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Abstract

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JEL Classification: D62, H23, Q52, Q58

Keywords: Carbon Pricing, carbon tax, cap-and-trade, climate change, Behavioral Industrial Organization

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How to Regulate Carbon Emissions with Climate-conscious Consumers[†]

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January 10, 2022

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1 Introduction

There is unanimous agreement among economists that carbon pricing is the most powerful and most efficient instrument to curb CO_2 emissions. But, in almost all countries actual carbon prices are insufficient to achieve the ambitious climate goals of the Paris agreement, and there is strong political opposition to raising them. Therefore, it becomes increasingly clear that additional efforts are required. In particular, the many voluntary contributions of consumers, firms, and local governments play an important role in mitigating climate change. This raises the question of how carbon pricing and the efforts of climate-conscious agents interact. It turns out that this crucially depends on whether carbon pricing is implemented by using price regulation (a carbon tax) or quantity regulation (cap-and-trade).

In this paper, we assume that some consumers (firms, local governments) are morally concerned consequentialists (e.g. Utilitarians), who are willing to reduce their consumption of the polluting good if their behavior affects the total level of emissions. Furthermore, we assume that there is a political constraint on the emission price. No matter whether this price is a carbon tax or a permit price determined by a market for emission permits, it cannot be higher than some upper bound $\bar{p}$, because a higher price would cause political unrest. We show that under these two assumptions price regulation (i.e. a carbon tax) complements voluntary efforts to reduce emissions and encourages consumers to consume less of the polluting good. Quantity regulation (i.e. cap-and-trade) on the other hand discourages morally motivated consumers to reduce emissions and may even induce them to increase consumption and emissions.[1]

The problem of cap-and-trade is the so-called "waterbed effect". The total amount of emissions is fixed by the number of emission permits issued by the regulator. If morally motivated agents reduce their emissions voluntarily, for example by investing in solar panels, by buying energy efficient appliances, or by using the train rather than a short-distance flight, they cannot reduce the overall level of emissions because total emissions are solely determined by the number of emission permits. The mechanism is as follows: If consumers reduce e.g. their energy consumption, then the power companies burn less fossil fuels and therefore need fewer emission permits. This reduction in the demand for permits reduces the permit price.

[1] We use the terms "climate-conscious", "morally motivated" and "morally concerned" consumers interchangeably.

Because the supply of permits if fixed and completely price inelastic, the price must fall up to the point where these permits are bought by some other companies that use them to increase their pollution. This is the waterbed effect: If the water level is pushed down in one area of the bed, the water level in other areas must rise, because the quantity of water in the bed is fixed.

In our model rational consumers understand this effect. They know that with quantity regulation reducing their consumption has no effect on total emissions. Because they are consequentialists, they will not engage in additional consumption reductions despite their moral concerns about pollution. With price regulation, on the other hand, the emission price does not adjust if consumption is reduced, so every reduction in consumption reduces total emissions one-to-one. This encourages climate-conscious consumers to consume less of the polluting good. These different reactions of consumers to price and quantity regulation are unimportant if the regulator is unconstrained: Both regimes can implement the first-best allocation. If the regulator is constrained by keeping the carbon price below a threshold, these additional efforts of environmentally conscious consumers are important. Consumption of the harmful good is strictly lower under price than under quantity regulation if the permit price equals the upper threshold.

Reducing consumption is not the only way to reduce pollution. It is also possible to invest in offsets, such as planting trees, restoring moors, or carbon capture and storage, which also reduces greenhouse gases in the atmosphere. Furthermore, if there is an emissions market, consumers can buy and delete emission rights which effectively reduces total emissions. We allow for these actions in our model. It turns out that the possibility of buying and deleting emission rights has a counterproductive effect. Under quantity regulation morally concerned consumers buy and delete emission rights rather than reduce their consumption. Because they derive a positive utility from doing so, they are induced to increase their consumption so that they can compensate more. The regulator anticipates the additional demand for emission permits. He has to ensure that the emission price is weakly below $\bar{p}$, so he will choose the number of emissions permits such that the additional demand for permits (in order to delete them) is exactly offset by the additional number of permits. Thus, in equilibrium the possibility to buy and delete emission rights increases emissions!

Investing in offsets has a positive effect. In the main model we assume that the scope for offsets is small. This seems to reflect the current stage of technology. In this case the regulator will buy the second best efficient amount of offsets which drives up their price such that consumers don't want to engage in it. In Subsection 3.2 we assume that offsets can be produced with constant returns to scale at an affordable cost. This case may become relevant if the technology for carbon capture and storage matures and becomes much cheaper at a large scale. In this case the regulator buys only a limited amount of offsets. With price regulation, morally motivated consumers also buy offsets which effectively reduces green house gases in the atmosphere. With quantity regulation, however, consumers do not buy offsets but rather buy and delete emission rights.

Irrespective of whether the scope for offsets is small or not, we show that *material social welfare* (that ignores moral utility) is always higher with price regulation than with quantity regulation. This is because only price regulation induces climate-conscious consumers to consume less of the polluting good. But there is also a downside to price regulation. Morally concerned consumers suffer from violating a social norm. This is not the case with quantity regulation. A consumer who knows that her actions cannot have any effect on total emissions does not have to be morally concerned about her actions. Thus, whether price or quantity regulation leads to a higher *total social welfare* (that takes the disutility from norm violation into account) depends on how high these moral costs are. If the norm is sufficiently descriptive, i.e. puts enough weight on average consumption in society, material welfare is always strictly higher under price regulation.

In Section 4 we look at the distributional consequences of price and quantity regulation. We assume that there are two groups of consumers, rich and poor, and that the rich have a lower marginal utility of money than the poor. With quantity regulation consumers only care about the price of the polluting good, because they cannot affect total emissions. If the marginal utility of money is sufficiently small for the rich, they do not reduce their consumption but rather buy and delete emission permits. Thus, the burden of adjustment is borne entirely by poor consumers who cannot afford to buy and delete emission permits but have to reduce their consumption. With price regulation, on the other hand, both consumer groups are morally motivated to reduce their consumption. Thus, the two groups bear the burden of emission reductions more equally.

In Section 5 we relax the assumptions of consequentialism and rationality. Some consumers have non-consequentialist moral convictions, and some do not understand the waterbed effect. We look at the interaction of selfish consumers and two different types of consumers with moral preferences: consequentialists ("Utilitarians") as described above and deontologists ("Kantians"), who consider it their moral duty to follow an ethical norm no matter what the consequences. Kantians behave in the same way under price and under quantity regulation. They are observationally equivalent to "naïve" Utilitarians, i.e. to consequentialists who do not understand that with an emissions market their actions cannot affect total emissions. We ask how a political (or educational) campaign that increases the share of morally concerned consumers (or reduces the share of naïve consumers) affects the utility of the different groups. With price regulation an increase of morally motivated consumers reduces emissions and benefits both selfish and moral consumers. With quantity regulation an increase of the share of Kantian consumers leaves total pollution unaffected but reduces the emissions price. This benefits selfish consumers, while Kantian consumers are worse off. In this case nobody has a material interest in convincing consumers to behave morally or in explaining to naïve Utilitarians how the emissions market works.

In Section 6 we allow for uncertainty and imperfect competition and show that this does not affect our qualitative results and can even strengthen them. Imperfect competition drives up the price for the consumption good, but as long as the price increase is smaller than the social cost of carbon, our results are unaffected. Uncertainty is analyzed in a classical paper by Weitzman (1974), who shows that quantity regulation can be superior to price regulation if uncertainty about the price is less harmful than uncertainty about the quantity. However, in Weitzman (1974) there is no upper bound on the emission price. Thus, with uncertainty total emissions will sometimes be inefficiently high and sometimes inefficiently low. In contrast, in our model the upper bound on the emission price implies that total emissions are always too high. The regulator must guarantee that the emission price never exceeds $\bar{p}$. Thus, with quantity regulation he will choose the number of permits such that in the worst possible state of nature the emission price is just equal to $\bar{p}$. In all other states it will be lower. In contrast, with price regulation the emission price is always equal to $\bar{p}$. Thus, in expectation consumers will consume more with quantity regulation than with price regulation. This holds even if there are no moral preferences.

In the formal model we restrict attention to the consumption decisions of individual consumers. However, consumers also affect the decisions of firms and governments. For example many firms declared that they want to become "carbon neutral" until, say, 2030. Similarly, (regional) governments engage in significant efforts to reduce carbon emissions in addition to carbon pricing. Presumably, firms and governments want to cater to climate-conscious customers, owners, and voters. Section 7 concludes by arguing that these additional efforts are wasted under quantity regulation, but can yield a significant contribution to mitigating climate change with price regulation. All proofs are relegated to the Appendix A.

Our paper is related to three strands of the literature: First, there is a large literature on the efficient regulation of negative externalities (Baumol and Oates, 1988). This literature goes back to Pigou (1920) who first proposed to use taxes (price regulation) to internalize negative externalities. The idea of quantity regulation through cap-and-trade is implicit in Coase (1960) and spelled out formally by Montgomery (1972). In a seminal paper Weitzman (1974) compares price and quantity regulation in a model with uncertainty regarding the costs and benefits of abatement.[2] His analysis has been extended in many directions, e.g. to stock pollutants (Hoel and Karp, 2002), commitment and flexibility (Requate, 2005), and political economy issues (Helm, 2005). Surveys on this literature are offered by Hepburn (2006) and Goulder and Schein (2013).[3] To the best of our knowledge, our paper is the first to consider how the presence of morally motivated agents affects this trade-off.

Second, there is a literature discussing the interaction of different policy instruments (Fankhauser, Hepburn, and Park, 2010; Goulder, Jacobsen, and van Benthem, 2012). This literature shows that different policy measures can be (perfect) substitutes, so adding one instrument to another may have very little or no effect. For example, if a pollution tax is imposed on a good that is already covered by cap-and-trade regulation, then the tax will be fully offset by a reduction of the permit price and does not have any additional effect on

[2]The optimal mixture of the two instruments is analyzed, among others, by Roberts and Spence (1976), Pizer (2002), Mandell (2008), and Ambec and Coria (2013).

[3]Goulder (2013), Schmalensee and Stavins (2017) and Narassimhan et al. (2018) provide overviews and evaluations of real world cap-and-trade systems.

aggregate emissions (Goulder, 2013). Perino (2015) considers a general equilibrium model with two sectors, one of which is regulated by cap-and-trade. He shows that voluntary climate action may increase total emissions due to leakage to the other sector that is regulated by a tax. While this literature studies the interaction of different instruments in an inefficient policy mix, we consider the interaction of one type of regulation (either price or quantity regulation) with the moral preferences of consumers. We analyze how the intrinsic (moral) motivation of climate-conscious consumers is affected by the chosen policy instrument and how it affects the efficiency of regulation.

Finally, our paper is related to the behavioral and experimental economics literature. Pollution and climate change is a leading example of a public good problem. There is an extensive literature in experimental economics showing that social preferences mitigate public good problems. Many experimental subjects are willing to give up own resources in order to help others.[4] This literature also shows that some informal and formal institutions can increase and sustain cooperation (Ostrom, 1990; Fehr and Gächter, 2000). In our paper, consumers do not have social preferences about the consumption or income of others but moral concerns about the environment. They suffer if their own consumption departs from the social norm. Therefore, closer related to our work is the economic literature on how social norms affect behavior (Benabou and Tirole, 2006; Krupka and Weber, 2013; Bénabou, Falk, and Tirole, 2018). In particular, several empirical papers of that literature show that social norms have an important impact on decisions affecting the environment (Nyborg, Howarth, and Brekke, 2006; Allcott and Rogers, 2014; Schwirplies and Ziegler, 2016; Jakob et al., 2017). In a lab experiment, Ockenfels, Werner, and Edenhofer (2019) directly investigate whether an emissions tax performs better than a cap-and-trade system for reducing carbon emissions. They find that an emissions tax yields more abatement than cap-and-trade, which confirms our theoretical results. Finally, there is a discussion on whether markets erode social responsibility and moral concerns (Sandel, 2012; Bartling, Weber, and Yao, 2015; Sutter et al., 2020; Dewatripont and Tirole, 2022). In our paper, it is not the market per se that affects moral behavior but the type of market mechanism. We consider two market instruments, price and quantity regulation, and show that price regulation fosters moral behavior, while quantity regulation renders it irrelevant.

[4]For surveys of this literature see Ledyard (1995) and Chaudhuri (2011).

2 The Model

Consider an economy with two consumption goods, a good X that pollutes the environment with greenhouse gas emissions and a numéraire good Y that involves no externalities. Each consumption unit of X generates one unit of emissions. Both goods are produced at constant marginal costs. The unit production cost of good X is $c > 0$, the unit production cost of the numéraire good Y is normalized to 1. There is no uncertainty and there is perfect competition so that all goods are sold at marginal cost. In Section 6.1 we consider the effects of uncertainty and in Section 6.2 we introduce imperfect competition.

The negative externalities can be mitigated by reducing consumption (and thereby emissions) or by offsetting emissions, e.g. by planting trees, restoring moors, etc. One unit of the offset good Z reduces emissions by one unit. The offset good is produced with cost function $k(z)$ with $k'(z) > 0$ for $z > 0$, and $k''(z) > 0$. The offset good is also produced by a competitive industry and thus the equilibrium price is $q = k'(z)$. Firms are owned by consumers, which implies that the profits of the offset industry $\pi_Z = qz - k(z)$ are part of consumers' income.

There is a continuum of identical consumers with wealth m and material utility function

$$U^M = v(x) + y - D(\bar{x} - \bar{z}) \tag{1}$$

where x and y denote the amounts consumed of good X and Y, respectively. Let $v'(x) > 0$ and $v''(x) < 0$. Consumers suffer from the environmental damage $D(\cdot)$ that is caused by aggregate consumption $\bar{x}$ net of aggregate offsets $\bar{z}$. We assume that $D(\cdot)$ is a continuous function with the following properties: for $\bar{x} > \bar{z}$ it holds that $D'(\cdot) > 0$ and $D''(\cdot) > 0$, while for $\bar{z} \geq \bar{x}$ we have $D(\cdot) \equiv 0$. To guarantee that all optimization problems have an interior solution we assume that $v'(0) = +\infty$, $k'(0) = 0$, and $D'(0) = 0$. In Section 4, we allow for consumers that are heterogeneous regarding their marginal rates of substitution between the two consumption goods.

2.1 Material Welfare

Material social welfare is defined as material utility minus production costs. Note that due to quasi-linear utility, the amount consumed of the numéraire good Y equals income minus expenditures for consumption of good X and offsets Z. Thus, material welfare is given by

$$W^M(\bar{x}, \bar{z}) = v(\bar{x}) + m - c\bar{x} - k(\bar{z}) - D(\bar{x} - \bar{z}). \tag{2}$$

There is a unique interior solution for the first-best levels of consumption, $x^* > 0$, and offsets, $z^* > 0$, that is uniquely characterized by the following first-order conditions[5]

$$\frac{\partial W^M}{\partial \bar{x}} = 0 \iff v'(x^*) - c - D'(x^* - z^*) = 0, \tag{3}$$

$$\frac{\partial W^M}{\partial \bar{z}} = 0 \iff D'(x^* - z^*) - k'(z^*) = 0. \tag{4}$$

This implies

$$v'(x^*) - c = D'(x^* - z^*) = k'(z^*). \tag{5}$$

2.2 Regulation

The regulator has two instruments to deal with harmful emissions. First, he can reduce aggregate consumption by either imposing a consumption tax (price regulation, $R = P$) or by introducing an emissions market where a fixed number of emission permits ($\bar{E}$) is traded (quantity regulation, $R = Q$). We denote the tax as well as the permit price by p. Revenues from emission pricing are redistributed lump-sum to consumers. Note that with price regulation the total amount of emissions is determined by the consumption decisions of all consumers, while with quantity regulation the total amount of emissions is fixed. The emissions price will always adjust such that the total amount of emissions is exactly $\bar{E}$.

Second, the regulator can mitigate emissions by buying offsets financed by (lump sum) taxation. Let the number of offsets purchased by the government be z^G and the number of offsets bought by consumers z^C, with $\bar{z} = z^G + z^C$.

[5] Material welfare is a strictly concave function. To see this, note that $\partial^2 W^M/\partial \bar{x}^2 < 0$, $\partial^2 W^M/\partial \bar{z}^2 < 0$, and

$$\frac{\partial^2 W^M}{\partial \bar{x}^2} \times \frac{\partial^2 W^M}{\partial \bar{z}^2} - \left(\frac{\partial^2 W^M}{\partial \bar{x} \partial \bar{z}}\right)^2 = D''(\bar{x} - \bar{z})k''(\bar{z}) - v''(\bar{x})[D''(\bar{x} - \bar{z}) + k''(\bar{z})] > 0.$$

The imposed Inada conditions ensure that $0 < z^* < x^*$.

2.3 Moral Preferences and Total Welfare

We depart from the standard model by assuming that consumers have moral concerns about pollution. They incur a moral cost if their emissions harm the environment. In the basic model, we assume that all consumers are "moral consequentialists" (e.g. Utilitarians) who base the moral judgment of an action on its consequences. In Section 5, we allow for heterogeneous moral convictions (selfish consumers, consequentialists, and deontologists). Moral concerns are modeled as follows. The consumer compares her consumption level x to a social norm that is determined endogenously. The social norm consumption level x_0 is a weighted average of the socially efficient consumption level x^* and the average actual consumption level in society x^R, which depends on the regulatory regime $R \in \{P, Q\}$, i.e.

$$x_0^R = \alpha x^* + (1 - \alpha)x^R \ . \tag{6}$$

If $\alpha = 1$ the norm is fully "injunctive" and requires that everybody should consume the socially efficient quantity x^* that maximizes material social welfare. If $\alpha = 0$ the norm is purely "descriptive", i.e. the consumers shall not consume more of X than everybody else does.[6] Actual social norms are somewhere in between.

If the consumer consumes more than the social norm x_0^R prescribes, she suffers a moral cost, i.e. her utility is reduced by $\beta^R[x - x_0^R]^+$, where $[x - x_0^R]^+ = \max\{0, x - x_0^R\}$ and $R \in \{P, Q\}$. Because consumers are consequentialists they suffer form the moral cost only if their consumption actually affects overall pollution. This is the case with price regulation, but not with quantity regulation. Thus, with price regulation $\beta^R = \beta > 0$, while with quantity regulation we have $\beta^Q = 0$.

The consumer may compensate for her wrong doing by offsetting some of her emissions ($z \geq 0$) at price q. Furthermore, if there is an emissions market, she can buy and delete emission rights ($e \geq 0$) at price p which reduces the total amount of emissions by e. This increases her utility by $\beta\{\min\{e + z, [x - x_0^R]^+\}$. Thus, the total utility function of a consumer

[6] The distinction between injunctive and descriptive norms goes back to Cialdini, Reno, and Kallgren (1990). They define a descriptive norm as "what most other people do". In contrast, "injuctive norms specify what ought to be done". This should not be confused with the legal definition of an "injunctive norm".

is given by

$$
\begin{aligned}
U(x,z,e) &= v(x) + \tilde{m} - (c+p)x - D(\bar{x} - z^G - z^C) - qz - pe \\
&\quad -\beta^R[x - x_0^R]^+ + \beta \min\{z + e, [x - x_0^R]^+\}, \qquad (7)
\end{aligned}
$$

with $\beta^P = \beta$ and $\beta^Q = 0$. A consumer's income is initial wealth plus profits from firms producing offsets plus net transfers from the government; $\tilde{m} = m + q\bar{z} - k(\bar{z}) + (p\bar{x} - qz^G)$.

Recall that there is a continuum of consumers. Thus, the effect that each consumer has on the damage experienced by herself is negligible and is ignored by the consumer. However, the aggregate utility loss of *all* consumers is given by $D'(\cdot) > 0$ which is not negligible, but equal to the social cost of carbon. To illustrate: If a consumer emits one additional ton of CO_2, then she will ignore how this additional consumption affects her own utility via the damage function $D(\cdot)$. However, the utility loss aggregated over all consumers is equal to the social cost of carbon and is not ignored by the consumer. A moral consequentialist feels responsible for the environmental damage that she imposes on all other consumers, but she ignores the negligible effect on herself.[7]

If consumers have moral concerns, we have to distinguish between material social welfare as defined in (2) and total social welfare which includes the moral feelings of consumers:

$$
\begin{aligned}
W^T &= v(\bar{x}) - c\bar{x} - D(\bar{x} - \bar{z}) - k(\bar{z}) - \beta^R[\bar{x} - x_0^R]^+ + \beta \min\{\bar{z} + \bar{e}, [\bar{x} - x_0^R]^+\} \\
&= W^M(\bar{x}, \bar{z}) - \alpha\beta^R[\bar{x} - x^*]^+ + \beta \min\{\bar{z} + \bar{e}, \alpha[\bar{x} - x^*]^+\} \ . \qquad (8)
\end{aligned}
$$

We are mainly interested in material welfare and assume that this is what the regulator wants to maximize, but we will also consider the effects of regulation on total welfare. Note that in the first best there is no difference between material and total welfare.

Observation 1. *Total social welfare* (8) *and material social welfare* (2) *coincide at consumption level x^* and total offsets z^*, defined by* (3) *and* (4).

If everybody consumes x^*, people do not suffer from consuming too much and they cannot increase moral utility by buying offsets.

[7]For additional supportive philosophical arguments see Tiefensee (2019).

2.4 Consumer Demand

The consumer's demand for offsets and/or emission rights is always given by a corner solution. If a consumer's moral concerns β are lower than the price for offsets or emission permits, she prefers not to compensate her consumption at all. If, on the other hand, her moral concerns are higher, she completely offsets her moral wrong doing.[8] With price regulation

$$z^P = \begin{cases} 0 & \text{if } \beta < q, \\ [x^P - x_0^P]^+ & \text{if } \beta \geq q. \end{cases} \tag{9}$$

With quantity regulation the consumer can compensate her emissions either by buying offsets at price q or by buying and deleting emission rights at price p. Because these are perfect substitutes, she will never engage in the more expensive of the two options. The total amount of compensations purchased is

$$z^Q + e^Q = \begin{cases} 0 & \text{if } \beta < \min\{p, q\} \\ [x^Q - x_0^Q]^+ & \text{if } \beta \geq \min\{p, q\}, \end{cases} \tag{10}$$

with $z^Q = 0$ for $q > p$ and $e^Q = 0$ for $p > q$.

In the following we restrict attention to the case where in both regulatory regimes average consumption is larger than the consumption level required by the social norm, i.e. $x^R \geq x_0^R$.[9] The consumer's demand for the consumption good depends on whether she will buy offsets/emission rights. With price regulation buying and deleting emission rights is not an option and she will not buy offsets if $\beta < q$. In this case the first-order condition (FOC) for her optimal consumption decision is given by

$$v'(x^P) = c + p + \beta. \tag{11}$$

If, on the other hand, $\beta \geq q$, the consumer fully offsets her wrong doing by choosing $z^P = x - x^0$. Note, that this makes the choice of z – indirectly – a function of x. The consumer

[8] If $\beta = q$ ($\beta = p$, respectively) the consumer is indifferent whether or not to purchase offsets (whether or not to buy and delete emission rights). Without loss of generality we assume that she chooses to compensate in this knife-edge case.

[9] If aggregate consumption $x^R < x_0^R = \alpha x^* + (1 - \alpha)x^R$, then we have $x^R < x^*$, so consumers consume too little. In this case the regulator would lower the emission tax or increase the number of emission permits up to the point where $x^R = x^*$.

anticipates that she will fully offset her consumption which eliminates the moral cost but increases the price of good X to $p+q$. Thus, her optimal consumption is given by

$$v'(x^P) = c + p + q. \tag{12}$$

With quantity regulation the demand for good X is derived similarly. If $\beta < \min\{p, q\}$ the consumer will not buy offsets nor will she buy and delete emission rights. Furthermore, she knows that her consumption decision has no effect on total emissions. Therefore the FOC for her optimal consumption is

$$v'(x^Q) = c + p. \tag{13}$$

If, on the other hand, $\beta \geq \min\{p, q\}$, the consumer either buys offsets or emission rights (whatever is cheaper) to compensate for the emissions caused by her consumption. In this case we have

$$v'(x^Q) = c + p + \min\{p, q\} - \beta. \tag{14}$$

Let π denote the sum of the "prices" (including the moral price) that the consumer considers in her consumption decision and define the consumer's moral demand $\hat{x}(\pi)$ by

$$v'(\hat{x}(\pi)) = \pi. \tag{15}$$

Then we can summarize this discussion in the following lemma.

Lemma 1. *The consumer's demand functions for the consumption good under price and under quantity regulation are given by*

$$x^P = \begin{cases} \hat{x}(c+p+\beta) & \textit{if } \beta < q \\ \hat{x}(c+p+q) & \textit{if } \beta \geq q \end{cases} \quad \textit{and} \quad x^Q = \begin{cases} \hat{x}(c+p) & \textit{if } \beta < \min\{p,q\} \\ \hat{x}(c+p+\min\{p,q\}-\beta) & \textit{if } \beta \geq \min\{p,q\} \end{cases} \tag{16}$$

and her demand functions for offsets and/or buying and deleting emission rights are

$$z^P = \begin{cases} 0 & \textit{if } \beta < q \\ x^P - x_0^P & \textit{if } \beta \geq q \end{cases} \quad \textit{and} \quad z^Q + e^Q = \begin{cases} 0 & \textit{for } \beta < \min\{p,q\} \\ x^Q - x_0^Q & \textit{for } \beta \geq \min\{p,q\} \end{cases} \tag{17}$$

with $z^Q = 0$ if $p < q$ and $e^Q = 0$ if $q < p$.

2.5 Implementing the First Best

If the regulator is not constrained in his choice of p or $\bar{E}$, it is not difficult to implement the first-best allocation (x^*, z^*). With price regulation, a sufficiently high emission tax implements $x^P = x^*$. With quantity regulation the number of emission permits $\bar{E}$ can be set equal to x^*. This directly implements the optimal amount of X (if no consumer buys and deletes emission rights). Note that if all consumers choose x^*, the social norm is $x_0 = x^*$, so all consumers comply with the norm. A consumer who consumes $x = x^*$ has no incentive to purchase offsets or to buy and delete emission rights, i.e. $0 = e^Q = z^C < z^*$. Thus, the first-best allocation is attainable only if the regulator purchases the optimal amount of offsets $z^G = z^*$.

Proposition 1. *If the emission price is unconstrained, the regulator can implement the first best by buying offsets $z^G = z^*$ and*

(a) either price regulation that sets the emission price to $p^* \in [D'(x^*) - \beta,\ D'(x^*)]$ for $k'(z^*) \geq \beta$ and $p^* \in [D'(x^*) - q,\ D'(x^*)]$ for $k'(z^*) < \beta$,

(b) or quantity regulation that restricts the number of emission permits to $\bar{E} = x^*$.

3 Second-Best Optimal Regulation

We now assume that there is a political constraint on the emission price p.

Assumption 1. *No matter whether there is price or quantity regulation, the regulator is constrained to implement an emission price p that satisfies*

$$0 \leq p \leq \bar{p} < D'(x^* - z^*) - \beta. \tag{18}$$

This constraint is due to political reasons. Many countries are finding it difficult if not impossible to raise carbon prices to the appropriate level. In the US carbon pricing is considered politically toxic and the Biden administration has basically given up on raising the current taxes on energy consumption. In France, the 'yellow vest' movement forced the Macron administration to largely roll back its increase of fuel taxes. In Switzerland, the electorate rejected a proposed increase of the carbon price in 2021. One reason why carbon pricing is so unpopular is that it is directly reflected in the price for gasoline, which is one of the most visible of all consumption prices.[10]

Note that constraint (18) implicitly imposes an upper bound on β and requires that $\beta < D'(x^* - z^*) = k'(z^*)$. If β was larger than this upper bound, moral concerns would be sufficient to implement the first best even if there is a constraint on the emission price.

Assumption 1 implies that the first-best allocation cannot be implemented with carbon pricing. In particular, there will always be too much consumption of the harmful good, $x > x^*$. In the main part of the paper we focus on this distortion only, i.e. we allow the regulator to purchase the (second best) optimal number of offsets. This requires that the efficient number of offset is sufficiently small that the regulator can buy them without massive tax increases that would infuriate the electorate. This is the case if the marginal cost of producing the offset increases very quickly, so the efficient amount of offsets is limited and small.

A modest role for offsets seems to be the realistic case at the current state of technology. The space required to plant trees or restore moors is limited and the opportunity cost of using land for this purpose increases rapidly. However, it is conceivable that at some point in the future it becomes possible to use carbon capture and storage at a large scale and at an affordable cost. Therefore, in Subsection 3.2 we consider the case where the marginal cost of producing offsets is constant, so that it would be efficient to have a "large" amount of offsets. In this case it makes sense to limit the number of offsets that the regulator can buy which introduces a second inefficiency.

Proposition 2. *Suppose that Assumption 1 holds. Under price regulation the regulator chooses $p = \bar{p}$. Under quantity regulation he fixes the number of emission permits $\bar{E}$ such that the resulting permit price is $\bar{p}$.*

The second-best optimal amount of offsets $z^R = \hat{z}(x^R)$ depends on the consumption level x^R, $R \in \{P, Q\}$, and is implicitly defied by

$$D'(x^R - \hat{z}) \equiv k'(\hat{z}). \tag{19}$$

[10]See Carattini, Carvalho, and Fankhauser (2018); Carattini, Kallbekken, and Orlov (2019) for a discussion of why carbon pricing is so unpopular.

For any $x^R > x^*$, consumers will not purchase any offsets, so $\hat{z}$ will be bought entirely by the regulator.

The intuition for Proposition 2 is straightforward. The regulator will guarantee that the second-best amount of offsets is produced. This drives up the marginal cost of offsets and therefore the price q so much that consumers will not buy them. Note, however, that with quantity regulation, consumers may purchase emission permits. Given that the regulator buys the second-best optimal level of offset $\hat{z}(x)$, material welfare is a concave function of x that is maximized at x^*. Because of Assumption 1, x^* cannot be implemented. Therefore, the regulator wants to reduce x as much as possible, which is achieved by setting $p = \bar{p}$ under price regulation and by choosing a number of permits $\bar{E}$ such that the resulting permit price is exactly $\bar{p}$. Given Proposition 2 we can now focus on $p = \bar{p}$ and $z = \hat{z}(x)$.

3.1 Price versus Quantity Regulation

The next proposition describes consumer behavior under optimal price and quantity regulation, respectively.

Proposition 3. *For any $\beta > 0$ that satisfies Assumption 1 consumption differs between a regime with price regulation and one with quantity regulation.*

(i) With price regulation the optimal consumption level is given by

$$x^P(\beta) = \hat{x}(c + \bar{p} + \beta). \tag{20}$$

and consumers do not buy any offsets.

(ii) With quantity regulation the optimal consumption level is given by

$$x^Q(\beta) = \begin{cases} \hat{x}(c + \bar{p}) & \text{if } \beta \leq \bar{p} \\ \hat{x}(c + 2\bar{p} - \beta) & \text{if } \beta > \bar{p}. \end{cases} \tag{21}$$

Consumers do not buy any offsets, but they may buy and delete emission rights

$$e^Q(\beta) = \begin{cases} 0 & \text{if } \beta \leq \bar{p} \\ \hat{x}(c + 2\bar{p} - \beta) - x_0^Q & \text{if } \beta > \bar{p}. \end{cases} \tag{22}$$

The regulator sets

$$\bar{E}(\beta) = x^Q(\beta) + e^Q(\beta) = \begin{cases} \hat{x}(c+\bar{p}) & \text{if } \beta < \bar{p} \\ (1+\alpha)\hat{x}(c+2\bar{p}-\beta) - \alpha x^* & \text{if } \beta \geq \bar{p} \end{cases} \tag{23}$$

Optimal consumption is decreasing in β under price regulation, but weakly increasing in β with quantity regulation. Furthermore,

$$x^Q(\beta) > x^P(\beta) > x^*. \tag{24}$$

The proposition shows that consumption is decreasing in β with price regulation, but increasing in β with quantity regulation! The intuition for the case of price regulation is straightforward. If consumers are more strongly concerned about pollution, they will consume and pollute less, because consumption becomes (morally) more expensive. It may be more surprising that the opposite result holds with quantity regulation if $\beta \geq \bar{p}$. The reason is as follows. On the one hand, consumers know that with quantity regulation their consumption decision has no effect on total pollution, so moral concerns do not induce them to consume less. On the other hand, consumers feel good about buying and deleting emission permits. If $\beta \geq \bar{p}$ they do so, and the more they consume the more permits they buy and delete. Thus, if β increases they derive more utility from this compensation, so they will consume more in order to compensate more. However, the regulator anticipates this behavior. He has to make sure that the permit price will not exceed $\bar{p}$. Thus, the regulator chooses the number of permits such that the additional demand for permits by consumers who want to buy and delete them will be met without the price exceeding $\bar{p}$. Thus, in equilibrium, buying and deleting emission rights does not reduce consumption, but increases it.

To evaluate the total effect on emissions we have to take the offsets into account that are bought by the regulator. The next proposition shows that the effect of regulation on consumption goes in the same direction as the effect on net emissions, i.e. consumption minus offsets.

Proposition 4. *For any $\beta > 0$, optimal price regulation implements an emission level $\mathcal{E}^P = x^P - z^P$ that is inefficiently high but strictly smaller than the level of emissions $\mathcal{E}^Q = x^Q - z^Q$ under optimal quantity regulation, i.e.*

$$x^* - z^* < \mathcal{E}^P(\beta) < \mathcal{E}^Q(\beta)\ . \tag{25}$$

The intuition for this proposition is that even though a higher consumption level induces the regulator to invest more in offsets, the slope of the increase in offsets is less than one. Hence, more consumption implies a higher level of total emissions.

We are now in position to evaluate material and total social welfare under the two regulatory regimes.

Proposition 5. *The regulatory regime effects social welfare as follows:*

(i) Material social welfare (2) *is unambiguously higher with price regulation than with quantity regulation, i.e.*

$$W^M(x^P, z^P) > W^M(x^Q, z^Q) \ . \tag{26}$$

(ii) The difference in material welfare is strictly increasing in β,

$$\frac{d(W^M(x^P, z^P) - W^M(x^Q, z^Q))}{d\beta} > 0. \tag{27}$$

(iii) Total social welfare (8) *is higher with price than with quantity regulation if and only if*

$$W^M(x^P, z^P) - W^M(x^Q, z^Q) > \begin{cases} \alpha\beta[x^P - x^*] & \text{if } \beta < \bar{p} \\ \alpha\beta[x^P + x^Q - 2x^*] & \text{if } \beta \geq \bar{p}. \end{cases} \tag{28}$$

This is always the case if the social norm is sufficiently descriptive, i.e. α *is sufficiently small.*

Proposition 5(i) shows that material social welfare is strictly higher with price regulation than with quantity regulation. Furthermore, by Proposition 5(ii) the more important moral concerns of consumers are, the more pronounced is the advantage. Price regulation complements moral motivations and induces consumers to pollute less. Quantity regulation has the exact opposite effect. In equilibrium, it induces morally motivated consumers to pollute more, the more they are concerned about the environment.

Proposition 5(iii) considers total social welfare that includes the moral feelings of consumers. With price regulation climate-conscious consumers suffer from violating the social norm. This is not the case with quantity regulation. A consumer who knows that her actions cannot have any effect on total emissions does not have to be morally concerned about her actions. Furthermore, with quantity regulation consumers can derive positive utility from buying and deleting emission permits. Thus, if these feelings are very strong, total social welfare may be larger under quantity than under price regulation. However, if α is sufficiently small, i.e., if the norm is sufficiently descriptive, this cannot be the case. In the extreme case where $\alpha = 0$ there are no moral feelings in equilibrium because everybody is choosing the same consumption level that equals the social norm. In this case material and total social welfare coincide.

3.2 Digression: Affordable Offsets at a Large Scale

So far we assumed that the scope for offsets is small. In this section, we briefly consider the case where offsets can be produced with constant returns to scale at a constant cost $\bar{q}$. This case might become relevant in the future when the technology for carbon capture and storage matures. Note that if $\bar{q} < \bar{p}$ the carbon price would be inefficiently high, so in this case the political constraint would no longer be binding. Thus, we restrict attention to the more interesting case where $\bar{q} \geq \bar{p}$. Furthermore, we assume that the regulator can buy only a limited amount of offsets $\bar{z}^G$. If he wanted to buy more, he would have to raise taxes which would infuriate the electorate.

Assumption 2. *Offsets can be produced with constant marginal cost $\bar{q} \geq \bar{p}$. No matter whether there is price or quantity regulation, the regulator is constrained to buy a limited number of offsets $\bar{z}^G$ that is inefficiently small.*

Assumptions 1 and 2 imply that the regulator will set $p = \bar{p}$ under price regulation, he will set $\bar{E}$ such that the resulting permit price is $\bar{p}$ under quantity regulation, and he will always buy the maximum amount of offsets $z^G = \bar{z}^G$.

With quantity regulation consumers will not buy offsets but rather buy and delete emission permits which is equally efficient and cheaper.[11] Thus, the analysis of quantity regulation remains unchanged.

[11] If $\bar{p} = \bar{q}$ consumers are indifferent. In this case we assume that they will buy and delete emission permits.

With price regulation, however, consumers will buy offsets if $\beta \geq \bar{q}$. By Lemma 1 we have

$$z^P = \begin{cases} 0 & \text{if } \beta < \bar{q} \\ x^P - x_0^P & \text{if } \beta \geq \bar{q} \end{cases} \tag{29}$$

and

$$x^P = \begin{cases} \hat{x}(c + \bar{p} + \beta) & \text{if } \beta < \bar{q} \\ \hat{x}(c + \bar{p} + q) & \text{if } \beta \geq \bar{q} \end{cases} \tag{30}$$

Note that consumption of X decreases with β as long as $\beta < \bar{q}$ and stays constant for $\beta \geq q$. The reason is that consumers do not reduce their consumption but buy offsets if $\beta \geq \bar{q}$. Consumption is independent of β for $\beta \geq \bar{q}$, and so is the number of offsets bought. The possibility to buy offsets increases the efficiency of price regulation because the social cost of reducing consumption beyond $x(c + \bar{p} + \bar{q})$ is higher than the social cost of buying offsets. For this reason we get the same qualitative results as in Propositions 4 and 5.

Proposition 6. *Suppose that Assumption 1 and 2 hold. For any $\beta > 0$, optimal price regulation implements an emission level $\mathcal{E}^P$ that is inefficiently high but strictly smaller than the level of emissions $\mathcal{E}^Q$ under optimal quantity regulation, i.e.*

$$x^* - z^* < \mathcal{E}^P(\beta) < \mathcal{E}^Q(\beta)\ . \tag{31}$$

Furthermore, because price regulation is more efficient if consumers can buy offsets at a constant price $\bar{q} \leq \beta$, the welfare comparison of Proposition 5 continues to hold.

In the next sections we go back to the case where the scope for offsets is small and the regulator buys the efficient amount of offsets.

4 Distributional Effects

We now distinguish two different types of consumers, called rich (r) and poor (p). We assume that both consumer groups have quasi-linear utilities as in (7), but the rich have a lower marginal utility of money:[12]

$$\begin{aligned} U(x, z, e) &= v(x) + \delta_i[m_i + p\bar{x} + \pi_Z - (c + p)x - qz - pe] - D(\bar{x} - \bar{z}) \\ &\quad -\beta^R[x - x_0^R]^+ + \beta \min\{z + e, [x - x_0^R]^+\}, \end{aligned} \tag{32}$$

[12] Alternatively, we could have assumed that the rich have a higher marginal utility from consuming good X and higher moral concerns β.

with $i \in \{r,p\}$, $\delta := \delta_r < \delta_p := 1$. The lower marginal utility of money implies that the rich consume more of the harmful good and their utility is less affected by a price increase. This reflects the common observation that wealthy people often do not react much to the prices of the goods they consume. They do not care whether a plastic bag in the supermarket costs an additional 50 cent, they drive an SUV even if fuel consumption is more expensive, and they do not give up on vacations to far away destinations just because the flight costs a few hundred dollars more. However, all consumers are affected by moral concerns. It is not obvious whether the rich have stronger or weaker moral concerns than the poor. It could be argued that wealth is correlated with education and that better educated people are more climate-conscious. It could also be argued that the rich got rich because they have less moral concerns. We do not take a position on this but simply assume that both types of consumers have the same β. We assume that $\delta\bar{p} < \beta < \bar{p}$. For the rich, the perceived maximum price is lower than the moral concern, while it is higher for the poor.

Assumption 1 implies that the regulator will set $p = \bar{p}$ and choose $\bar{E}$ such that the resulting permit price is $\bar{p}$.[13] Furthermore, by Proposition 2 consumers will not buy any offsets, so we can ignore them in their consumption decisions in the following. In this section we are interested in whether the poor or the rich adjust their consumption more under price as compared to quantity regulation. Let $\Delta_i^j := x_i^N - x_i^j$ denote the adjustment of consumption of consumer group $i \in \{r,p\}$ under regulation $j \in \{P,Q\}$ as compared to the level of consumption x_i^N that they would choose if there was no regulation. The next proposition characterizes these adjustments.[14]

Proposition 7. *Let $\delta\bar{p} < \beta < \bar{p}$. With price regulation both consumer groups reduce their consumption as compared to a situation without regulation, i.e. $\Delta_p^P > 0$ and $\Delta_r^P > 0$. In contrast, with quantity regulation the poor reduce their consumption, $\Delta_p^Q > 0$ while the rich increase it, $\Delta_r^Q < 0$.*

[13] Note that for rich consumers an even higher price p is necessary to implement the respective optimal consumption level.

[14] Strictly speaking, the result requires that the poor, who consume less than the rich and thus less than average consumption, consume more than the social norm. Let the consumption of type $i \in \{r,p\}$ under regime $R \in \{P,Q\}$ be x_i^R. Fraction μ of the population is poor and fraction $1-\mu$ is rich, so that average consumption is $\bar{x}^R = \mu x_p^R + (1-\mu)x_r^R$. The welfare optimal average consumption is $x^* = \mu x_p^* + (1-\mu)x_r^*$, where x_i^* is implicitly defined by $v'(x_i^*) = \delta_i c + D'(x^* - z^*)$. If the norm is sufficiently injunctive (α sufficiently large) and there are not too many rich consumers (μ is large), then $x_p^P > x^0 = \alpha x^* + (1-\alpha)\bar{x}^R$. Note that if this holds, then for all $R \in \{P,Q\}$ it holds that $x^0 < x_p^j < x_r^j$.

The effect of price regulation is straightforward. The emission price increases the perceived price for both types of consumers, so they will both consume less. The effect of quantity regulation is more involved. Consider first the consumption choices of poor consumers. With no regulation they perceive the price to be $c + \beta$ because they have moral concerns and they can affect the total amount of emissions. With quantity regulation they understand that they cannot affect total emissions, but they have to pay $\bar{p} > \beta$. Thus, their perceived price increases and they consume less. Now consider the rich. They will increase their consumption as compared to the case of no regulation for two reasons. First, they understand that their consumption does not affect total pollution with quantity regulation, so moral concerns no longer reduce their consumption. Second, because $\delta\bar{p} < \beta$ they will compensate for their emissions by buying and deleting emission permits. On the one hand, this increases the perceived price by $\delta\bar{p}$, because for every unit of X they will buy an additional emission permit in order to delete it. On the other hand, it increases their utility by $\beta > \delta\bar{p}$, which reduces the perceived price by β. The overall effect of quantity regulation on the perceived price is negative, and thus they will consume more.

Proposition 7 has some important policy implications. First, the political constraint on the pollution price $\bar{p}$ is usually determined by poor consumers who suffer more from higher prices than the rich. With quantity regulation the rich do not reduce their consumption at all but rather increase it, so all the adjustment has to be done by the poor. This makes quantity regulation very ineffective. The larger the fraction of the rich, the smaller is the effect of quantity regulation. Second, if the poor see that the rich increase their consumption and "buy themselves out" by buying and deleting emission permits, they may feel that it is unfair that the entire adjustment burden has to be borne by them. To be sure, the poor also benefit from the revenues of emission pricing that are redistributed lumpsum to all consumers. Nevertheless, emission pricing is politically more acceptable if the rich and the poor share the burden of adjustment, as they do with price regulation.

5 Selfish, Kantian and Naïve Consumers

Welfare economics is based on the assumptions of rational choice and consequentialism, so it is natural to start out with a model in which all consumers are fully rational and moral consequentialists. However, in the real world many consumers are not familiar with the functioning of an emissions market and may fail to understand that their behavior cannot affect total emissions. They are "naïve" in the sense that they do not see any difference between price and quantity regulation. Furthermore, consumers who are morally concerned need not be consequentialists. Many consumers are better described as deontologists (e.g. Kantians) who aspire to follow an ethical rule or a moral duty, independently of what the consequences of this action are.[15]

In this section, we allow for different moral convictions and degrees of rationality. We assume that a fraction $1-\lambda$ of consumers is selfish and has no moral concerns. These consumers simply maximize their material utility. The remaining fraction λ consists of two types of morally concerned consumers – consequentialists as in Section 2 and deontologists – who follow an ethical rule: "You shall not consume more than the social norm". We assume that deontologists are equally morally strict as consequentialists, so they follow the same social norm $x_0^R = \alpha x^* + (1-\alpha)x^R$, but, to a deontologist this social norm applies no matter what the consequences. For concreteness, we will call consequentialists "Utilitarians" and deontologists "Kantians".

Furthermore, there are naïve Utilitarians who do not understand the functioning of an emissions market and believe that any reduction of their emissions reduces total emissions by exactly this amount. In our model Kantian consumers and naïve Utilitarian consumers are observationally equivalent.[16] Let the share of Kantians and naïve Utilitarians in the population be $\lambda^K \geq 0$ and the share of sophisticated Utilitarians $\lambda^U \geq 0$, $\lambda^K + \lambda^U = \lambda < 1$. To avoid uninteresting case distinctions we restrict attention to the case where $\beta < \bar{p}$, so buying and deleting emission rights is not an issue.

With price regulation all morally concerned consumers choose consumption level $\hat{x}(c+$

[15] Kantian decision makers are also analyzed by Roemer (2010) and Alger and Weibull (2016).

[16] For Kantian consumers it does not matter whether they are naïve or sophisticated.

	share	price regulation	quantity regulation
Kantians naïve Utilitarians selfish	λ^K λ^U $1-\lambda$	$\hat{x}(c+\bar{p}+\beta)$ $\hat{x}(c+\bar{p}+\beta)$ $\hat{x}(c+\bar{p})$	$\hat{x}(c+\bar{p}+\beta)$ $\hat{x}(c+\bar{p})$ $\hat{x}(c+\bar{p})$
Total consumption	1	$x^P = \lambda\hat{x}(c+\bar{p}+\beta)$ $+ (1-\lambda)\hat{x}(c+\bar{p})$	$x^Q = \lambda^K\hat{x}(c+\bar{p}+\beta)$ $+(1-\lambda^K)\hat{x}(c+\bar{p})$

Table 1: Consumption decisions of different consumer types.

$\bar{p}+\beta)$, while selfish consumers consume more and choose $\hat{x}(c+\bar{p})$. This gives rise to total emissions $x^P = \lambda\hat{x}(c+\bar{p}+\beta) + (1-\lambda)\hat{x}(c+\bar{p})$.[17] With quantity regulation, sophisticated Utilitarian consumers act like selfish consumers, so their consumption is $\hat{x}(c+\bar{p})$. Selfish, Kantian and naïve Utilitarian consumers do not change their behavior as compared to a regime with price regulation. Thus, total consumption and pollution is given by $x^Q = \lambda^K\hat{x}(c+\bar{p}+\beta) + (1-\lambda^K)\hat{x}(c+\bar{p})$. The social planner will set the quantity of emission permits $\bar{E}$ such that $\bar{E} = x^Q(\bar{p})$ which gives rise to emission price $\bar{p}$. Because Utilitarians consume more under quantity regulation while all others do not change their behavior, total emissions are higher with quantity than with price regulation, as in Section 3.

The focus of this section is on the effects of a political or educational campaign that changes the composition of the population. For example, a new report of the IPCC or a political movement (e.g. "Fridays for Future") may raise the awareness of climate change and turn some selfish consumers into climate conscious consumers. The government could also make an effort to better explain the functioning of an emissions market to the public, thereby reducing the share of naïve consumers. Because these campaigns change the preferences of some part of the population, we cannot compare social welfare before and after the policy change. However, we can assess how consumers who did not change their type are affected,

[17]This assumes that $x > x_0$ for all morally concerned consumers, which is the case if α is sufficiently large:

$$\alpha > \frac{\hat{x}(c+\bar{p}) - \hat{x}(c+\bar{p}+\beta)}{\hat{x}(c+\bar{p}) - x^*}.$$

which gives rise to important distributional effects.

Proposition 8 (Price regulation). *Suppose that the share of climate conscious consumers, λ, increases. With price regulation all consumers (both selfish and moral) who did not change their type benefit from the conversion of some selfish to moral consumers.*

If a selfish consumer gets morally concerned, she consumes less and total pollution is reduced. The consumption choices of selfish and climate conscious consumers who did not change their type are unaffected, but both types benefit from the reduction of pollution. There is also a negative effect on all consumers because tax revenues go down and less money can be redistributed. Furthermore, moral types are adversely affected because the social norm gets stricter. However, under Assumption 1, these effects are dominated by the positive effect of less pollution.

Consider now the case of quantity regulation and assume that the number of emission rights $\bar{E}$ is fixed.[18]

Proposition 9 (Quantity regulation). *Suppose that the share of morally concerned consumers, λ, increases and that $\beta < \bar{p}$.*

- *If the share of sophisticated Utilitarians, λ^U increases, there is no effect.*
- *If the share of Kantian and naïve Utilitarian consumer, λ^K, increases, the demand for emission permits is reduced. Because the supply of emission permits is fixed, total pollution is unaffected, but the pollution price goes down. Selfish and sophisticated Utilitarian consumers unambiguously benefit from the price decrease, while Kantian and naïve Utilitarian consumers are strictly worse off.*

With a fixed emission cap, an increase of the share of Kantian consumers cannot affect total pollution, but it does affect the permit price p. A decrease in p has three effects: It reduces the amount px that consumers have to pay for their consumption x, it reduces the

[18] An increase of the number of Kantian consumers reduces the emission price. Thus, the regulator could respond by reducing the number of emission rights. However, many existing emissions markets fixed the number of emission rights for many years. For example, in the European Emissions Trading System the amount is fixed until 2030.

lumpsum redistribution $p\bar{x}$ that each consumer gets, and it affects the individual consumption decisions. At the margin, the last effect is positive but has a second order effect on utility due to the envelope theorem. Because selfish and sophisticated Utilitarian consumers consume more than $\bar{x}$, they benefit from the price reduction, while Kantian and naïve Utilitarian consumer consume less than $\bar{x}$ and therefore lose out.

These propositions show that with price regulation total emissions are reduced and everybody benefits if the population gets more climate conscious. With quantity regulation, however, only selfish and sophisticated Utilitarian consumers benefit, while Kantian and naïve Utilitarian consumer lose out, and there is no effect on total emissions. Thus, quantity regulation gives rise to perverse incentive effects: Kantian consumers have no material interest to convince selfish consumers to follow their moral duty, and nobody wants to educate naïve Utilitarians about the functioning of the emissions market.

6 Robustness Checks

6.1 Uncertainty

In a canonical paper, Weitzman (1974) compares price and quantity regulation in a world with uncertainty. He shows that quantity regulation outperforms price regulation if fluctuations in price are less harmful than fluctuations in quantity of emissions. In our setup, quantity regulation always yields a lower level of material efficiency. In this subsection we show that our result continues to hold even if we allow for uncertainty.

Suppose that the benefit from consuming good X is $\theta v(x)$, where $\theta > 0$ is a state of nature that is unknown ex ante and distributed according to c.d.f. $F(\theta)$ on $[\underline{\theta}, \bar{\theta}]$. The state θ shifts the marginal abatement cost curve (opportunity costs of reduced consumption). A consumer's ex post utility is

$$U = \theta v(x) + \tilde{m} - (c+p)x - D(\bar{x} - \bar{z}) - \beta^R[x - x_0^R(\theta)]^+ + \beta \min\{e + z, [x - x_0^R(\theta)]^+\} \quad (33)$$

where the social norm $x_0^R(\theta) = (1-\alpha)\bar{x}(\theta) + \alpha x^*(\theta)$ depends on θ and on the regulatory regime $R \in \{P, Q\}$. Material welfare in state θ is

$$W^M(\bar{x}, \bar{z}|\theta) = \theta v(\bar{x}) + m - c\bar{x} - k(\bar{z}) - D(\bar{x} - \bar{z}). \quad (34)$$

The first-best levels of consumption and offsets are characterized by the following first-order conditions.

$$\theta v'(x^*(\theta)) = c + D'(x^*(\theta) - z^*(\theta)) \tag{35}$$

$$D'(x^*(\theta) - z^*(\theta)) = k'(z^*(\theta)). \tag{36}$$

Differentiating the equation system with respect to θ shows that $dx^*/d\theta > dz^*/d\theta > 0$.

The time structure is as follows. First, the regulator sets the tax p or the quantity of emission permits $\bar{E}$ without knowing state θ. Then the state of nature materializes and is publicly observed. Finally, consumers and the regulator make their purchasing decisions of goods X and Z.

Because the regulator has to fix the price or the quantity before the uncertainty is resolved, he cannot implement the efficient emission level x^* even if there is no upper bound on the emission price p. Sometimes emissions will be too high and sometimes they will be too low. If the marginal damage function is (almost) linear in emissions, a price $p \approx D'(\cdot)$ achieves (almost) the first best and price regulation is optimal. On the other hand, if the marginal damage function is highly convex because of a tipping point at some emission level $\check{x}$ so that $x^*(\theta)$ is just below $\check{x}$ for all θ, then quantity regulation that sets the quantity just below the tipping point is optimal. This is the famous result of Weitzman (1974). However, with a sufficiently low price cap on p, this result no longer holds, and price regulation is *always* optimal.

We assume that for any state θ the price cap $\bar{p}$ is too low to implement the first-best allocation.

Assumption 3. *For all* $\theta \in [\underline{\theta}, \bar{\theta}]$, $p \leq \bar{p} \leq D'(x^*(\underline{\theta}) - z^*(\underline{\theta})) - \beta$.

The next result establishes that with Assumption 3 price regulation always yields lower consumption and higher material welfare than quantity regulation, independent of the distribution of the state of the world.

Proposition 10. *Suppose that there is ex ante uncertainty about* $\theta \in [\underline{\theta}, \bar{\theta}]$ *distributed according to some c.d.f.* $F(\theta)$ *which affects marginal utility and thereby marginal abatement cost.*

(i) For any realization of θ, the amount consumed of good X under price regulation is lower than the amount under quantity regulation but higher than the first best amount, i.e.

$$x^*(\theta) < x^P(\bar{p}, \theta) < x^Q(p^*(\theta), \theta) \quad \forall \theta \in [\underline{\theta}, \bar{\theta}] \ . \tag{37}$$

(ii) Expected material welfare is strictly higher with price than with quantity regulation, i.e.

$$\mathbb{E}[W^M(x^Q, z^Q)] < \mathbb{E}[W^M(x^P, z^P)] \ . \tag{38}$$

To understand the intuition for this result, note that Assumption 3 implies that emissions are always inefficiently high. The regulator has to fix $\bar{E}$ such that the price never exceeds $\bar{p}$. Thus, in most states the emission price will be lower than $\bar{p}$. This implies that in these states consumption is higher than under price regulation even if there are no moral concerns. Thus, the introduction of uncertainty unambiguously strengthens our result.

6.2 Imperfect Competition

We now consider the effect of imperfect competition. Suppose that good X is produced by symmetrically differentiated firms that are able to charge a markup $\mu^R > 0$, so the monetary price for good X is $c + \mu^R + \bar{p}$. Note that the markup may depend on the regulatory regime $R \in \{P, Q\}$. The reason is that depending on the type of regulation the consumer faces a different "moral price" that depends on her moral concerns β^R. We assume that the moral price (including the markup) is always too low to implement the welfare optimal consumption level. Furthermore, we assume that with quantity regulation there is perfect competition on the emissions market. The following proposition shows that our main result still holds under a weak condition.

Proposition 11. *Suppose that good X is produced by symmetrically differentiated firms that charge markup $\mu^R(\beta)$ in regulatory regime $R \in \{P, Q\}$ in equilibrium. If $-1 < d\mu^P/d\beta$ and $d\mu^Q/d\beta < 1$, then $x^* < x^P < x^Q$ and $W^M(x^P, z^P) > W^M(x^Q, z^Q)$.*

Note that with price regulation an increase of β has the same effect as an increase of an excise tax imposed on consumption. Thus, $d\mu^P/d\beta > -1$ requires that firms do not reduce the price of the good by more than the tax increase, so the effective price paid by consumers goes up because of the tax. With quantity regulation an increase of β has the same effect as an increase of a subsidy on consumption (if $\beta > \bar{p}$, otherwise there is no effect). Thus, $\mu^Q/d\beta < 1$ requires that firms do not increase the price by more than the increase in subsidy. Thus, the effective price paid by consumers goes down because of the subsidy. This second condition is of course equivalent to the first condition on a tax increase. This condition is empirically very plausible and satisfied in many oligopoly models.[19]

Thus, the only effect of market power is that it increases the price and thus reduces the consumption of good X without affecting the ordering. This brings quantities closer to the first-best quantity, but price regulation still outperforms quantity regulation.

7 Conclusions

Many consumers are morally concerned about their carbon footprint. They are prepared to voluntarily reduce emissions by saving energy, investing in renewables, or changing their consumption patterns. With an emission tax (price regulation) climate action by climate conscious consumers reduces total emissions. In contrast, with cap-and-trade (quantity regulation) these efforts do not affect total pollution and are discouraged. The difference between price and quantity regulation is amplified if consumers can compensate for their emissions by buying and deleting emission permits or by investing in offsets.

Our analysis applies not only to consumption decisions of consumers. Many firms are pressured by their customers, employees, and shareholders to make substantial efforts to reduce carbon emissions. For example, Blake Morgen listed 101 multinational companies that are committed to become carbon neutral in the near future on *Forbes.com* in 2019.[20] Similarly, many (regional) governments are pressured by voters to make significant efforts to reduce CO_2 emissions. The European Green Deal and the climate action of the Biden administration are prominent examples. In addition, many US states impose clean energy standards to reduce

[19] For example, it is always satisfied in symmetric Cournot models for any demand functions as long as the the stability conditions for a Cournot equilibrium hold. See Vives (1999, p. 104).

[20] https://www.forbes.com/sites/blakemorgan/2019/08/26/101-companies-committed-to-reducing-their-carbon-footprint/?sh=74e6f444260b

non-renewable energy consumption and to increase the production of renewable energy. In the EU, several countries heavily subsidize the production of solar and wind energy. Germany alone has spent about 300 billion Euros since 2001 to subsidize renewable energy, and it wants to spend another 40 billion Euros to shut down all coal-fired power stations until 2038. These initiatives are often on top of cap-and-trade systems, such as the Regional Greenhouse Gas Initiative (RGGI) and the Western Climate Initiative (WCI) in North America or the Emissions Trading System (ETS) in the EU, and so have little or no effect on total emissions. However, as long as the carbon price is too low, additional carbon action is urgently needed to achieve the two-degree-goal. With cap-and-trade, these additional efforts are largely wasted and discouraged. With price regulation these measures would be more effective and, as we show, voters would have a stronger incentive to push for them.

Furthermore, quantity regulation gives rise to dysfunctional distribution and incentive effects. It shifts the burden of adjustment to the poor while the rich buy themselves out and may even increase their consumption. Climate action of morally concerned agents lowers the carbon price and thereby subsidizes consumption of those who are less environmentally conscious. There are no incentives for Kantian consumers to convince selfish consumers to become climate conscious and for selfish consumers to educate "naïve" consumers about the functioning of cap-and-trade. In contrast, with price regulation rich and poor households have similar incentives to reduce their carbon emissions. Furthermore, everybody benefits if agents are motivated to take climate action. These are powerful arguments in favor of price regulation that policy makers should take into account.

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A Appendix

Proof of Lemma 1. The result follows directly from the analysis preceding the lemma. □

Proof of Proposition 1. The result follows directly from Lemma 1 and the definitions of x^* and z^*.. □

Proof of Proposition 2. Consider the second best amount of offsets $\hat{z}$. Note that

$$0 < \frac{d\hat{z}}{dx} = \frac{D''(x^R - \hat{z})}{k''(z) + D''(x^R - \hat{z})} < 1. \tag{A.1}$$

Thus, for $x^R > x^*$ we have $\hat{z}(x^R) > z^*$. This implies that $q = k'(\hat{z}(x)) > k'(z^*) > \beta$, where the final inequality follows from Assumption 1. Hence, if the regulator chooses z^G optimally for any $x^R > x^*$ implemented by the regulation, no consumer buys offsets. This follows directly from $q > \beta$.

If the regulator chooses z optimally given x^R, material welfare,

$$W^M(x^R, \hat{z}(x^R)) = v(x^R) + m - cx^R - k(\hat{z}(x^R)) - D(x^R - \hat{z}(x^R)), \tag{A.2}$$

is solely a function of x^R. From the envelope theorem it follows that

$$\frac{dW^M}{dx^R} = v'(x^R) - c - D'(x^R - \hat{z}) \tag{A.3}$$

and using (A.1), we get

$$\frac{d^2W^M}{dx^2} = v''(x^R) - D''(x^R - \hat{z})\frac{k''(\hat{z})}{k''(\hat{z}) + D''(x^R - \hat{z})} < 0. \tag{A.4}$$

Material welfare $W^M(x^R, \hat{z}(x^R))$ is a strictly concave function of x^R that is maximized at $x^R = x^*$, where $\hat{z}(x^*) = z^*$. Thus, the regulator is interested in implementing the lowest feasible x^R. Under price regulation this is achieved by setting $p = \bar{p}$. Under quantity regulation, he sets the number of emission permits $\bar{E}$ so that the resulting permit price is $\bar{p}$. □

Proof of Proposition 3. Consider price regulation first. By Proposition 2 we know that the regulator sets $p = \bar{p}$ and buys the second-best optimal amount of offsets, while consumers don't buy any offsets. Thus, demand for good X is given by

$$x^P(\beta) = \hat{x}(c + \bar{p} + \beta). \tag{A.5}$$

The higher the moral concerns of consumers (higher β), the lower is consumption of the harmful good. Since all consumers are identical, the norm violation is given by

$$\begin{aligned} x^P - x^0 &= x^P - [\alpha x^* + (1-\alpha)x^P] && \text{(A.6)} \\ &= \alpha[x^P - x^*] && \text{(A.7)} \end{aligned}$$

Now, consider quantity regulation. The regulator chooses $\bar{E}$ such that the resulting permit price is $\bar{p}$. By similar arguments as above, $q > \beta$ and thus consumers do not purchase offsets, but they may buy and delete emission permits.

$$e^Q(\beta) = \begin{cases} 0 & \text{if } \beta < \bar{p} \\ \hat{x}^Q - x_0^Q & \text{if } \beta \geq \bar{p}. \end{cases} \tag{A.8}$$

Anticipating this the consumer's demand for good X is

$$x^Q(\beta) = \begin{cases} \hat{x}(c + \bar{p}) & \text{for } \beta < \bar{p} \\ \hat{x}(c + \bar{p} - (\beta - \bar{p})) & \text{for } \beta \geq \bar{p}. \end{cases} \tag{A.9}$$

Consumption is independent of β until $\beta = \bar{p}$. Thereafter consumption is increasing with β. The consumer anticipates that she will buy and delete one emission permit for every unit of consumption. The cost of this is $\bar{p}$, but the benefit is $\beta \geq \bar{p}$. Thus, the larger β the more the consumer enjoys buying and deleting emission rights and so the more she will consume. Note that $x_0^Q = \alpha x^* + (1-\alpha)\hat{x}(c + 2\bar{p} - \beta)$, so we can write

$$e^Q(\beta) = \begin{cases} 0 & \text{if } \beta < \bar{p} \\ \alpha(\hat{x}(c + 2\bar{p} - \beta) - x^*) & \text{if } \beta \geq \bar{p}. \end{cases} \tag{A.10}$$

The regulator sets the total number of emission rights such that $p = \bar{p}$, i.e.

$$E(\beta) = \begin{cases} \hat{x}(c + \bar{p}) & \text{if } \beta < \bar{p} \\ \hat{x}(c + 2\bar{p} - \beta) + e^Q & \text{if } \beta \geq \bar{p} \end{cases} \tag{A.11}$$

Substituting e^Q and rearranging yields

$$E(\beta) = \begin{cases} \hat{x}(c+\bar{p}) & \text{if } \beta < \bar{p} \\ (1+\alpha)\hat{x}(c+2\bar{p}-\beta) - \alpha x^* & \text{if } \beta \geq \bar{p} \end{cases} \tag{A.12}$$

Note that for $\beta < \bar{p}$ the total number of emission rights is unaffected by β. However, if $\beta \geq \bar{p}$ the total number of emission rights increases with β. □

Proof of Proposition 4. By (A.1), a higher x leads to a higher z. The increase in z due to an increase in x, however, is less than 1. This leads to the ordering provided in the proposition. □

Proof of Proposition 5. Part (i) follows from the observation that $W^M(x, \hat{z}(x))$ is a strictly concave function that is maximized at x^*, and the ordering of the consumption levels provided by Proposition 3.

Part (ii): Note that $x^P = \hat{x}(c+\bar{p}+\beta)$ is a decreasing function in β. Moreover, $x^Q = \hat{x}(c+\bar{p})$ for $\beta < \bar{p}$ and $x^Q = \hat{x}(c+2\bar{p}-\beta)$ for $\beta \geq \bar{p}$. Thus, x^Q is a (weakly) increasing function in β. The result follows then from the arguments made in part (i).

Part (iii) follows directly from the definition of total social welfare (8). □

Proof of Proposition 6. The proof follows the lines of the proofs of Proposition 4 and 5. □

Proof of Proposition 7. Recall that $\hat{x}(\pi)$ is the optimal consumption of a consumer who faces the perceived price π. We distinguish three cases:

1. *No regulation:* If there is no regulation, the emission price is $p = 0$ and there is no quantity constraint. Consumers know that they can affect emissions with their consumption. The perceived price for the poor is $\pi = c + \beta$, while it is $\pi = \delta c + \beta$ for the rich. Thus

$$x_p^N = \hat{x}(c+\beta) \tag{A.13}$$

$$x_r^N = \hat{x}(\delta c+\beta) \tag{A.14}$$

2. *Price regulation:* With price regulation the perceived price for the poor is $\pi = c + \bar{p} + \beta$, while for the rich it is $\pi = \delta(c + \bar{p}) + \beta$, so we have

$$x_p^P = \hat{x}(c + \bar{p} + \beta) \tag{A.15}$$
$$x_r^P = \hat{x}(\delta(c + \bar{p}) + \beta) \tag{A.16}$$

3. *Quantity regulation:* With quantity regulation the perceived price for the poor is $\pi = c + \bar{p}$. The rich will buy and delete emission rights in order to compensate emissions, so their perceived price is $\pi = \delta(c + 2\bar{p}) - \beta$. Thus we have

$$x_p^Q = \hat{x}(c + \bar{p}) \tag{A.17}$$
$$x_r^Q = \hat{x}(\delta(c + 2\bar{p}) - \beta) \tag{A.18}$$

With price regulation we get

$$\Delta_p^P = \hat{x}(c + \beta) - \hat{x}(c + \bar{p} + \beta) > 0 \tag{A.19}$$
$$\Delta_r^P = \hat{x}(\delta c + \beta) - \hat{x}(\delta(c + \bar{p}) + \beta) > 0 \tag{A.20}$$

Both consumer groups reduce their consumption because the perceived price increases. However, with quantity regulation we get

$$\Delta_p^Q = \hat{x}(c + \beta) - \hat{x}(c + \bar{p}) > 0 \tag{A.21}$$
$$\Delta_r^Q = \hat{x}(\delta c + \beta) - \hat{x}(\delta(c + 2\bar{p}) - \beta) < 0 \tag{A.22}$$

Because $\beta < \bar{p}$ the poor perceive a higher price and reduce their consumption, while the rich will buy and delete emission permits and increase their consumption. This follows from $\delta\bar{p} < \beta$ which implies $\delta c + \beta > \delta(c + \bar{p}) > \delta(c + \bar{p}) - (\beta - \delta\bar{p}) = \delta(c + 2\bar{p}) - \beta$. □

Proof of Proposition 8. Share λ chooses $x^m := \hat{x}(c + \bar{p} + \beta)$ and share $1 - \lambda$ chooses $x^s := \hat{x}(c + \bar{p})$, with $x^s > x^m$. Total consumption is

$$x^P = \lambda\hat{x}(c + \bar{p} + \beta) + (1 - \lambda)\hat{x}(c + \bar{p}) = x^s - \lambda(x^s - x^m). \tag{A.23}$$

An increase of λ reduces the consumption of those selfish consumers that have been turned into moral consumers. It does not affect the consumption decisions of consumers who did not change type. Material welfare is given by

$$W^M = \lambda v(x^m)) + (1-\lambda)v(x^s) + m - cx^P - D(x^P - \bar{z}) - k(\bar{z}). \tag{A.24}$$

The regulator purchases the second-best amount of offsets, $\hat{z}(x^P)$, implicitly defined by $D'(x^P - \hat{z}) = k'(\hat{z})$. Note that $d\hat{z}/dx^P \in (0,1)$. With $x^P > x^*$ we have $\hat{z}(x^P) > z^*$, which implies that $q = k'(\hat{z}(x^P)) > k'(z^*) > \beta$. Hence, consumers do not purchase offsets.

The utility of selfish consumers is

$$U^S = v(x^s) + m - k(\hat{z}) + \bar{p}[\lambda x^m + (1-\lambda)x^s] - (c+\bar{p})x^s - D(\lambda x^m + (1-\lambda)x^s - \hat{z}). \tag{A.25}$$

The effect of an increase in λ on those selfish consumers that stay selfish is

$$\frac{dU^S}{d\lambda} = (x^s - x^m)\left\{\frac{d\hat{z}}{dx^P}[k'(\hat{z}) - D'(x^P - \hat{z})] + D'(x^P - \hat{z}) - \bar{p}\right\} > 0. \tag{A.26}$$

Recall that $k'(\cdot) - D'(\cdot) = 0$ by the definition of $\hat{z}$ and that $D'(\cdot) - \bar{p} > 0$ by Assumption 1. A reduction of aggregate consumption affects selfish consumers because it reduces the tax revenues that are redistributed lumpsum to consumers and it reduces pollution. Furthermore, it induces the regulator to buy more offsets that have to be paid for by lumpsum taxes. However, due to the envelope theorem, this latter effect is of second order.

The utility of moral (K and U) consumers is

$$\begin{aligned} U^K = U^U &= v(x^m) + m - k(\hat{z}) + \bar{p}[\lambda x^M + (1-\lambda)x^s] - (c+\bar{p})x^m \\ &\quad - D(\lambda x^m + (1-\lambda)x^s - \hat{z}) - \beta\{x^m - \alpha x^* - (1-\alpha)[\lambda x^m + (1-\lambda)x^s]\}. \end{aligned} \tag{A.27}$$

We assumed that $\alpha > [x^s - x^m]/[x^s - x^*]$ so that $x^m > x_0^P$ (see footnote #17). Differentiation of (A.27) with respect to λ yields

$$\frac{dU^K}{d\lambda} = \frac{dU^U}{d\lambda} = (x^s - x^m)\left\{\frac{d\hat{z}}{dx^P}[k'(\hat{z}) - D'(x^P - \hat{z})] + D'(x^P - \hat{z}) - \bar{p} - \beta(1-\alpha)\right\} > 0. \tag{A.28}$$

Note that $k'(\cdot) - D'(\cdot) = 0$ by the definition of $\hat{z}$ and that $D'(\cdot) - \bar{p} - \beta > 0$ by Assumption 1. The effect on moral consumers (U and K) is similar to the one on selfish (S) consumers. There is an additional effect because the reduced aggregate consumption makes the social norm stricter, which has an additional negative effect on the utility of moral consumers. However, the total effect is still positive.

□

Proof of Proposition 9. The amount of emission permits is fixed to $\bar{E} = x^Q(\bar{p})$. This implies that (i) total consumption is fixed, (ii) the regulator does not have to adjust $z^G = \hat{z}(\bar{E})$, (iii) and thus also net emissions are constant. The social norm does not change either. The only effect of an increase of λ^K is that it affects the emission price p.

Note that $q = k'(\hat{z}(\bar{E})) > k'(z^*) > \beta$ and that we assumed that $\beta < \bar{p}$. Thus, consumers neither purchase offsets nor emission permits. Share λ^K chooses $x^m = \hat{x}(c + p + \beta)$ and share $1 - \lambda^K$ chooses $x^s = \hat{x}(c + p)$. Let p^Q be the market clearing permit price, i.e.

$$\bar{E} \equiv \lambda^K \hat{x}(c + p^Q + \beta) + (1 - \lambda^K)\hat{x}(c + p^Q). \tag{A.29}$$

Implicit differentiation of (A.29) with respect to λ^K yields

$$\frac{dp^Q}{d\lambda^K} = \frac{x^s - x^m}{\lambda^K \hat{x}'(c + p^q + \beta) + (1 - \lambda^K)\hat{x}'(c + p^Q)} < 0. \tag{A.30}$$

We consider a marginal increase in λ^K so that $\bar{p} > p^Q > \beta$.

The utility of selfish and sophisticated Utilitarian consumers is

$$U^S = v(x^s(p^Q)) + m - k(\hat{z}) + p^Q\bar{E} - (c + p^Q)x^s(p^Q) - D(\bar{E} - \hat{z}). \tag{A.31}$$

We differentiate the above expression with respect to λ^K and obtain:

$$\frac{dU^S}{d\lambda^K} = -\lambda^K(x^s - x^m)\frac{dp^Q}{d\lambda^K} + \frac{dx^s}{dp^Q}\frac{dp^Q}{d\lambda^K}[v'(x^s) - c - p^Q] \tag{A.32}$$

$$= -\lambda^K(x^s - x^m)\frac{dp^Q}{d\lambda^K} > 0. \tag{A.33}$$

Note that $v'(x^s) = c + p^Q$ by the definition of x^s.

The utility of Kantian and naïve Utilitarian consumers is

$$U^K = v(x^m(p^Q)) + m - k(\hat{z}) + p^Q\bar{E} - (c + p^Q)x^m(p^Q) - D(\bar{E} - \hat{z}) - \beta[x^m(p^Q) - \alpha x^* - (1 - \alpha)\bar{E}]. \tag{A.34}$$

Differentiating the above expression with respect to λ^K yields

$$\frac{dU^K}{d\lambda^K} = [v'(x^m) - c - p^Q - \beta]\frac{dx^m}{dp^Q}\frac{dp^Q}{d\lambda^K} + [\bar{E} - x^M]\frac{dp^Q}{d\lambda^K} \tag{A.35}$$

$$= (1-\lambda^K)(x^s - x^m)\frac{dp^Q}{d\lambda^k} < 0. \tag{A.36}$$

To obtain the final line, we used the fact that $\bar{E} = \lambda^K x^m + (1-\lambda^K)x^s$ and that by the definition of x^m it holds that $v'(x^m) = c + p^Q + \beta$.

□

Proof of Proposition 10. Assumption 3 implies that $\beta < k'(z^*(\underline{\theta}))$. If the regulator purchases the second-best amount of offsets $z^G = \hat{z}(\bar{x}, \theta) = \arg\max_{\bar{z}} W^M(\bar{x}, \bar{z}|\theta)$, then $q > \beta$. This implies that consumers never purchase any offsets.

Let $x^R = x^R(p, \theta)$ be the amount consumed under regulation R for permit price/tax $p \leq \bar{p}$. Expected material welfare is

$$\mathbb{E}[W^M(x^R, \hat{z}(x^R, \theta)|\theta)] = \int_{\underline{\theta}}^{\bar{\theta}} \left\{\theta v(x^R) + m - cx^R - k(\hat{z}(x^R, \theta)) - D(x^R - \hat{z}(x^R, \theta))\right\} dF(\theta). \tag{A.37}$$

The integrand of the above expression is a strictly concave function in x^R that is maximized at $x^R = x^*(\theta)$. Note that for $x^R = x^*(\theta)$ we have $\hat{z} = z^*(\theta)$.

Under price regulation, the demanded quantity $x^P(p, \theta)$ is implicitly defined by

$$\theta v'(x^P) = c + p + \beta. \tag{A.38}$$

The quantity $x^P(p, \theta)$ is decreasing in p and increasing in θ. Under Assumption 3 the consumed amount is too high from a welfare point of view for any $p \leq \bar{p}$. Thus, the regulator optimally specifies $p = \bar{p}$.

Under quantity regulation, the amount consumed of good X, $x^Q(p, \theta)$ solves

$$\theta v'(x^Q) = \begin{cases} c + p & \text{for } \beta < p, \\ c + p - (\beta - p) & \text{for } \beta \geq p. \end{cases} \tag{A.39}$$

Demand for good X is decreasing in p and increasing in θ. While consumers do not purchase offsets in equilibrium, they may buy and delete emission permits under quantity regulation. By Lemma 1 a consumer's demand for emission permits is

$$e^Q(p,\theta) = \begin{cases} 0 & \text{for } \beta < p, \\ x^Q(p,\theta) - x_0^Q(p,\theta) & \text{for } \beta \geq p. \end{cases} \tag{A.40}$$

Demand for good X is too high from a welfare point of view. Thus, the regulator will choose $\bar{E}$ as low as possible so that $p \leq \bar{p}$ in any state θ. The demand for emission permits is $E(p,\theta) = x^Q(p,\theta) + e^Q(p,\theta)$. Let the market clearing price be $p^*(\theta)$, i.e., $E(p^*(\theta),\theta) = \bar{E}$. Since demand varies with the state of nature, the condition $p^*(\theta) \leq \bar{p}$ implies that with quantity regulation the permit price is often strictly lower than the upper bound.

The two statements of the proposition now follow readily:

(i) From (A.38) and (A.39) it follows directly that for any given price $p \leq \bar{p}$, $x^P(p,\theta) < x^Q(p,\theta)$ for all θ. Furthermore, demand is always decreasing in the price and the equilibrium permit price $p^*(\theta) \leq \bar{p}$ while the emission tax is always equal to $\bar{p}$. This increases the difference between $x^P(\theta,\bar{p})$ and $x^Q(\theta,p^*(\theta))$. Finally, by Assumption 3 it holds that $x^*(\theta) < x^P(\bar{p},\theta)$ for all θ.

(ii) Ex post material welfare – the integrand of (A.37) – is strictly concave in x^R and maximized at $x^R = x^*(\theta)$. Thus, part (i) directly implies that ex post material welfare is strictly higher under price than quantity regulation for any state θ. Hence, expected material welfare is also higher.

□

Proof of Proposition 11. Note first that for any consumed quantity of good X the government buys the second best optimal amount of offsets $\hat{z}(x)$. As in Section 3 this leads to a price q for good Z that is so high that $z^C = 0$ (irrespective of the regulatory regime).

By Lemma 1 the demand for good X under price regulation is

$$x^P(\beta) = \hat{x}(c + \bar{p} + \mu^P + \beta), \tag{A.41}$$

and under quantity regulation is

$$x^Q(\beta) = \hat{x}(c + \bar{p} + \mu^Q - \max\{\beta - \bar{p}, 0\}), \tag{A.42}$$

where μ^R is the equilibrium markup charged by firms under regulatory regime price $R \in \{P, Q\}$. The markup μ^R depends on the regime because the regime affects the "moral price" paid by consumers and thereby the relevant section of the demand curve $\hat{x}(\cdot)$ at which firms choose their markup.

Note that if $\beta = 0$, then there is no difference in the demand function between price and quantity regulation and the equilibrium markup must be the same. For $\beta > 0$ we have that $x^P(\beta) < x^Q(\beta)$ iff $\mu^P + \beta > \mu^Q - \max\{\beta - \bar{p}, 0\}$. Two cases have to be distinguished:

(i) If $\beta < \bar{p}$ we have that $x^P(\beta) < x^Q(\beta)$ iff $\mu^P + \beta > \mu^Q$. Note that in this case μ^Q is independent of β while μ^P may vary with β. However, if $d\mu^P/d\beta > -1$, it must be the case that $x^P(\beta)$ decreases with β (starting at $\beta = 0$) while $x^Q(\beta)$ stays constant. Therefore $x^P(\beta) < x^Q(\beta)$.

(ii) If $\beta \geq \bar{p}$ we have that $x^P(\beta) < x^Q(\beta)$ iff $\mu^P + \beta > \mu^Q - (\beta - \bar{p})$. By (i) we know that at $\beta = \bar{p}$ we have $x^P(\beta) < x^Q(\beta)$. If $d\mu^P/d\beta > -1$, then $x^P(\beta)$ decreases as β further increases. Furthermore, if $d\mu^Q/d\beta < 1$, then $x^Q(\beta)$ increases as β increases. Therefore, as β increases the difference between $x^Q(\beta)$ and $x^P(\beta)$ gets larger.

Thus, the ordering of quantities is not affected by the introduction of market power. The remaining question is whether this also holds for material welfare. Note that firms are owned by consumers. Thus firms' profits increase consumers' income one-to-one. Therefore the only effect of market power on material welfare is the reduced consumption of good X. By the proof of Proposition 2 we know that $dW^M(\bar{x}, \hat{z}(\bar{x}))/d\bar{x} < 0$ for $\bar{x} > x^*$. We can therefore conclude that

$$W^M(x^P, z^P) > W^M(x^Q, z^Q). \tag{A.43}$$

□