on emissions in either of the regimes. At unit elasticity (Cobb-Douglas case) a 2% increase in m induces a 0.54% reduction in aggregate emissions if both sectors are regulated by a tax (note, the level of the taxes is irrelevant for this result) but increases total emissions by 0.17% if sector Y is regulated by a binding cap, everything else equal. While the absolute value of the effect is smaller under a partial cap than under a tax, it has the opposite sign, is still sizable and clearly different from the zero-effect predicted by conventional analysis of instruments overlapping a cap-and-trade scheme.

The change in emissions in sector X in the two policy regimes (and hence the total effect in the cap-and-trade scenario) appear to be the same in Figure 1. While the differences are indeed very small, formally they are only identical if the elasticity of substitution of goods in consumption and the elasticity of substitution of inputs in sector Y are identical ($\sigma_u = \sigma_y$). If $\sigma_u > \sigma_y$, i.e. if consumers are more willing to substitute X for Y than firms in sector Y are to replace the clean input by the dirty input, then the change in emissions is, in absolute terms, smaller in the cap scenario and vice versa. The impact of varying σ_y on the relative size of changes in sector X emissions is illustrated in Figure 2. While there clearly is an effect, it is very small in magnitude unless the two factors are highly complementary in production. But even at $\sigma_y = 0.1$ the difference between the two changes in emissions is only 0.0133% of total emissions or 7.8% of the change in the tax-tax scenario.

Another interesting dimension is the difference between the change in emis-

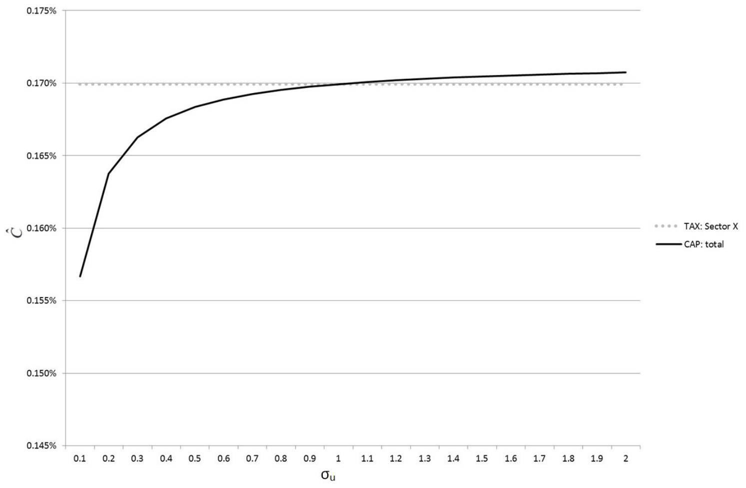

Figure 2: Changes in sector *X* emissions for price-based and mixed (tax-cap) regulatory regimes as a function of the elasticity of substitution in production σ_y. ($\sigma_u = 1, \hat{m} = 2\%$)

sions predicted by Proposition 2 and that of a naïve projection of a typical campaign message or carbon footprint calculator result. An example of the latter is the U.S. Environmental Protection Agency (EPA)'s "household carbon footprint calculator"[9] that states at its front page: "You can use the following online calculator to get a rough 'ballpark' estimate of your personal or family's greenhouse gas emissions and explore the impact of taking various actions to reduce your emissions." After asking for detailed information about car use, electricity and heat consumption and many other aspects of a household's lifestyle, it not only calculates a household carbon footprint but produces a list of tailored suggestions how this footprint can be reduced, estimating the associated reduction in the carbon footprint to the nearest pound of CO_2 per year for each. The latter is a simple linear function of the number of miles not driven or the number of light bulbs exchanged with energy efficient varieties. In the context of the present model this naïve projection of emission reduction is equivalent to $\hat{C}_x$ for $\hat{m} < 0$ and to $\hat{C}_y$ for $\hat{m} > 0$ in the tax-tax scenario because it ignores that the money saved in one sector will be spend in another and it keeps emission intensities of sectors constant. Table 2 presents the projected carbon reductions of the tax-tax and the partial cap scenarios and of a naïve version of the cap scenario where leakage effects are ignored. The last column gives the change in preferences required for these effects. The difference between column one and two is usually called the leakage effect. It comes from taking into account the change in emissions in other sectors of the economy (or abroad) but keeping everything else the same. Columns two and three

[9]Available at: $http://www.epa.gov/climatechange/ghgemissions/ind-calculator.html$ (last accessed: 26^{th} March 2015)

naïve campaign	tax-tax	partial cap	naïve cap	$\hat{m}$
-1 (from sector X)	4.17	-1	-1	-11.8
-1 (from sector Y)	-0.75	0.24	0	2.8

Table 2: Comparison of different projections of changes in total emissions (in percent) computed for $\sigma_u = \sigma_y = 1$ and the corresponding change in preferences.

contrast the two policy regimes analyzed above. Columns three and four indicate the contribution of considering intra-jurisdictional leakage effects for interventions overlapping a partial cap-and-trade program.

The scale of preference changes (column five in Table 2) is very different for the two sectors. This is driven by the differences in carbon intensity of the two sectors. Inducing a given reduction in pollution from a pollution intensive good (y) requires a much lower adjustment in the quantity demanded than for a less pollution intensive good (x). Note that the relative size of entries in a given row is not affected by the scale as all effects are linear in $\hat{m}$.

4 General climate campaign: Reduce your carbon footprint!

Instead of targeting a particular good or sector, many real world climate campaigns also focus on reductions of personal carbon footprints or total household emissions. Reductions in total household emissions are at the heart of both scientific research (Dietz et al., 2009; Druckman et al., 2011) and government run carbon footprint calculators[10]. Moreover, carbon footprint labels as e.g. defined by (BSI, 2011) or ISO 14067 measure the life-cycle emissions of specific products irrespectively of whether they occur within a cap-and-trade scheme. They provide the information necessary for consumers to reduce their personal carbon footprints.

In order to analyze a campaign that increases intrinsic motivation of households to reduce their carbon footprint, the utility function of the representative consumer needs to be specified in more detail. I follow Kotchen & Moore (2008), who formalize a common norm activation model adopted from the social psychology literature (Schwartz, 1970) to model voluntary restraint in household electricity consumption, in assuming that utility is additively separable into a «pure» consumption component $v(x,y)$ with $v_x > 0, v_y > 0, v_{xx} < 0, v_{yy} < 0$ and $v_{xy} > 0$ and intrinsic motivation to reduce the personal carbon footprint or voluntary restraint $m \cdot h(PCF)$ where $PCF = x\frac{C_x}{X} + y\frac{\bar{C}_y}{Y}$ is the personal carbon footprint and the voluntary restraint function $h()$ satisfies $h' > 0$. $\frac{C_x}{X}$ and $\frac{\bar{C}_y}{Y}$ are emission intensities of goods x and y, respectively. A similar but linear representation can be found in

[10]See e.g. the EPA's version ($http://www.epa.gov/climatechange/ghgemissions/ind-calculator.html$, accessed 26th March 2015) or the UK government's "Act on CO_2 Calculator" ($http://carboncalculator.direct.gov.uk/index.html$, accessed 31st March 2014).

Heyes & Kapur (2011). To reflect that an individual consumer's decisions cannot affect emission intensities I distinguish between an individual's consumption (lower case letters) and aggregate consumption (upper case letters) for both goods. This specification of the utility function represents «warm glow» type intrinsic motivation (Andreoni, 1990) where the parameter $m \geq 0$ measures the degree to which a consumer cares about her carbon footprint. The higher m, the higher the weight consumers place on reducing their personal carbon footprint relative to the direct benefits of consumption. A climate campaign that increases m of a representative consumer can hence be interpreted as activating the norm of some consumers to reduce their carbon footprint (or intensifying it in others).

Note that the resulting utility function

$$u(x,y;m,C_x,C_y,X,Y) \quad = \quad v(x,y) - m \cdot h\left(x\frac{C_x}{X} + y\frac{\bar{C}_y}{Y}\right), \tag{10}$$

is neither homothetic nor does it satisfy the conditions of non-satiation but features a bliss point. Hence, for each set of intrinsic motivation $m > 0$, price p_y and strictly positive emission intensities for both goods, there is an income level for which the budget constraint ceases to be binding. A consumer would hence rather 'burn' some of her money than spending it on something that further increases her personal carbon footprint. In what follows I restrict attention to cases where the budget constraint is binding and hence non-satiation holds in the relevant range as this is the empirically more plausible case. In a richer model where consumers decide on their labor supply, this problem is likely to disappear as consumers would not sacrifice leisure to earn money that they do not intend on spending.

It is important to recall that Lemmas 1 - 4 hold regardless of the representation of campaigns or the type of utility function. Moreover, the qualitative effect of a campaign on emissions in the two policy scenarios only depends on the shift in relative demand of the two goods. Under a purely tax based climate policy regime, the net effect on total emissions depends on whether demand shifts towards or away from the emission intensive sector. Under a partial cap, a shift of demand away from the capped sector will always increase total emissions. Hence, how the campaign increasing the urge of consumers to reduce their personal carbon footprint affects emissions in the two regimes depends on how an increase in m affects relative demand of the two goods (at given prices). This is determined by how it affects the marginal rate of substitution. Using the specific utility function of the representative consumer (10), the marginal rate of substitution is

$$MRS_{yx} \quad = \quad \frac{u_x}{u_y} = \frac{v_x - m \cdot h'(PCF) \cdot \frac{C_x}{X}}{v_y - m \cdot h'(PCF) \cdot \frac{\bar{C}_y}{Y}}.$$

The partial derivative with respect to m using $MRS_{yx} = 1/p_y$ is hence

$$\frac{\partial MRS_{yx}}{\partial m} \quad = \quad \frac{h'(PCF)}{u_y} \cdot \left[\frac{\bar{C}_y}{p_y \cdot Y} - \frac{C_x}{X}\right]. \tag{11}$$

The first term on the right hand side of (11) is unambiguously positive. The sign of (11) therefore depends on the term in square brackets and hence on the relative carbon intensity of the capped and the uncapped sectors measured in tons of CO_2 emissions per unit of the numeraire. If the capped sector Y is more emission intensive than the uncapped sector X, then the marginal rate of substitution increases in m which implies that demand shifts from sector Y to X. In the tax-tax regime this implies that total emissions go down, as emission intensity is also the criterion determining whether emissions go up or down. This regulatory regime therefore is supportive of the campaign induced preference change. However, in the partial cap regime, a campaign increasing the intrinsic motivation of consumers to reduce their personal carbon footprint would increase aggregate emissions. Sector X would expand, increasing emissions while output of sector Y would contract but not its emissions due to the binding cap and input substitution by firms in that sector.

Proposition 3 *A climate campaign successfully increasing the intrinsic motivation of consumers to reduce their personal carbon footprint:*

- *reduces total emissions, if all sectors are subject to an emission tax, regardless of which sector is more emission intensive.*
- *increases total emissions in the partial cap-and-trade regime, if the sector subject to a cap-and-trade scheme is more emission intensive (i.e. $r = \bar{C}_y/C_x \cdot X/(p_yY) > 1$).*
- *reduces total emissions in the partial cap-and-trade regime, if the sector not covered by the cap is the more emission intensive one (i.e. $r = \bar{C}_y/C_x \cdot X/(p_yY) < 1$).*

Existing cap-and-trade schemes tend to focus on emission intensive sectors like power generation, steel production, air transport and others. The average emission intensity of the sectors covered is therefore higher than in sectors not bound by the cap. Using the same data as in Section 3.3 confirms this for the EU ETS. In 2011 the EU ETS covered about 41.3% of all greenhouse gas emissions in the EU[11] but its output is valued at 14.6% of the total value generated by all sectors.[12]

$$r_{EUETS} = \frac{\bar{C}_y}{C_x} \cdot \frac{X}{p_yY} = \frac{0.413}{0.587} \cdot \frac{0.854}{0.146} \approx 4.14 > 1$$

[11] European Environmental Agency

[12] The value of the output produced by EU ETS and non-EU ETS sectors is taken from EUROSTAT's sector specific GDP tables for the year 2011 giving the supply for sixty sectors. The following sectors were classified as EU ETS sectors: Manufacture of paper and paper products (C17); Manufacture of coke and refined petroleum products (C19); Manufacture of chemicals and chemical products (C20); Manufacture of other non-metallic mineral products (C23); Manufacture of basic metals (C24); Electricity, gas, steam and air conditioning supply (D35). While the definition of sectors does not perfectly overlap with the roughly 11,000 installations covered by the EU ETS, the EUROSTAT statistics are likely to include a wider set of firms and hence is likely to underestimate the emission intensity of the EU ETS sector.

where the numbers plugged in represent shares of total emissions and GDP, respectively. While this is only a rough estimate, the EU ETS sectors clearly have an above average emission intensity. In such a setting a climate campaign raising the intrinsic motivation to reduce personal carbon footprints or total household emissions is predicted to unambiguously increase total emissions under a binding and exogenous cap.

There is a further interesting aspect to this result. Because all consumers are alike in this simple model, an increase in aggregate emissions implies that each consumer's carbon footprint increases as well, despite a campaign that successfully increased the desire of all consumers to emit less. So the campaign not only increased total emissions, it also makes everyone feel worse about it.

There are two ways of justifying the preference structure used here: The first is empirical. There is experimental evidence that consumers care about their personal carbon footprint even if they are fully aware that this has no impact on total emissions (Braaten, 2014).[13] A second view is that what consumers really care about are aggregate emissions but that they misconceive the impact of their individual choices on aggregate outcomes. This misconception is supported by the way many climate campaigns are framed. While they focus on the emissions technically associated with specific choices or products or rank particular options in terms of climate impacts, they are usually silent on interactions with the existing regulatory environment. Unless consumers are aware of the - often complicated - regime of environmental regulation, can identify all emissions covered by a cap-and-trade scheme in the entire production process of a good and know some general equilibrium theory (or happen to have read this paper), they are unlikely to be able to correctly deduce a course of action that is in line with their objective to reduce aggregate emissions. Hence, if the second interpretation is correct, then unless consumers (and campaigners and regulators) fully understand the implications of cap-and-trade schemes, additional mitigation efforts are misallocated with effects potentially running counter of those intended. The extend of the misconception would affect the size of effects with the paradoxical effect of campaigns overlapping a cap-and-trade scheme vanishing if consumers care about net emissions instead of personal carbon footprints, posses complete knowledge of production processes and environmental regulation and a master general equilibrium theory. However, currently at least the former seems highly unlikely because the identification of emissions subject to a cap-and-trade scheme is highly complex outside the electricity sector (which is usually fully covered and involves only a small amount of trade with jurisdictions not participating in the cap-and-trade scheme) and campaigns and labels do generally not provide any information on this aspect.

[13] See also Crumpler & Grossman (2008) for related evidence in the context of charitable giving.

5 Extensions

This section checks the robustness of the results derived above. First, a further option, namely the purchase and retirement of emission allowances by consumers is considered. Second, the assumptions on supply elasticities of inputs are relaxed. Third, the industry structure is extended to include additional sectors. Fourth, other regulatory interventions overlapping a partial cap-and-trade scheme are briefly discussed.

5.1 Retiring of allowances

Consumers wanting 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 permanently withholding them from the market and hence making them unavailable 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.[14]

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 Baylis et al. (2014) 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, but 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. Baylis et al. (2014) conduct a series of simulations 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%.[15] This is confirmed by a more detailed CGE based analysis

[14] 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.

[15] 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.

of intra-economy leakage effects by Carbone (2013) and Winchester & Rausch (2013). The former finds leakage rates in the range between -8.5% and 27.29%.

Note that Baylis et al. (2014) consider an exogenous increase in regulatory stringency. Compared to that purchasing and retiring of allowances by consumers has an additional effect on their budget to be spend on purchases of consumption goods. If good x is a normal good, then the fact that consumers spend money on retiring permits ceteris paribus results in a contraction of sector X. 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.

5.2 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 these assumptions are relaxed?

The broad answer to this question is that the size of effects might be affected, but generally they do not vanish. The basic mechanism in this model is that shifts in demand induced by a climate campaign result in some of the clean factor relocating from one sector into the other and thereby causing emissions to leak. As long as this is the case the basic reasoning is unaffected although scales of course might differ.

A simple way to induce inelastic supply of the dirty input is to interpret the dirty input as the amount of fossil fuels consumed and each unit being associated with a fixed amount of carbon emissions. Fossil fuels are produced by converting one unit of the clean input into dirty input (see Baylis et al., 2014). In this case condition (1) becomes

$$\alpha_{XL}\hat{L}_x + \alpha_{YL}\hat{L}_y + \alpha_{XC}\hat{C}_x + \alpha_{YC}\hat{C}_y = 0, \tag{12}$$

where α_{ij} represents the share of the clean input used in sector i for purpose $j \in \{L, C\}$. In this specification the price of the dirty input in the absence of environmental regulation is the same as the one for the clean input w. If environmental regulation takes the form of a tax, it is added to the costs of converting the clean input into dirty input. If there is a cap-and-trade, the allowance price is reduced by w. Keeping the assumption that the cap is binding, the new price of emission allowances is still strictly positive. 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. It can be shown that Propositions 1 and 2 still hold with just minor re-interpretations of coefficients (see appendix). However, if the supply of the dirty input is perfectly inelastic, the results break down. The problem becomes trivial and is equivalent to an aggregate cap on emissions with trading restrictions between sectors (Burniaux & Martins, 2012).

The elasticity of supply for the clean input does not matter if the rest of the setup (especially the constant returns-to-scale technology in sector X) is as above.

Since the price of the clean input does not change (Lemmas 1 and 3), equilibrium supply of the clean input stays the same as well and hence all propositions still hold. This also holds if the supply of the clean input is perfectly elastic (see appendix).

As mentioned above, this holds for campaigns affecting consumers' preferences for consumption. If campaigns would successfully change the supply of the clean factor (e.g. a successful "work less" or "spend time in nature instead of in a factory harming it" type of campaign) then the conclusions might be different. But this is left to future research.

5.3 Extending the industry structure

Given the strong results in Section 3.2, are there plausible and straightforward extensions of the model that could change the results? The simple two sector setup focuses on shifts in demand and factors between different regulatory frameworks and no attention is paid to heterogeneity of sectors subject to the same instrument. However, both the part of the economy subject to an emissions tax and that subject to a cap-and-trade scheme in reality would consist of different sectors or at least a set of heterogeneous firms each with their own emission intensity. So far any of these parts of the economy were only allowed to vary in scale, keeping composition fixed. However, campaigns and the resulting shift in preferences would plausibly also affect relative demand for specific sectors or firms.

For the part of the economy subject to a carbon tax, composition effects are well described by the analysis in section 3.1. Keeping everything else the same, a shift towards emission intensive sectors or firms increases emissions and a shift towards less emission intensive ones decreases emissions. This might hence both re-enforce or dampen any effect brought about by changes in the scale of this part of the economy as is well known from the literature on trade and the environment (Copeland & Taylor, 2004).

Cap-and-trade schemes cover firms with different emission intensities (e.g. coal vs. gas fired power plants) and some cover several sectors (e.g. electricity, pulp and paper, basic metals, chemicals etc.). While shifts in the composition within the cap-and-trade scheme does not affect emissions directly, it affects the amount of clean input that is released into or taken from the sectors not covered by the cap and hence the size of the scale effect. Hence, it could be conceived that a campaign focusing on a particularly emission intensive sector under a cap-and-trade scheme (e.g. air transport) might induce demand to shift towards a sector also covered by the cap that is less emission intensive (e.g. electricity powered rail transport). The net effect might be that overall the sectors under the cap demand more not less of the clean input which would imply a negative scale effect for the part of the economy outside the cap. In this case the results derived in Sections 3.2 and 4 would no longer hold qualitatively. However, to identify the exact effects one would need to consider the substitution patterns, emission intensities and regulatory environment for each specific case. In the above example, also diesel-powered trains and coaches might attract some of the business and since both are typically not covered by cap-and-trade schemes, the net effect on emissions is ambiguous.

5.4 Other instruments overlapping a cap-and-trade scheme

The question of how regulatory interventions overlapping a partial cap-and-trade scheme affect total emissions is of much broader relevance. While cap-and-trade schemes are often considered the flagship climate policy instruments if they are used, they are hardly ever the only piece of environmental regulation directly or indirectly aiming at reducing greenhouse gas emission of industries subject to the cap. There are policies supporting renewable energy[16], emission rate standards (e.g. President Obama's Climate Action Plan targeting US coal-fired power plants), energy efficiency requirements[17], restrictions on products (e.g. the ban of incandescent light bulb in EU, the US and other countries) or even carbon taxes (UK Carbon Price Floor) overlapping with cap-and-trade schemes. A detailed analysis of these policies is beyond the scope of this paper, but the basic analytical framework can be easily extended to investigate the impact of such policies. Jarke & Perino (2015) do this for the case of policies supporting renewable energy, promoting energy efficiency and the diffusion of power-to-heat and power-to-gas solutions. Their results are somewhat more optimistic in that these policies generally reduce aggregate emissions despite the binding cap in the targeted sector. However, if e.g. feed-in tariffs are financed by a levy on electricity instead of by a lump-sum tax, then this might be reversed and an expansion of the renewable sector might cause total emissions to increase.

6 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 than is currently the case. So far, climate campaigns by 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 at least in the short to medium run.

[16] In 2013 over 70 countries had some form of feed-in tariff for renewables in place (REN21, 2013, p. 68).

[17] For an up-to-dated overview of energy efficiency policies, see the Energy Efficiency Policies and Measures Database of the International Energy Agency (IEA) accessible under `http://www.iea.org/policiesandmeasures/energyefficiency`.

Campaigns that target goods produced by sectors not covered by a cap-and-trade scheme are predicted to 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 tend to shift demand away from sectors subject to the cap and shift it - and both clean and dirty resources - toward sectors not subject to an upper bound on carbon emissions. Total emissions are predicted to increase as a result. If all sectors are regulated by carbon taxes, then campaigns focusing on personal carbon footprints are effective as aggregate emission reductions depend on shifting consumption from emission intensive to less intensive sectors. Hence, campaigns to reduce carbon footprints or avoid emission intensive goods can act as complements to a tax based climate policy. Once a part of the economy is subject to a binding cap on emissions, however, this no longer holds. Only campaigns explicitly taking the regulatory setting and substitution elasticities into account are likely to be effective in reducing aggregate emissions within the period for which .

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 short or medium-term 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 Proofs

A.1 Proof of Lemma 1

The exogenous shock is the change in m and hence tax rates are constant $\hat{t}_x = \hat{t}_y = 0$. From conditions (2) and (4) it immediately follows that if $\hat{t}_x = 0$, then also $\hat{w} = 0$. Similarly, given $\hat{t}_y = 0$ and $\hat{w} = 0$, then (3) and (5) imply that $\hat{p}_y = 0$.

A.2 Proof of Lemma 2

Since prices are fixed (Lemma 1), conditions (6) and (7) imply that $\hat{L}_x = \hat{C}_x$ and $\hat{L}_y = \hat{C}_y$, respectively. Using conditions (2) and (3) shows that output quantities change in line with inputs. Condition (1) establishes the link across sectors.

A.3 Proof of Proposition 1

Emissions of sectors X and Y follow directly from Lemma 2 and condition (9). The result on total emissions then only requires to totally differentiate $C = C_x + C_y$ and rearranging of terms.

A.4 Proof of Lemma 3

The result for sector X is analogue to that of Lemma 1. The condition for sector Y follows from conditions (3), (5) and $\hat{C}_y = \hat{w} = 0$.

A.5 Proof of Lemma 4

The first part of Lemma 4 is is analogue to Lemma 2. Condition (3) and $\hat{C}_y = 0$ yield $\hat{Y} = \theta_{YL}\hat{L}_y$. Again, condition (1) establishes the link across sectors.

A.6 Proof of Proposition 2

To replace $\hat{Y}$ and $\hat{p}_y$ in condition (9) it is necessary to express them as functions of $\hat{X}$. From condition (7) and $\hat{C}_y = \hat{w} = 0$ if follows that $\hat{L}_y = \sigma_y \hat{t}_y$. Using this, Lemmas 3 and 4 yields $\hat{Y} = \frac{\theta_{YL}}{\theta_{YC}}\sigma_y \hat{p}_y$ and $\hat{p}_y = -\frac{\alpha_x}{\alpha_y}\frac{\theta_{YC}}{\sigma_Y}\hat{X}$.

A.7 Proofs for inelastic supply of dirty input

In the tax-tax case, Lemma 2 allows to simplify condition (12) to $(\alpha_{XL} + \alpha_{XC})\hat{X} + (\alpha_{YL} + \alpha_{YC})\hat{Y} = 0$. Solving this for $\hat{Y}$, plugging it into (9) and solving for $\hat{X}$ yields $\hat{C}_x = \hat{X} = (\alpha_{YL} + \alpha_{YC})\sigma_u \hat{m}$. Equivalently, for $\hat{C}_y = \hat{Y} = -(\alpha_{XL} + \alpha_{XC})\sigma_u \hat{m}$. These terms replace those in Proposition 1 if the dirty input is not perfectly elastic but follows condition (12).

In the partial cap case, Lemma 4, condition (3) and $\hat{C}_y = 0$ allow to simplify condition (12) to $(\alpha_{XL} + \alpha_{XC})\hat{X} + \frac{\alpha_{YL}}{\theta_{YL}}\hat{Y} = 0$. Solving for $\hat{Y}$ and using conditions

(3), (5) and (7) yields $\hat{p}_y = -\frac{\alpha_{XL}+\alpha_{XC}}{\alpha_{YL}}\frac{\theta_{YC}}{\sigma_y}\hat{X}$ Substituting this and the expression for $\hat{Y}$ into (9) and solving for $\hat{X}$ yields $\hat{C}_x = \hat{X} = \frac{\sigma_u}{1+\frac{\alpha_{XL}+\alpha_{XC}}{\alpha_{YL}}\theta_{YL}+\frac{\alpha_{XL}+\alpha_{XC}}{\alpha_{YL}}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{m}$. This term replaces the one in Proposition 2 if the dirty input is not perfectly elastic but follows condition (12).

A.8 Proofs for perfectly elastic supply of clean input

With a perfectly elastic supply of the clean input, condition 1 has to be dropped and replaced by a condition obtained from totally differentiating the (binding) budget constraint ($X + p_yY = wL + t_xC_x + t_yC_y$) which yields

$$\beta_x\hat{X} + \beta_y(\hat{Y} + \hat{p}_y) - \gamma_L\hat{L} - \gamma_{XC}\hat{C}_x - \gamma_{YC}(\hat{C}_y + \hat{t}_y) = 0, \tag{13}$$

where β_i is the share of income spend on consumption of good i, e.g. $\beta_x = X/(X + p_yY)$, $\gamma_L = (wL)/(wL + t_xC_x + t_yC_y)$ and γ_{iC} the share of income generated from lump-sum transfers originating from environmental regulation in sector i. It holds that $\beta_x + \beta_y = 1$ and $\gamma_L + \gamma_{XC} + \gamma_{YC} = 1$.

For the tax-tax case using Lemmas 1 and 2 to simplify (13) and solving for $\hat{Y}$ yields $\hat{Y} = -\frac{\beta_x-\gamma_{XC}}{\beta_y-\gamma_{YC}}\hat{X}$. Plugging this into (9), solving for $\hat{X}$ and simplifying yields $\hat{X} = \frac{\beta_y-\gamma_{YC}}{1-(\gamma_{XC}+\gamma_{YC})}\sigma_u\hat{m}$. Substituting in the definitions of β_i and γ_{ij} yields $\hat{C}_x = \hat{X} = \frac{L_y}{L}\sigma_u\hat{m}$. Since $\alpha_y = \frac{L_y}{L}$ the first part of Proposition 1 holds if supply of the clean input is perfectly elastic. The proofs for the second and third part are analogous.

For the partial cap case using Lemmas 3 and 4 condition (13) becomes $\beta_x\hat{X} + \beta_y(\hat{Y} + \hat{p}_y) = \gamma_{XC}\hat{X} + \gamma_{YC}\frac{\hat{p}_y}{\theta_{YC}}$. Using $\hat{p}_y = \frac{\theta_{YC}}{\theta_{YL}\sigma_y}\hat{Y}$ (from conditions (3), (5) and (7)) and solving for $\hat{X}$ yields $\hat{Y} = -\hat{X}\frac{\sigma_y\theta_{YL}(\beta_x-\gamma_{XC})}{\beta_y\theta_{YC}+\beta_y\sigma_y\theta_{YL}-\gamma_{YC}}$. Substituting this and again $\hat{p}_y = \frac{\theta_{YC}}{\theta_{YL}\sigma_y}\hat{Y}$ into (9) and rearranging yields,

$$\hat{C}_x = \hat{X} = \frac{\sigma_u}{1 + \frac{(\sigma_y\theta_{YL}+\sigma_u)(\beta_x-\gamma_{XC})}{\beta_y\theta_{YC}+\beta_y\sigma_y\theta_{YL}-\gamma_{YC}}}\hat{m}. \tag{14}$$

Substituting in the definitions of β_i, γ_{iC} and θ_{YC} and simplifying yields $\hat{C}_x = \hat{X} = \frac{\sigma_u}{1+\frac{wL_x}{p_yY}+\frac{wL_x\theta_{YC}\sigma_u}{p_yY\theta_{YL}\sigma_y}}\hat{m}$. Using the definitions of α_i and θ_{YL} this becomes $\hat{C}_x = \hat{X} = \frac{\sigma_u}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YL}}\hat{m}$. This proves that Proposition 2 holds if the supply of the clean input is perfectly elastic.