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Pigou pushes preferences: decarbonisation and endogenous values

Linus Mattauch[*] Cameron Hepburn[†] Nicholas Stern[‡]

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Abstract

Avoiding unmanageable climate change implies that global greenhouse gas emissions must be reduced rapidly. A significant body of literature shows that policy instruments such as carbon prices can make an important contribution to this goal. In contrast, changes in preferences or values are rarely considered, even though other major socioeconomic transitions – such as those from reducing smoking and drink-driving – have succeeded partly because values have changed. This article examines the impact of climate policy-induced changes in consumers' values. We demonstrate that when changes in values through policies occur, and are not accounted for, such policies are inefficient. First, target-achieving carbon taxes must be adjusted if they crowd-in or -out social preferences. Second, when the urban built environment changes mobility preferences, low-carbon infrastructure investments are more valuable. Third, policy-induced changes in preferences for active travel and low-meat diets could increase the net benefits of the transition to zero emissions, in turn affecting optimal policy.

JEL codes: A12, D91, H23, Q54, Q58

Keywords: climate change, carbon pricing, endogenous preferences, crowding-in, transport infrastructure, health co-benefit

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1 Introduction

The High-Level Commission on Carbon Pricing concluded that carbon prices in the range of US $50-100/t CO_2 by 2030 globally are needed to deliver the temperature targets of the Paris agreement (Stiglitz and Stern, 2017).[1] The Commission also found that other climate policy interventions, working in concert with carbon pricing, are required to efficiently achieve global climate targets (Stiglitz and Stern, 2017). This article explores the relationship between carbon prices and policies that change consumers' preferences, intentionally or unintentionally.

Our starting point is that an increasingly large body of evidence within economics and other social sciences indicates that preferences can be endogenous to policy decisions (Bowles, 1998; Alesina and Fuchs-Schündeln, 2007; Fehr and Hoff, 2011; Fuchs-Schündeln and Schündeln, 2015; Hoff and Stiglitz, 2016). Even our values[2] and culture[3] – upon which preferences are based (Hoff and Stiglitz, 2016) – are amenable to change by policy. Changes in values and culture can in turn drive long-lasting changes in behaviour[4] as shown by changes in attitudes to issues such as smoking, drink-driving and recycling (Nyborg and Rege, 2003; Convery et al., 2007; Nyborg et al., 2016). Much research in economics, however, continues to assume that preferences are exogenous, despite notable exceptions (Gintis, 1974; Pollak, 1978; von Weizsäcker, 1971). Within environmental economics, there is a small literature on endogenous preferences (Perino, 2015; van den Bijgaart, 2018), norms (Ulph and Ulph, 2018; Dasgupta et al., 2016) and culture (Schumacher, 2015).

This article has a dual purpose: First, we argue that the transition to a low-carbon economy will be more efficient[5] if it is recognised that preferences can be endogenous to policy decisions. We examine three examples in which policy affects preferences: (i) the impact of carbon prices on preferences for low-carbon consumption options; (ii) the impact of transport infrastructure on mobility preferences; and (iii) the impact of policy on preferences for

[1] These targets imply that greenhouse-gas emissions must be reduced to net zero in the second half of this century (IPCC, 2013; Clarke et al., 2014). This is reflected in the language of "achiev[ing] a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases" (United Nations/Framework Convention on Climate Change, 2015, Article 4), see also Fuglestvedt et al. (2018).

[2] 'Values' are defined by the Oxford English Dictionary as 'the principles or moral standards held by a person or social group; the generally accepted or personally held judgement of what is valuable and important in life'.

[3] 'Culture' is relevantly defined as 'a way of life or social environment' and as 'the philosophy, practices, and attitudes of an institution, business, or other organization'.

[4] It is established that values shape human actions by influencing emotions, and that values are acquired through social interactions and learning experiences (Schwartz, 1994); see Akerlof (2017) and Roos (2018) for applications in economics and Corner et al. (2014) for climate change.

[5] This notion needs some care when preferences are endogenous, see below.

low-carbon diets and active travel. Second, we develop a simple theoretical model that illustrates the core idea, and employ it to elucidate aspects of these three examples. It has the property that a change in values towards low-carbon consumption leads to more climate change mitigation, which is helpful for reaching climate targets in absence of adequate regulation. It is also advantageous to the individual to adjust values: one can get more utility if one puts more value on cheaper options. The model permits us to answer two guiding questions: If a carbon price has an influence on values, how does this affect Pigouvian[6] pricing? How is appropriate policy different when it is recognised that it can shift low-carbon preferences and decisions through changed values?

Specifically, we formally demonstrate the following results. First, if carbon policy changes consumers' values, not merely relative prices, then the policy will be inefficient unless one accounts for that change in values. Second, if low-carbon infrastructure increases the propensity to consume low-carbon goods over time, the marginal value of investing into such infrastructure is higher. Third, a shift in values towards active travel and low-carbon diets can lead to substantial health benefits, in addition to lowering the cost of the low-carbon transition.

To be clear, we are not advocating for interventions to undermine people's freedom to develop their own objectives and to make their own choices. Rather, we observe that policy often indirectly or directly affects values and preferences – whether we like it or not. Public dialogue and discussion can inform the evolution of societal values, without violating freedoms. This can help resolve conflicts between different freedoms – shifts in societal attitudes have reduced the freedom to smoke, and increased the freedom to enjoy public spaces without an increased risk of cancer. Shifts in preferences for transport, energy and food choices could protect freedoms by reducing deaths and impacts from climate change. In the cases of smoking and drink-driving, societies chose to guide the processes of shifting values (Nyborg and Rege, 2003; Stuber et al., 2008; Levy et al., 2012; Mons et al., 2013; Watling and Armstrong, 2015) and information and education campaigns took place, alongside price interventions and bans (Stern, 2015, Ch. 10). The scale of the challenge of reducing greenhouse gas emissions suggests that a similar combination of approaches – mindful of the balance of individual freedoms – may be desirable to meet socially-agreed goals (Markowitz and Shariff, 2012; Stern, 2015). Such goals (e.g. emissions targets agreed by inclusive scientific and political processes) simplify analysis in the presence of endogenous preferences. When policy can alter people's preferences, welfare analysis requires going beyond the simple ordinal utility, as discussed further in Section 5).

[6]See Pigou (1920). In this context, a Pigouvian price is the price at which the external cost is fully internalised with the impact of prices on preferences being accounted for.

Our contribution builds on several key articles. Bowles and Hwang (2008) examines optimal public good provision with endogenous preferences, and Frey and Stutzer (2008) and Bowles and Polania-Reyes (2012) discuss crowding-in and -out of intrinsic motivation by policy measures, and relate the size and direction of the effects to the properties of these measures.[7] Bisin and Verdier (2001) study the intergenerational transmission of preference traits. Schumacher (2015) considers the relationship between culture and environmental quality. van den Bijgaart (2018) studies the optimal transition policy when habits are affected by past consumption decisions (Pollak, 1970; Ryder and Heal, 1973) and consumers fail to internalise shifts in habits. Ulph and Ulph (2018) find that taxes can be welfare-reducing when individuals adjust their consumption to conform to the norms of a group to which they wish to belong. Dasgupta et al. (2016) examine environmental policy given consumption norms and the social context of consumption. Daube and Ulph (2016) examines how values can help achieve objectives in situations of inadequate regulation. Jacobsen et al. (2012) develops a theory of voluntary public good provision when households are motivated to offset the environmentally harmful behaviour of others. Perino (2015) examines the effectiveness of climate campaigns as a function of the policy setting. Our work is novel in formally characterising how the possibility of such preference changes by policy affect appropriate regulation and Pigouvian taxation.

The remainder of this article is structured as follows: The next section describes the evidence that preferences are endogenous to policies and institutions, it then relates this thesis to specific examples relevant to the transition to the low-carbon economy. Section 3 constructs a simple illustrative model of endogenous preferences and carbon pricing. Section 4 extends this model to the cases of preference formation by (transport) infrastructure, as well as of the health benefits from low-carbon diets and active travel. Section 5 briefly explores normative and policy implications. Section 6 concludes.

2 Evidence of endogenous preferences

There is a wealth of evidence in psychology and sociology that the underpinnings of human choice – preferences, beliefs and decision-making processes (DellaVigna, 2009) – are culturally formed (Bowles, 1998; Hoff and Stiglitz, 2016). This importance of culture and values to our choices goes beyond the empirical evidence from behavioural economics that behaviour is context-dependent and may appear to be frequently "irrational" (Hoff and Stiglitz, 2016; Kahneman, 2011; Thaler and Sunstein, 2008). Preferences appear to be formed by cultural transmission and relate to our social identities (Akerlof

[7] See also the general approach of Bénabou and Tirole (2003, 2006) on intrinsic and extrinsic motivation.

and Kranton, 2000), worldviews and narratives (Hoff and Stiglitz, 2016).[8] Policy can and does change these worldviews, narratives, culture and values, and thus change preferences, which can alter decisions even if relative prices or specific decision contexts are unaffected.

Bowles (1998) provides a comprehensive review of evidence from biology, psychology and sociology on how preferences can change in market economies.[9] He argues that the assumption of fixed preferences limits the "explanatory power, policy relevance, and ethical coherence" of economic analysis (p. 75). Two surveys corroborate these conclusions. First, Fehr and Hoff (2011) find that preferences are prone to direct social influences; social institutions stimulate certain parts of people's identities through framing and anchoring effects.[10] They conclude that "[E]xogenous preferences is but a special and not very plausible example [. . .] among the possible set of assumptions about preferences that can be employed in explaining economic outcomes" (p. F409). Second, Hoff and Stiglitz (2016) concludes that preferences are formed through the social context and the use of cultural mental models to process information.[11] This literature provides evidence that policies shape preferences in respect to *consumption* options. A further set of papers demonstrates that policy can also shape preferences over *policy* options.[12]

[8]See Villacorta et al. (2003) for pro-environmental behaviour in particular. Further, Voors et al. (2012) and Cavatorta and Groom (2018) find that exposure to violent conflict changes preferences, Algan and Cahuc (2010) show that the level of trust among descendants of US immigrants is influenced by country of origin and the timing of arrival of their ancestors and O'Hara and Stagl (2002) and Russell and Zepeda (2008) consider how preferences may change through participation in community-supported agriculture.

[9]Bowles (1998) also argues that the primary channel for the development of preferences is cultural transmission. He finds that many economic incentives tend to negatively affect intrinsic motivation – behaviour is no longer driven by internal rewards Bowles (2008). See also Bowles (2016) on the impact of civic virtues in liberal societies.

[10]For example, Tompson et al. (2015) find, based on neurological evidence, that "personally and culturally tailored messages" (p. 58) lead to greater neural activation that causes greater subsequent behaviour change. Thus, it is argued that institutions are able to shape preferences by rendering particular identities, values and norms, more salient.

[11]Further examples include Deckers et al. (2017), who find a relationship between the prosociality of the mother and the prosociality of the child when at primary school; Tompson et al. (2015), who find differences between culturally salient messages for Western and non-Western societies; Algan and Cahuc (2010) on parent-child transmission of trust and economic preferences, and Malmendier and Nagel (2011) who show preferences for financial risk depend on experienced stock market returns. For a particularly drastic illustration of how mental models dominate women's everyday lives in India that lead to their suppression and to domestic violence, see Narayam (2018).

[12]For example, Fuchs-Schündeln and Schündeln (2015) shows that experience with democratic governments leads people to have a stronger desire for democracy. Further, Alesina and Fuchs-Schündeln (2007) demonstrate that East Germans have stronger preferences for state intervention then West Germans due to the different economic models in the two parts of the country in earlier times. As examples from environmental policy, Eliasson (2008) describe how public support for congestion charging in Stockholm

Given this evidence, in this paper we do not unpick the psychological and social processes through which policies change preferences and values.[13] We simply assume that policies can change preferences and/or the values that underpin them, and focus on the implications for the economics of decarbonisation. In terms of simple microeconomics, we can represent a change in values by shifting utility curves rather than by rotating the budget line caused by a change in relative prices (see Figure 1). The consequence of taking the evidence on changing culture and values seriously is that decarbonisation policy should account for potential shifts in preferences, and not merely focus on changing relative prices.

2.1 Three relevant examples

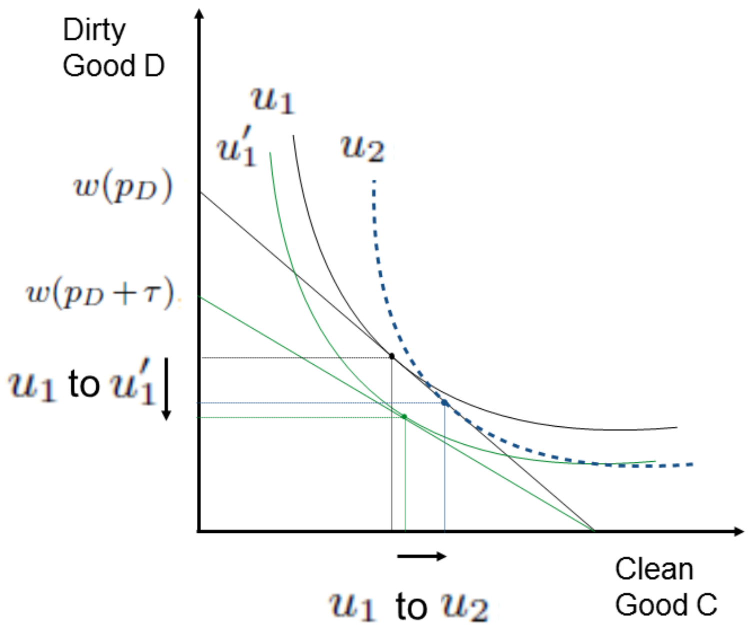
We now discuss three examples of endogenous preferences that are relevant to climate change mitigation policy. We focus on carbon-intensive and low-carbon consumption options in food and transport. This approach can be applied more broadly, however, for instance for energy efficiency, i. e. creating preferences that increase demand for energy-efficient options (Costa and Gerard, 2018; Hahn et al., 2016). In Sections 3 and 4 we formally explore the consequences for the design of climate policy.

Environmental pricing shapes environmental preferences: Several examples suggest that environmental pricing and subsidies can crowd-out or crowd-in environmental values, depending on the context – that is, the incentives increase or decrease intrinsic motivation to protect the environment. For instance, building on Perino et al. (2014), Lanz et al. (2018) find that a carbon price of £19/tCO_2 on food crowds-out intrinsic motivation to the extent that compensating for this effect requires the carbon price to rise by as much as £48/tCO_2. Frey and Oberholzer-Gee (1997) find that willingness to accept a nuclear waste site fell dramatically when monetary compensation was offered. Bowles and Polania-Reyes (2012) observes incentives may "... affect the process by which people learn new preferences" (p. 368). Lanz et al. (2018) and Mattauch and Hepburn (2016) conjecture that when pricing crowds out environmental preferences, the appropriate carbon price would need to be set higher than if preferences were fixed. Below we prove this conjecture and characterise first- and second-best policy options (Section 3). In contrast, Convery et al. (2007) find that the Irish

increased when the charge was put in place for a trial period: Carattini et al. (2018) study how support for pricing garbage by the bag increased when a Swiss court mandated a canton to introduce it.

[13]A literature in cognitive psychology finds that preferences are *not* stored in memory and retrieved, but are constructed when elicited (Lichtenstein and Slovic, 2006; Weber and Johnson, 2009).

Figure 1: Simple microeconomics of a shift towards less polluting consumption.



Preferences are commonly assumed to be fixed, so that only changes in (relative) prices affect the allocation of consumption between dirty and clean goods. Consider utility indifference curve u_1 at income w. An tax τ on the dirty good, D, increasing the price from p_D to $p_D + \tau$, rotates the budget constraint from $w(p_D)$ to $w(p_D + \tau)$, reducing dirty consumption and lowering utility to u_1', based on the same preferences as u_1. In contrast, a shift in values can be represented as a move in utility function from u_1 to u_2, which leads to lower consumption of D without any change in prices or budget.

plastic bag tax crowds-in environmental values.[14] In British Columbia, the salience of the carbon tax led to greater behaviour change than would be expected from an equivalent increase in gasoline prices (Rivers and Schaufele, 2015), a finding compatible with crowding-in environmental values.

Urban transport infrastructure shapes mobility preferences: Weinberger and Goetzke (2010) provide evidence that preferences for car ownership are determined by the built environment individuals are used to. When people move from a city with good public transport to a car-dependent city

[14]Similar taxes have now also been successfully implemented in the United Kingdom (Department for Environment Food & Rural Affairs, 2017) and several other countries.

they 'export' their mobility preferences to the new environment. They are more likely to own fewer vehicles due to learned preferences for lower levels of car ownership (Weinberger and Goetzke, 2010). Appropriate transport infrastructure is thus not only required to make low-carbon travel possible, but can also be a pre-condition for the learning of new mobility preferences. It is likely that this is mediated through peer effects (Weinberger and Goetzke, 2010, see also Mattauch et al., 2016; Mattauch and Hepburn, 2016). The finding is indicative of the well-established fact that urban form is a key determinant of energy consumption in cities (Newman and Kenworthy, 1999; Seto et al., 2014). Below we formally show that, when low-carbon infrastructure shapes mobility behaviour in this way, additional investments result in additional emission reductions, increasing the optimal level of such investment.

Policy can shape dietary and transport mode preferences to improve health and reduce emissions: Hawkes et al. (2015) describe the ways in which public health policies can help people "learn healthy food preferences". It is a societal choice as to which dietary habits should be fostered, consistent with robust evidence that diets are strongly influenced by cultural factors (Rozin and Vollmecke, 1986; Birch, 1999).[15] This is relevant to climate policy: Springmann et al. (2016) find that, by 2050, a shift toward more plant-based diets in line with standard dietary guidelines could reduce food-related greenhouse gas emissions by 29–70 % and decrease global mortality by 6–10 %.

Similarly, policies forming preferences for active travel modes have a health and environmental benefit. Increasing active travel in urban transport (such as walking and cycling) reduces obesity-related diseases, dementia and depression, and can also reduce local and global emissions Woodcock et al. (2009).[16] Dietary and travel choices might be understood as aris-

[15] A British supermarket chain claims that a third of Britons are aiming to reduce their meat-consumption, for both ethical reasons (including environmental concerns) and health-related motives (Waitrose, 2018). While this would be a relevant instance of a change in preferences and values that fosters decarbonisation, reliable data on changes in citizen's attitudes towards meat over time seems lacking.

[16] Numerous studies confirm the extensive health benefits from active travel increases. Woodcock et al. (2009) explore a scenario with greater active travel (slight increase in the distance walked and double increase in distance cycled), finding that the health gains from physical activity are greater than those from reduced air pollution in both London and Delhi. Rabl and De Nazelle (2012) calculate the benefits of switching from a car to cycling for trips under 5 km to be about 1300 Euro per person per year. Götschi et al. (2015) compare the health benefits that would accrue to the English population if they increased the proportion of active travel to the levels of Switzerland, California and the Netherlands and Mueller et al. (2017) systematically estimate what the health changes would be for populations in seven different cities in Europe following an increase in infrastructure encouraging active transport. For a comprehensive review see also Mueller et al. (2015).

ing from internally conflicting preferences (Loewenstein and Prelec, 1992; Loewenstein, 1996)) between unhealthy short-term desires and the long-term preference for good health. However, changes in preferences are also relevant, and the evidence suggests that values underlying preferences influence choice of travel mode (Hopkins, 2016; Hunecke et al., 2001; Steg, 2005) and diets (Allen et al., 2000). We formally discuss these ideas below.[17]

To the best of our knowledge, in none of the three cases illustrated above have the implications for adequate climate policy design been drawn by means of economic models, which is what we turn to next.

3 A model of a carbon tax that changes preferences

We construct a simple model to explore the potential importance of shifts in consumer preferences and the values underlying preferences. That is, we are interested in cases in which there is an (intended or unintended) impact of policy on the utility function itself, rather than only upon the choice set, relative prices, or budget constraints (see Figure 1).

After introducing the model in Subsection 3.1, we first set out some basic properties (Subsection 3.2): if carbon prices are insufficient and dirty goods are cheaper, a consumer is better off if her utility functions lead her to favour dirtier goods under some regularity (Proposition 1). If policy is aiming to meet a specific climate target, however, a shift in the utility function can help compensate for inadequate carbon pricing (Proposition 2). We then illustrate the main result of this section: when a carbon tax has an impact on values, the second-best tax differs from the conventional first-best tax depending on whether there is crowding-in or crowding-out (Proposition 3) – and we explore the strength of this effect. Furthermore, we demonstrate that there is a particular strength of crowding-in at which the second-best tax coincides with that first-best tax with fixed optimal values, but no crowding. The reason is that the crowding-in additionally helps to achieve the environmental target (Proposition 4). Finally, we sketch how such findings extend to optimal regulation and settings in which policy-makers might make costly attempts to change values.

We represent the influence of policy choices on consumers' values by augmenting the utility function with a parameter, α, that can be shifted by policy. Our aim is a simple formulation that can capture different underlying observationally-equivalent phenomena: changes in culture, values or habits. In a technical sense, we will refer to α as the consumer's 'appreci-

[17] Another example where preferences change in response to changes in values over time is in relation to status symbols (Veblen, 2007; Frey, 2008; Layard, 2011). We do not examine this here, but one might conjecture that the transition to the low-carbon economy would be facilitated if status symbols were low-carbon (Urry, 2013).

ation' of the clean good.[18] An increase in the appreciation of a good that the consumer already consumes can increase utility. One can think of α as resulting from culture or social influence, reflecting learned or inherited values or tastes. Although not our primary focus, we make the assumption that we can meaningfully think of appreciation as welfare-relevant, that is, we can compare utilities for different α in a meaningful way. This is true if utility is cardinal or if consumers have preferences over their appreciation (dependent on the allocation of goods),[19] as discussed further in Section 5.

3.1 Basic approach

Suppose consumers have a simple choice between two goods, one relatively clean C and one relatively dirty D, where the consumer's utility is also a function of the appreciation parameter α. The social planner problem may be expressed as:

$$\max_{C,D,\alpha} U(C, D, \alpha) \tag{1}$$

subject to

$$p_C C + p_D D = w - \xi D \tag{2}$$

where w is income, ξ is the damage intensity of dirty consumption – effectively environmental damage reduces income – and p_C and p_D are both consumer prices and production costs, since we abstract from modelling production. We assume $U_C, U_D > 0$.

We parametrise utility as:

$$U(\alpha C, (1-\alpha)D) = [(\alpha C)^\gamma + ((1-\alpha)D)^\gamma]^{\frac{1}{\gamma}} \tag{3}$$

and further assume $0 < \gamma < 1$, meaning that clean and dirty consumption are substitutes and $\alpha \in [0, 1]$ to ensure the problem has a solution.[20] For most of the analysis, we use the specific constant-elasticity-of-substitution

[18]The OED defines 'appreciation' as the action of 'assessing the nature or quality of something or someone; judgement, estimation.' See also Becker and Mulligan (1997), who incorporate 'appreciation' into their utility function. In their model, appreciation captures the vividness of the future, rather than a set of environmental values as here.

[19]The link between α and the structure of preferences is straightforward: higher α places greater weight on the clean good, C, in Equation (1), and thus re-shapes orderings and indifference curves. However, the relationship of α to welfare is far less straightforward, however. On the one hand, a consumer may experience greater utility from higher α from a positive self-image. On the other hand, α might rise as appreciation of the scale of the damage from pollution increases, which might the individual miserable, reducing utility. So there are plausible cases in which welfare decreases or increases as α increases.

[20]One might think that it is more natural to consider the parametrisation $[\alpha C^\gamma + (1-\alpha)D^\gamma]^{\frac{1}{\gamma}}$. While this indeed simplifies the process of calculating optimal appreciation for optimal environmental regulation, the problem of optimising appreciation for an environmental target then has no meaningful solution.

utility. It is occasionally more convenient to work with a generalisation of the specific function, however:

$$U(\alpha C, (1-\alpha)D). \tag{4}$$

This structure imposed on the interaction between goods and appreciation ensures that relevant problems have a solution. The functional form is related to those used in the literature on status-seeking and habits, where α represents the learned or inherited taste of the consumer or social influence.[21]

For such a general function, the first-order condition is

$$\frac{U_C}{U_D} = \frac{\alpha U_x}{(1-\alpha)U_y} = \frac{p_C}{p_D + \xi} \tag{5}$$

where U_x, U_y denote the derivative with respect to the first and second component of the function, respectively. Taken together with the budget constraint, this gives the optimal allocation (for fixed appreciation), which is unique if preferences are convex. For the parameterised case, the optimal ratio of consumption of clean to dirty goods for a given appreciation is:

$$\frac{C}{D} = \left(\frac{(1-\alpha)}{\alpha}\right)^{\frac{\gamma}{(\gamma-1)}} \left(\frac{p_C}{p_D + \xi}\right)^{\frac{1}{(\gamma-1)}} \tag{6}$$

Consider a policy maker intent on achieving a particular target[22], expressed here as a fixed amount of the dirty good, $\widetilde{D} > 0$, which in our model also leads to fixed emissions. This also determines consumption of the clean good via the budget equation: $\widetilde{C} = (1/p_C)\left(w - (p_D + \xi)\widetilde{D}\right)$.[23]

Now suppose the social planner can, at no cost, influence the level of appreciation of the clean good. Assuming utility is parametrised as in Equation (3), then the socially optimal appreciation α^{SO} to achieve the agreed emissions target is:

$$\alpha^{SO} = \left(\frac{\widetilde{D}}{\widetilde{C}}\right)^{\frac{\gamma}{\gamma-1}} / \left(1 + \left(\frac{\widetilde{D}}{\widetilde{C}}\right)^{\frac{\gamma}{\gamma-1}}\right). \tag{7}$$

This equates the marginal utility loss from a reduced value of dirty consumption with the marginal utility gain from a higher value of clean consumption.

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[21] See Abel (1990); van den Bijgaart (2018).

[22] The climate policy targets agreed by nations, rather than being understood as representing some 'optimal' level of warming, reflect a considered judgement of the best set of objectives in a complex and uncertain world, see for instance Kunreuther et al. (2013).

[23] This is only the case in a setting with two goods, which is the simplest possible for our research questions. In practice, consumers will optimise choice over a variety of products, and abatement possibilities, but subject to a constraint on total emissions.

3.2 Properties of the decentralised equilibrium

Consider a representative consumer who ignores the production externality, ξD, but who also faces a (unit) tax τ on dirty consumption (which is fully recycled to her). Suppose that she does not by herself adjust appreciation, and denote appreciation by α^M. (where M stands for "market"). Assuming the same parametrisation as above, her problem is:

$$\max_{C,D} U(\alpha^M C, (1-\alpha^M)D) \tag{8}$$

subject to

$$p_C C + (p_D + \tau)D = w + L. \tag{9}$$

L is the part of the budget of which the dependency on the tax and the damages are ignored by the consumer, $L = \tau D - \xi D$.

Pigouvian regulation and optimal appreciation First consider the case of optimally regulating the externality. For a general utility function, the first-order condition of the consumer is:

$$\frac{U_C}{U_D} = \frac{\alpha U_x}{(1-\alpha)U_y} = \frac{p_C}{p_D + \tau}. \tag{10}$$

In the classical treatment with exogenous appreciation ($\alpha^M = \alpha$), by comparison to Equation (5) it can be seen that the standard Pigouvian tax is $\tau = \xi$.

For the parameterised case, the optimal solution for a given appreciation is:

$$\frac{C^M}{D^M} = \left(\frac{(1-\alpha^M)}{\alpha^M}\right)^{\frac{\gamma}{(\gamma-1)}} \left(\frac{1}{1+\tau}\right)^{\frac{1}{(\gamma-1)}} \tag{11}$$

Instead, with variable appreciation the following can be established:

Proposition 1. *The optimal appreciation in the imperfectly regulated decentralised case ($\tau \neq \xi$) differs in general from the optimal appreciation in the socially optimal allocation, provided that $U(C) = U(\alpha C, (1-\alpha)D(C))$ is a strictly concave function in the domain given by $\alpha \in [0,1], p_c C \in [0, w]$.*

The proposition implies that it can be advantageous to adjust values to the level of environmental protection: a consumer can get more total utility if she puts more value on the consumption option that is cheaper. Without the concavity assumption, it is possible that the maximum value of U for simultaneously chosen allocation and appreciation is a boundary value, which is the same for the social planner and decentralised case. Variables with * denote the fully optimal solution in what follows.

Proof. Compare Equation (5) to Equation (10), which both yield an allocation of consumption and differ only by the occurrence of ξ and τ. According to the concavity assumption, the maximum α^* is in each case given by:

$$\frac{\mathrm{d}U(\alpha C^*,(1-\alpha)D^*)}{\mathrm{d}\alpha} = \frac{\partial U}{\partial x}C^* - \frac{\partial U}{\partial y}D^* = 0 \tag{12}$$

i.e., making use of the envelope theorem. In general, α^* depends on ξ and τ respectively, except in degenerate cases. □

We illustrate the assumptions of this result by the parameterised version of utility: the proposition is true for $0 < \gamma < 0.5$, since only then does the relevant expression depend on the carbon price. For $\gamma > 0.5$, the optimum is at the boundary at $C = (1/p_c)w, \quad \alpha = 1$. This insight is obtained by differentiating the value function of the social planner problem with respect to α :

$$\frac{\partial U(C,D,\alpha)}{\partial \alpha} = [(\alpha C)^{\gamma} + ((1-\alpha)D)^{\gamma}]^{\frac{1}{\gamma}-1}[\alpha^{(\gamma-1)}C^{\gamma} - (1-\alpha)^{(\gamma-1)}D^{\gamma}] \tag{13}$$

Setting to zero and inserting the optimal solution $\frac{C^*}{D^*}$ yields:

$$\alpha^* = \frac{\Omega}{1+\Omega} \text{ with } \Omega = \big(\frac{p_C}{p_D+\xi}\big)^{\frac{\gamma}{(2\gamma-1)}}. \tag{14}$$

In the decentralised case one finds by analogy:

$$\alpha = \frac{\Omega}{1+\Omega} \text{ with } \Omega = \big(\frac{p_C}{p_D+\tau}\big)^{\frac{\gamma}{(2\gamma-1)}}. \tag{15}$$

This only characterises a maximum for $\gamma < 0.5$, however, because otherwise the utility function is not concave in C.

We next describe an idealised formulation of how appreciation could be adjusted.

Appreciation not optimal, but can be adjusted at no cost: first-best case In real-world cases, it cannot be assumed that $\alpha^M = \alpha^*$, that is that the relative appreciation of clean and dirty goods equals the socially optimal appreciation (with the externality fully corrected). Instead, suppose for the first-best case, the government has a policy instrument to adjust appreciation ϵ : information campaigns or education (abstracting from the costs incurred for the government to do so, just as typically one abstracts from the transaction costs of levying taxes etc.). Think of this as acting on appreciation as follows:

$$U((\alpha+\epsilon)C, (1-(\alpha+\epsilon))D). \tag{16}$$

In this case, trivially, the first-best appreciation adjusting policy is $\epsilon = \alpha^* - \alpha^M$. *In the remainder of this section, we think of this instrument as the parallel case to individualised lump-sum taxes in public finance and hence rule it out.*

Target-compatible regulation Suppose as discussed that the government's problem is to set a "target-compatible" carbon price.[24] Further, in order to set a benchmark, let us suppose that appreciation happens to be the ideal level desired by the social planner, α^{SO}, so that only the tax needs to be set to achieve the agreed target.

The "target-optimal" tax can be determined by solving the problem given by Equations (8) and (9) with optimal appreciation to give the first-order condition of the consumer:

$$(1-\alpha^{SO})\frac{\partial U}{\partial Y} = \alpha^{SO}\frac{(p_D+\tau)}{p_C}\frac{\partial U}{\partial X} \tag{17}$$

Recall that a fixed environmental target $\widetilde{D}$ also fixes $\widetilde{C} = \frac{1}{p_C}(w-(p_D+\xi)\widetilde{D})$ and so determines a socially optimal allocation. This in turn determines a pair of derivatives evaluated at this allocation: $(\frac{\partial U}{\partial X})^{FB}$, $(\frac{\partial U}{\partial Y})^{FB}$. From Equation (17) one can deduce the "first-best" tax that achieves the target. Let:

$$z^{FB} = (\frac{\partial U}{\partial Y})^{FB}/(\frac{\partial U}{\partial X})^{FB} \tag{18}$$

that is the inverse of the marginal utility rate of substitution at the specified allocation. Then:

$$\tau^{FB} = p_C\frac{1-\alpha^{SO}}{\alpha^{SO}}z^{FB} - p_D. \tag{19}$$

Further, in conventional economic analysis, one would not think of α as optimal, but as part of fixed preferences (*fixed appreciation* case). Denote by α^M the case of the actual appreciation of consumers, not the optimal one. z^{FA} still denotes the marginal utility rate of substitution, but with α^M specified:

$$\tau^{FA} = p_C\frac{1-\alpha^{M}}{\alpha^{M}}z^{FA} - p_D. \tag{20}$$

For the parametrisation specified above, $z^{FA} = \left(\frac{1-\alpha^M}{\alpha^M}\right)^{\gamma-1}\left(\frac{\widetilde{D}}{\widetilde{C}}\right)^{\gamma-1}$.

We next formalise the basic property of our approach that a change in climate-friendly values, ceteris paribus, reduces emissions. If the tax is set too low so that the climate target will not be reached, then a change towards climate-friendly values helps to make up for inadequate regulation and closes some of the gap between actual and desired emissions.

Proposition 2. *Let utility be parametrised as in Equation* (3)*, so that clean and dirty consumption are substitutes. A marginal positive change in appreciation will reduce emissions,* ceteris paribus.

[24] We assume that a positive carbon price τ is required to achieve the environmental target – the target for dirty consumption is smaller than the consumer would choose without intervention.

Proof. Derive Equation (11) with respect to α^M, to find that

$$\frac{C^M/D^M}{\partial \alpha^M} > 0 \qquad \text{if } \gamma > 0. \tag{21}$$

□

Economists often correctly stress the importance of regulation, given inadequate voluntary action. Environmentalists often correctly stress the importance of voluntary action, given inadequate regulation. Standard models with fixed preferences are unable to make sense of voluntary reduction as a change in values. The above result reconciles these views, identifying merit of both approaches. It is similar to Perino (2015), who studies the impact of climate campaigns (understood as modifications of the utility function) on aggregate emissions in general equilibrium. Importantly, Perino (2015) shows that the result hinges on total or partial regulation of an economy's emission by a tax or a permit scheme and the emission-intensity of the sectors regulated. This is not our focus, instead we elaborate on the consequences for regulation when the tax itself affects preferences.

3.3 Pricing that changes preferences

Thus far, we have examined how prices and preferences can separately contribute to achieving a specific environmental target. However, our analysis has assumed separability between prices and preferences – prices did not affect preferences. Bowles and Polania-Reyes (2012) provides ample evidence against this assumption, so we move to consider the case when, as in Lanz et al. (2018) (see Section 2.1), environmental prices can change preferences by crowding-in or -out. We model this examining the properties of *any* instrument that influences both the relative price and appreciation in a static setting. We model the shift in appreciation caused by a carbon price for *target-compatible* regulation. The consumer problem is:

$$\max_{C,D} U((\alpha^M + f(\tau))C, (1 - (\alpha^M + f(\tau))D) \tag{22}$$

subject to the budget constraint:

$$p_C C + (p_D + \tau)D = w + L. \tag{23}$$

We assume throughout that $\alpha^M < \alpha^{SP}$, so that if $f(\tau) > 0$, appreciation is crowded-in by environmental pricing and crowded-out otherwise. Further, we assume that $0 < \alpha^M + f(\tau) < 1$ to ensure that the problem is well-defined.

The first-order condition for the consumer is:

$$\left(1 - (\alpha^M + f(\tau)\right) \frac{\partial U}{\partial Y} = \frac{1}{p_C}(p_D + \tau)(\alpha^M + f(\tau))\frac{\partial U}{\partial X} \tag{24}$$

In practice, the effects of a tax may be small, so, as an approximation, assume that f is linear $f = \beta\tau$, with β as the "crowding-in constant." In this case, equation (24) can be rearranged to the following implicit expression for a second-best tax:

$$\frac{1}{p_C}(p_D + \tau^{SB}) = \frac{1 - (\alpha^M + \beta\tau^{SB})}{(\alpha^M + \beta\tau^{SB})} z^{SB}(\beta, \tau^{SB}). \tag{25}$$

z^{SB} is still the inverse of the marginal rate of utility substitution, however it may in general depend on β and τ. For the parametrisation chosen, it is given by:

$$z^{SB} = (\frac{\partial U}{\partial Y})^{SB} / (\frac{\partial U}{\partial X})^{SB} = (\frac{1 - \alpha^M + \beta\tau}{\alpha^M + \beta\tau})^{\gamma-1} (\frac{\widetilde{D}}{\widetilde{C}})^{\gamma-1}$$

Therefore, the second-best tax is given implicitly by:

$$\tau^{SB} = \frac{1}{p_C} (\frac{1 - (\alpha^M + \beta\tau^{SB})}{(\alpha^M + \beta\tau^{SB})})^{\gamma} (\frac{\widetilde{D}}{\widetilde{C}})^{\gamma-1} - p_D. \tag{26}$$

Note that there are limits on whether this solution is economically meaningful, given by $\alpha + \beta\tau = 1$ and $\alpha + \beta\tau = 0$. In the first case, the consumer only derives utility from the clean good, in the second case, it is impossible to reach a target. We explored the solution to Equation (26) numerically for various values of γ (see Figure 2 for an illustration for $\gamma = 0.5$). Our simulation indicates that, even before reaching the limits of an economically meaningful outcome, there are no solutions to Equation (26) for negative β and ambitious environmental targets.

Mattauch and Hepburn (2016) and Lanz et al. (2018) state that the carbon tax needs to be adjusted in the presence of crowding-out: Suppose preferences are endogenous to a carbon price. If there is crowding-out, then the carbon price to achieve a target needs to be higher than if they were exogenous. This can now be proved.

Proposition 3. *Let utility be parametrised as above. When $\beta < 0$, ("crowding-out") the second-best carbon price τ^{SB} needs to be higher than the conventional first-best price τ^{FA} (fixed appreciation) to achieve the desired level of mitigation and lower if $\beta > 0$.*

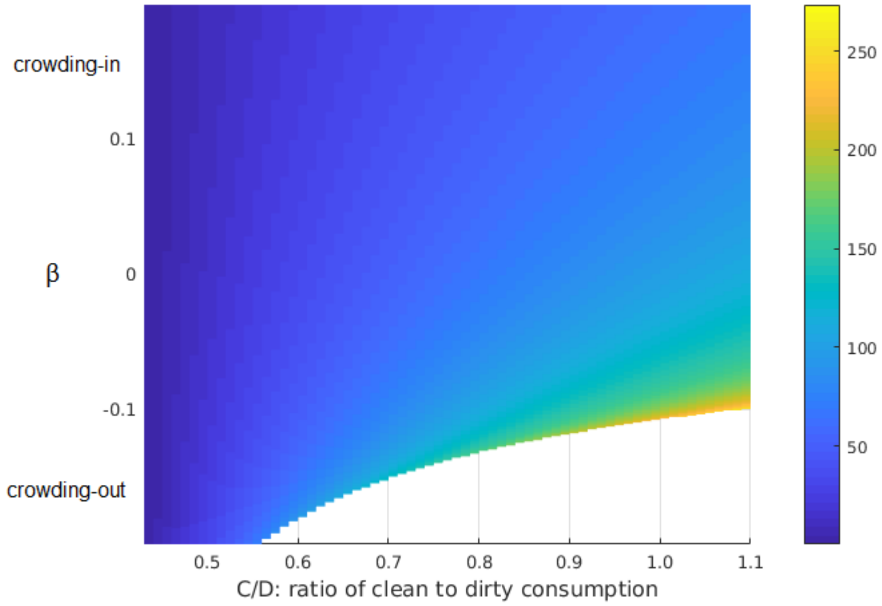
Proof. Compare the parametrised version of Equations (20) and (25) for a positive carbon price. For $\beta > 0$,

$$\frac{1 - \alpha^M}{\alpha^M} > \frac{1 - (\alpha^M + \beta\tau^{SB})}{(\alpha^M + \beta\tau^{SB})} \tag{27}$$

as long as the second-best tax is positive. Since the same environmental target is to be achieved and noting $\gamma > 0$, this implies $\tau^{FA} > \tau^{SB}$. The inequality is reversed if $\beta < 0$.

□

Figure 2: Target-achieving CO_2 price as a function of the strength of crowding-in social preferences β and of the environmental target



Parametrisation with $p_D = p_C = 1, \gamma = 1/2, \alpha = 0.3$, additionally varying the environmental target. Prices need to be higher with crowding-in and more ambitious environmental targets. Solutions in the right bottom corner do not exist. Prices normalised to 100 for $\beta = 0, C/D = 1$.

Further, since we have defined a social optimum in Subsection 3.1, we can compare the target-compatible carbon prices with optimal appreciation with the case in which appreciation is endogenous. The next result characterises how the optimal case relates to Proposition 3.

Proposition 4. *Let utility by parametrised as above. When $\beta > 0$ ("crowding in"), there exists a unique value $\beta^\dagger$ such that the second-best tax equals the socially optimal carbon price τ^{FB} (with optimal appreciation). The second-best tax is higher than the socially optimal price if $\beta < \beta^\dagger$ and* vice versa*.*

Given that there is crowding-in, there will be just one value of how much is crowded in which makes it possible for the tax to both achieve the target and at the same time crowd-in enough to achieve optimal appreciation.

Proof. We prove that $\tau^{SB}(\beta)$ is monotone as an implicit function and then apply the Intermediate Value Theorem. Equation (26) defines an implicit function $F(\tau^{SB}, \beta) = 0$, which we assume to be continuously differentiable.

Noting

$$\frac{\mathrm{d}\tau^{SB}}{\mathrm{d}\beta} = -\frac{\partial F/\partial\beta}{\partial F/\partial\tau^{SB}} \tag{28}$$

it can be shown, by computing the derivatives on the right-hand side explicitly, that $\frac{\mathrm{d}\tau^{SB}}{\mathrm{d}\beta} < 0$ for $\beta > 0$. Further, note $\tau^{SB}(0) > \tau^{FB}(0)$, because by assumption $\alpha^M < \alpha^{SP}$. To complete the proof by the Intermediate Value Theorem, it remains to show that it is not the case that $\lim_{\beta\to\infty}\tau^{SB}(\beta) > 0$. (Since the function is monotonically decreasing, a limit exists in $[-\infty, \tau^{SB}(0))$.) Assume for contradiction that the limit is a real positive constant c. Then, from Equation (26) in the limit

$$c + p_D = (-1)^{\gamma}\left(\frac{\widetilde{D}}{\widetilde{C}}\right)^{\gamma-1}. \tag{29}$$

This is a contradiction because the right-hand side is an imaginary number for $0 < \gamma < 1$ while the left-hand side is real. □

Bowles (2016) argues that the *design of a monetary incentive itself* can lead to changes in the degree of crowding-in or -out of social preferences that comes with the incentive. The policy-maker's task is to align the "acquisitive" and the "constitutive part" of a price signal for mitigating climate change – that is to align the part of the price signal that is about getting something with that part which appeals to consumers' values and identities. Lanz et al. (2018) discuss that their experiment, summarised above, may be a case of "moral disengagement" (Bowles, 2016), while the likely salience of some environmental taxes (Rivers and Schaufele, 2015) is compatible with the acquisitive and constitutive part of the price signal being aligned. In the notation of the above results, such considerations would mean that β itself is a function of the design of a carbon price. The design features that may influence β are, for instance, likely to be related to political messaging around the policy reform, as is exemplified by the success of the Irish plastic bag tax (Convery et al., 2007; Bowles, 2016): communication of pollution regulation will make citizens feel empowered, not patronised.

Further, high trust in politicians correlates with higher carbon prices (Klenert et al., 2018; Rafaty, 2018). So it could be that it is "bad news" (Bowles, 2016) when trust is low and a government announces plans for an environmental tax, while it is not bad news when citizens trust their politicians. The importance of the political context for the success of environmental tax reforms suggests that β should also be a function of background variables such as the trust level. Future work could examine these extensions to the above model. Here we sketch two other possible extensions instead: arguments that characterise policy instruments under optimal, rather than target-compatible, regulation, and the case of costly changes of preferences:

Optimal regulation under a carbon price that changes preferences For the case of *optimal* regulation, assume again that the effect of the tax on appreciation is linear and consider the problem of the consumer:

$$\max_{C,D} U(\alpha^M C, (1-\alpha^M)D) = [((\alpha^M + \beta\tau)C)^\gamma + ((1-(\alpha^M+\beta\tau))D)^\gamma]^{\frac{1}{\gamma}} \quad (30)$$

subject to

$$p_C C + (1+\tau)p_D D = w. \quad (31)$$

The solution is given by

$$\frac{C^M}{D^M} = (\frac{1-(\alpha^M+\beta\tau)}{\alpha^M+\beta\tau})^{\frac{\gamma}{\gamma-1}}(\frac{p_C}{p_D+\tau})^{\frac{1}{\gamma-1}}. \quad (32)$$

Compare this to the socially optimal solution:

$$\frac{C^*}{D^*} = (\frac{1-\alpha^*}{\alpha^*})^{\frac{\gamma}{\gamma-1}}(\frac{p_C}{p_D+\tau})^{\frac{1}{\gamma-1}} \quad (33)$$

If $\alpha^* - \alpha^M = \beta\xi$ then the tax conventionally set at $\tau = \xi$ (see above) is Pigouvian, since it optimally corrects for the required change of appreciation. Otherwise, depending on the parameter values, there may be excessive or insufficient shifts in appreciation. Hence the optimal tax should account for $\alpha^* - \alpha^M \neq \beta\xi$. So there is just one specific relationship between how much appreciation needs to change and the strength of the crowding-in needed so that the conventional tax level is the optimal (Pigouvian) one. This yields, assuming $\alpha^* > \alpha^M$ and $\beta > 0$:

Proposition 5. *When taxes set to maximise utility do not crowd in values enough (too much), the government should adjust tax levels upwards (downwards) to achieve the social optimum.*

By symmetry, when taxes crowd out values, the optimum can only be reached by a tax when there was too much appreciation of the clean good prior to taxation.

Further work could explore the deviation of the conventional optimal tax when it affects appreciation. It could also explore the properties of the second-best tax, that is whether it is set above or below the (augmented) Pigou level.

Awareness campaign Furthermore, assume a real-world instrument designed to shift appreciation, such as awareness campaigns or educatory measures $\epsilon(T)$, will come at some opportunity cost of consumption T. We assume appreciation α^M is suboptimal. So consider the following modified consumer problem:

$$U((\alpha^M + \epsilon(T))C, (1 - (\alpha^M + \epsilon(T)))D). \tag{34}$$

subject to the budget constraint

$$p_C C + p_D D = w - T. \tag{35}$$

The consumer maximises utility subject to this policy intervention, in which an appreciation change is financed by a lump-sum tax. Suppose the consumer obtains optimal consumption at $C(T)$ and $D(T)$. Then, to maximise welfare, government will maximise indirect utility V with respect to T :

$$V((\alpha^M + \epsilon(T))C(T), (1 - (\alpha^M + \epsilon(T)))D(T)). \tag{36}$$

As a first-order condition for optimal appreciation-changing policy, one then obtains:

$$\frac{\partial V}{\partial Y} \Big/ \frac{\partial V}{\partial X} = -\frac{\frac{\partial C}{\partial T}(\alpha^M + \epsilon(T)) + \frac{\partial \epsilon}{\partial T}C(T)}{\frac{\partial D}{\partial T}(1 - (\alpha^M + \epsilon(T))) - \frac{\partial \epsilon}{\partial T}D(T)}. \tag{37}$$

This characterises a trade-off between adjusting appreciation and the cost of such measures. It is structurally independent of the degree to which the externality is uncorrected and whether a target is to be implemented. Further work could explore the quantitative interaction with a suboptimal carbon price, characterising: (a) the rule for how much adjustment of appreciation is optimal given an environmental target that is implemented, (b) if carbon prices are too low relative to some target, how this rule changes quantitatively, (c) welfare analysis of marginal changes to both instruments when both the carbon price and the awareness campaign are suboptimal.

4 Further applications: Transport infrastructure and health benefits

We illustrate how the idea that regulation can change preferences leads to new policy conclusions by two further applications: the role of urban transport infrastructure, and health benefits from choosing low-carbon consumption options.

4.1 Urban transport infrastructure

As noted in Subsection 2.1, Weinberger and Goetzke (2010) showed that the built urban environment can determine propensity for car ownership in the long run. If this holds, an evaluation of transport infrastructure that ignores the impact on preferences, focussing instead on price impacts, will lead to inefficient policy, as it will understate the benefits of shifting preferences that facilitate low-carbon transport.[25]

Consider the problem of providing low-carbon urban infrastructure in a static, if artificial, setting first. We abstract throughout this section from general equilibrium and other regulation, such as a carbon price, fuel tax or city toll, and focus instead on the problem of financing low-carbon urban infrastructure in isolation. Seen this way, this situation is formally similar to the case of Equations (34)-(36): Appropriate low-carbon urban infrastructure changes preferences in the desirable direction, but must be financed. Such changes are also typically assumed to change relative prices, however, so we consider low-carbon urban infrastructure as a policy instrument that changes both prices and preferences.

$$\max_{C,D} U((\alpha^M + f(I))C, (1 - (\alpha^M + f(I)))D) \tag{38}$$

subject to

$$p_C(I)C + p_D D - I = w \tag{39}$$

where, as in the previous section, α^M is some level of appreciation and the problem is to optimise in respect to clean and dirty mobility options, assuming $\alpha^M + f(I) < 1$. Here $f, f' > 0$ is a function that describes the impact of low-carbon infrastructure investment in an appreciation-equivalent manner. Lessons similar to those from the previous section could be drawn regarding the second-best nature of such regulation.

An intertemporal policy instrument that changes mobility preferences The findings of Weinberger and Goetzke (2010) imply that the effect of infrastructure on appreciation only occurs in the future, because values about mobility options are formed in the long term.

Consider a two period model, consisting of "now" and "the future". For simplicity, decision-makers optimise their mobility behaviour for the two periods separately. We think of this as two distinct generations, those taking urban transport decisions now and those who will live in future cities.

[25]Siegmeier (2016) analyses the role of static, *good-specific, utility-enhancing* infrastructure as public goods that are costly to provide for the government. He shows its importance relative to Pigouvian or sub-optimal taxes correcting the externality. This approach is related because obtaining enhanced utility of specific goods as result of a change in the external conditions, or of changed values, is formally equivalent: one can get enhanced utility from cycling either through better infrastructure or through building a personal identity that makes cycling more pleasurable.

Period 1:

$$\max_{C_1,D_1} U(\alpha_1^M C_1, (1-\alpha_1^M)D_1) \tag{40}$$

subject to

$$p_{c1}C_1 + p_{d1}D_1 = w_1 - T \tag{41}$$

Period 2:

$$\max_{C_2,D_2} U((\alpha_2^M + g(T))C_2, (1-(\alpha_2^M + g(T)))D_2) \tag{42}$$

subject to

$$p_{c2}(T)C_2 + p_{d2}D_2 = w_2 \tag{43}$$

Here we assume that the consumers ignore a consumption externality about urban environmental quality E.

Infrastructure investment needs to be financed in the first period, but will change both relative prices and appreciation in the second period. The latter effect is represented as a function $g(T) > 0$ with $g' > 0$. There is a trade-off between consumption losses due to infrastructure financing and correcting both externality and appreciation. The government optimises in respect to this choice by considering an indirect utility function with arguments $C_1(T), C_2(T), D_1(T), D_2(T)$, taking into account urban environmental quality in the second period and discounting the future. The government's problem is therefore:

$$\max_T V_1(\alpha_1^M C_1, (1-\alpha_1^M)D_1) + \frac{1}{(1+\rho)} V_2((\alpha_2^M + g(T))C_2, (1-(\alpha_2^M + g(T)))D_2, E(D_2)) \tag{44}$$

The trade-off between consumption losses due to infrastructure financing, and correcting both externality and appreciation is then represented by a first-order condition:

$$\alpha_1^M \frac{\partial V_1}{\partial C_1}\frac{\partial C_1}{\partial T} + (1-\alpha_1^M)\frac{\partial V_1}{\partial D_1}\frac{\partial D_1}{\partial T} + \frac{1}{1+\rho}\Big[\frac{\partial V_2}{\partial C_2}\big(g'(T)C_2 + (\alpha_2^M + g(T))\frac{\mathrm{d}C_2}{\mathrm{d}T}\big) + \frac{\partial V_2}{\partial D_2}\big(-g'(T)D_2 + (1-(\alpha_2^M + g(T)))\frac{\partial D_2}{\partial T}\big) + \frac{\partial V_2}{\partial E}\frac{\partial E}{\partial D_2}\frac{\mathrm{d}D_2}{\mathrm{d}T}\Big] = 0. \tag{45}$$

Note that, for the terms in the second period:

$$\frac{\mathrm{d}C_2}{\mathrm{d}T} = \frac{\partial C_2}{\partial T} + \frac{\partial C_2}{\partial p_{C2}} p'_{C2}(T) \quad \text{and} \quad \frac{\mathrm{d}D_2}{\mathrm{d}T} = \frac{\partial D_2}{\partial T} + \frac{\partial D_2}{\partial p_{C2}} p'_{C2}(T) \tag{46}$$

These terms represent the effect of the relative price change on the value of the policy. We now compare two different models by the following statement:

Proposition 6. *Assume clean and dirty mobility options are ordinary goods. For a given level of low-carbon infrastructure financing T, if $g > 0$, that is if infrastructure locks-in mobility preferences, in the second period, the social marginal value of clean (dirty) consumption is higher (lower) and hence more infrastructure investment is warranted.*

Proof. The second part of the left-hand side of Equation (45) characterises the value of an amount of investment needed to enhance environmental quality in the second period at its optimum value. If it was the case that $g = 0$ (no effect on preferences), all terms with g or g' in Equation (45) would disappear. Given that the clean good is ordinary, however, the terms multiplying $\frac{\partial V_2}{\partial C_2}$ are all positive, increasing the value of clean consumption of a fixed investment T, while the opposite is the case for the dirty good. □

Appropriate transport infrastructure can be assumed to raise the share of low-carbon transport due to lower relative prices and to lock-in of preferences for low-carbon transport, as exhibited by Weinberger and Goetzke (2010). We conclude that if there is suboptimal appreciation for the second-period, then infrastructure investment is more important than typically seen in economics. Such a conclusion, however, is more in line with the viewpoint of urban environmental studies.[26]

4.2 Reducing emissions and improving health from food and urban mobility choices

Section 2.1 also noted that public health policies can shape preferences to help people to make healthier and more environmentally-beneficial choices (Hawkes et al., 2015). The examples of Woodcock et al. (2009) and Springmann et al. (2016) highlight that significant welfare gains could be achieved by increasing active travel and reducing the fraction of animal-sourced foods, since such changes reduce both emissions and obesity-related diseases. Habitual car-driving for short trips or consuming large quantities of red meat beyond dietary requirements is structurally similar to smoking or drink-driving, generating both an "internality" (harm to the individual created by costs on future health) and an "externality" (harm to others). Such behaviour, taken together with stated preferences about the importance of health, indicates that citizens entertain different, conflicting, preferences about health outcomes, and for the purpose of decarbonisation only a subset of these preferences are helpful. Policy measures might strengthen prefer-

[26] We abstracted from a pricing instrument such as a city toll here; however, the most relevant situation for changing appreciation by infrastructure may be when such a price signal to improve environmental outcomes is missing (see Siegmeier (2016)). We conjecture that for mobility choices, the effect of infrastructure on values is stronger than for price instruments, which may have fewer effects on values.

ences for the healthy and low-carbon choices, while at the same time preserving the freedom for people to ultimately make their own decisions.

Two approaches could be useful to elucidate adequate policy for these examples. First, in behavioural economics, conflicting long- and short-term preferences are standardly modelled with time-inconsistent preferences (Laibson, 1997). Quasi-hyperbolic discounting can be used to make sense of the idea that while decision-makers have a long-term preference for staying in good health, they have a short-term preference for unhealthy food or inactive travel behaviour. One could hence combine the model of a quasi-hyperbolic decision maker with an environmental externality to study first and second-best policy. From the normative position of defining well-being as preference satisfaction, there is a difficulty with models of time-inconsistent preferences: should the long- or the short-term preference count in defining welfare? (Bernheim and Rangel, 2007) If society decides that it is the long-term preference, then a policy that encourages healthy, low-carbon behaviour is welfare-enhancing – to a greater degree than if only greenhouse gas emission were to be regulated. We thus conjecture that if, as a second-best option, a carbon price should be used to capture some of the health benefits to be gained by reducing meat consumption and increasing active travel, it should be set higher than the Pigouvian level resulting only from the environmental externality.

Alternatively, one could extend the model of Section 3 and account for the possibility of preference changes over mobility and health choices in order to model the reduction of diseases through mitigation policy. One reason to prefer this approach over the first one suggested here is that heterogeneity in tastes with regard to red meat consumption and car-driving (Gao et al., 2017; McLaren, 2007; Ogden et al., 2014; Woodcock et al., 2009) are difficult to represent credibly *only* through differences in time preference rates.

Formally, consider a decision-maker (in a static context, for simplicity) whose utility also depends on his health:

$$U(\alpha C, (1-\alpha)D, H, E) \tag{47}$$

subject to $C + D = w$. Here, let C, D denote clean and dirty consumption respectively, α the appreciation of the respective option, H health and E environmental quality, with consumers to some degree ignoring effects of their choices on environmental quality and health. Let α be representative of underlying values for mobility and food choices. Assume the following relationships between the consumption options, health and the environment:

$$E = f(D) \quad \text{and} \quad H = g(C, D) \tag{48}$$

with $f'(\cdot) < 0$, meaning that dirty consumption influences environmental quality negatively. For the case of transport, the shape of g is usefully approximated by $g(C, D) = g(C)$ with $g'(C) > 0, g''(C) < 0$ because there is some evidence that additional active travel does not crowd-out other types of physical activity (Laeremans et al., 2017). (However the shape of g will be more complicated for the case of diets.) Given that current outcomes are suboptimal, since too much greenhouse gases are emitted and health benefits not taken sufficiently into account – a partial "internality"– , one could calculate the societal benefit of a change in values, represented by α, similar to the model of Section 3. For example, if a tax on meat consumption, say, crowded in- or out intrinsic motivation to eat a plant-based diet, the above formal analysis would apply, but with an additional change to utility gained from health.

5 Discussion: normative and policy implications

If we do not debate how values are formed, they are at risk of developing without clarity about what is at stake, and with a risk that they are shaped to profit specific special interest groups rather than society as a whole.[27] Failing to discuss possible shifts in values also arguably places greater weight upon the status quo. Given the importance of changes in values to major social transitions, such as that necessary to a net zero carbon economy, it is important to account for how value changes interact with policy instruments.

We recognise, of course, that endogenising preferences makes welfare analysis more challenging, but progress can be made in one of three ways (see Mattauch and Hepburn, 2016, for a treatment of the relative merits of these approaches). We noted that our above analysis relies on the ability to compare utilities for different values in a meaningful way. One way to do this is to observe the existence of 'meta-preferences' beyond the first-order level of preferences which are endogenous. A consumer may, for instance, like herself more when intrinsically motivated to protect the environment. Another approach is to proceed by assuming that utility is cardinal, rather than ordinal. When the intensity of utility changes is taken into account, this gives a unit by which one can compare different preferences and their corresponding utility functions.

A third possibility, which we did not apply above, is to conduct welfare analysis with the equivalent income approach, but with given reference prices (Fleurbaey and Tadenuma, 2014; Fleurbaey, 2016). This approach relies on money-metric utilities and is related to compensating and equivalent variation, the classic method of doing welfare analysis with revealed preferences as the only source of information. The conversion of preferences into different prices, via money-metric utilities with reference prices, is another

[27]See also Bowles (2016), Fehr and Hoff (2011), Hoff and Stiglitz (2016) and Thaler and Sunstein (2008) for related views. Fehr and Hoff (2011) also refute the claim that endogenising preferences introduces too many degrees of freedom. Further, see Epstein and Robertson (2015) for an example of the potential of search engines to influence preferences.

way to compare different preferences.[28]

In this article, we have not needed to specify whether our utility functions have an ordinal or cardinal interpretation, as long as a comparison in terms of appreciation is possible. Our approach, however, relies on the assumption that a single parameter can be used to translate relevant aspects of values into "appreciation" for low-carbon consumption – and, crucially, we assume that the relationship between goods and their appreciation is cardinal and that appreciation can be given a numerical value. This assumption seems descriptive, not prescriptive.

We also have observed that there exist scientifically-informed and politically agreed environmental targets that have much greater legitimacy than anything emerging from a specific viewpoint on individual well-being. If these targets are taken as given, an analysis of the impact of shifts in values in achieving such targets, as conducted in this article, is simplified.

We next turn to broader policy implications of our study that could be examined in future work. One additional consideration absent from our models is the question of deliberate sequencing of policy (Meckling et al., 2017; Pahle et al., 2018): Should a price signal or an awareness campaign come first to foster further decarbonisation? Or should they be introduced at the same time? Scattered evidence in environmental psychology indicates that the sequence of behavioural interventions matters for the success of behaviour change with respect to mobility decisions (Gatersleben and Appleton, 2007; Bamberg, 2013). So if behaviour change facilitates the introduction of relative price changes and brings down the required level of carbon pricing, one can hypothesise that the timing and coordination between behavioural and price interventions also matters for the efficiency of environmental policy.

Further, there is a related question about the political economy of value changes. For any actor in government, is it easier to enact policy that changes relative prices by taxes, subsidies or bans, or is it easier to enact policy that changes relative preferences by information, persuasion and education? Some governments run awareness campaigns about the environment, although governments are often incapable of setting carbon prices anywhere near target-adequate levels (Stiglitz and Stern, 2017), for example because acceptability of carbon prices can be low as new taxes are usually unpopular (Klenert et al., 2018). This suggests that it could in some situations be politically easier, at least at the margin and relative to the status

[28]von Weizsäcker (1971, 2005, 2013) has pursued a different line of thinking about endogenous preferences, developing criteria under which preferences can change and Paretian welfare economics is still feasible. He considers preferences as "adaptive", defining them as follows. "[I]ndividuals have a tendency to value their present position or situation higher relative to alternatives than they would, if their present position or situation were a different one. We also may call this preference conservatism: a tendency of agents to stick to the place where they are." (von Weizsäcker, 2013, p. 14)

quo, to change preferences than relative prices. Furthermore, bringing in carbon pricing and returning revenue to consumers could be a way of beginning to change preferences, but then, once they have begun to change, the uses of revenues might become more open. A political economy extension to the model studied here could consider a government that faces political obstacles to price-changing and appreciation-changing policies.

Finally, notwithstanding the already substantial and growing base of empirical evidence, further systematic empirical work on the influence of policy instruments on preferences and values would be welcome, building on pioneering work such as that by Lanz et al. (2018). Such work could quantify the effects analysed here, and could take into account how values differ across the population.

6 Conclusion

Policy-induced changes in consumers' values are relevant and arguably important for decarbonisation policy, given the significant empirical evidence. Our understanding of climate change mitigation policy would be enhanced if relevant effects were taken into account in economic models.

We establish results about policy instrument design under the assumption that values and preferences are endogenous to the social context. First, if a climate target is to be achieved and carbon pricing is insufficient, a change in consumers' values towards low-carbon preferences helps to achieve the target. In other words, even under the assumption of separability between prices and preferences, strategies to change prices and preferences may be complementary.

Second, when the introduction of a carbon tax changes consumers' values, not merely relative prices, the target-compatible carbon price must be adjusted by the size of this effect. Third, when low-carbon infrastructure leads to the formation of low-carbon preferences over time, we should account for the climate-protection value of investing in such infrastructure. Finally, the potential for health gains through reductions in obesity-related diseases from low-carbon diets and active urban travel – also an area where policy shapes preferences – provide an additional reason for supporting the evolution of values towards healthy eating and travel.

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