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Abstract

We study a cap-and-trade market equilibrium where different regions belonging to an emissions trading regime have different ambitions about the stringency of the cap. Specifically, we introduce a segment of consumers with Kantian preferences and show that they would prefer a more stringent cap compared to other regions. When a region sets up a voluntary more stringent cap within a cap-and-trade market, dual carbon markets with dual prices on allowances can emerge with trade against both caps. We then show that labelling a subset of the allowances in a cap-and-trade market captures the higher willingness to pay driven by different ambition levels among agents within a trading scheme. We show under what circumstances a socially efficient outcome from carbon markets can be achieved by labelling allowances when there are heterogeneous preferences among regions about the ambition level in an emissions trading regime. Being voluntary, trade in labelled allowances is consistent with a bottom-up approach where efforts are built up gradually by actors, countries and regions that wants to take leadership in international climate policy.

Key words: emissions trading, emissions allowances, carbon markets, public goods, ethics; Kant
JEL Codes: D63, D62, D03, Q54

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1. Introduction

Carbon emissions trading schemes are one of the most important mechanisms in climate policy as suggested both in the policy literature and by its increasing use. Understanding carbon trade markets in the economic literature has so far been dominated by neoclassical rational choice theory as a framework for modeling social and economic behavior in carbon trade markets. However, the critique of neoclassical rational choice theory has gained new impetus, not least due to new research in behavioral and experimental economics. Many of the critics have focused on the apparent difficulty of rational choice theory to account for the role of moral or ethical concerns in human decision-making. Climate change, overfishing, deforestation, littering, and antibiotic resistance are all examples where moral and ethical concerns matter. Self-interest utilitarian (classical) economic theory predicts that individuals (and other actors) will not behave in accordance with collective rationality whenever this is in conflict with individual rationality. However, this is not what we empirically observe; overall, individuals to some extent do engage in cooperative behavior where moral and ethical concerns matter. Also, in managerial and political decision-making, many strategies now include sustainability and voluntary compliance with national and international sustainability initiatives and standards. Firms today voluntary choose to offset their greenhouse gas emissions on a regular basis. We see regions or nations that take leadership within international climate policy. Even regions within international emission trading schemes want to take leadership, for instance within the EU ETS where United Kingdom in 2013 introduced a national price floor on European allowances to underpin the price of carbon at a level that drives low carbon investment. Initiatives like these generate questions as to what extent self-interest utilitarian (classical) economic theory and individual rationality can predict such decisions, and to what extent regions within in a trading system should implement national policy instruments that may counteract the efficiency of the emissions trading system.

In this paper, we address these questions in a case when Kantian ethics informs individual and managerial decision-making in carbon trade markets (Kant, [1785] 1997). We study a cap-and trade market equilibrium where different regions belonging to an emissions trading regime have different ambitions about the stringency of the cap. We introduce a segment of consumers with Kantian preferences in a region and show that they would prefer a more stringent cap compared to other regions. When a region sets up a voluntary more stringent cap within the cap-and-trade market, dual carbon markets with dual prices on allowances can emerge with trade against both caps simultaneously. We then analyze to what extent labelling a subset of the allowances in a cap-and-trade market can capture the higher willingness to pay driven by different ambition levels among agents within a trading scheme. We show under what circumstances a socially efficient outcome from carbon markets can be achieved by labelling allowances.

1.1 Background

A number of authors have suggested modifications in the self-interest rational choice model. A first type of modification is to augment the model with prosocial behavior, such as fairness or altruistic preferences (see, e.g., Kahnemann et al. 1996; Andreoni 1990; Andreoni and Payne 2015), or with context and institutional factors, such as punishment and rewards (see, e.g., Fehr and Gächter 2000; Sefton et al. 2007; Sutter et al. 2010), while maintaining the assumption that agents maximize outcomes as in the standard theory.

A second type of modification that has received attention in the economics literature is to augment the optimizing behavior (not necessarily modifying preferences), as suggested in Rabin

(1995), Sen (2002) and Roemer (2010, 2015). In the words of Sen, for instance, it may imply a committed behavior that "arise[s] from self-imposed restrictions on the pursuit of one's own goals (in favor of, say, following particular rules of conduct)" (2002, 214). Rabin (1995) suggests a distinction between *moral preferences* and *moral rules.* The former describes behavior as moral preferences in the utility function, and the latter describes moral behavior as voluntary constraints (moral rules) reducing one's budget constraint—a form of constrained optimization. Vanberg (2008) argues that when moral concerns are included as additional preferences in an agent's utility function, one ignores the difference between *preferences over outcomes* and *preferences over actions*, thus failing to recognize that moral preferences belong in the second category. He claims that one cannot, however, account for preferences over actions within a standard rational choice theory. Rather, this would require a shift of perspective, from a theory of rational choice to a theory of rule-following behavior.

Roemer (2010, 2015) assumes that individuals' cooperative behavior can be explained by an optimization protocol following the categorical imperative of Kant ([1785] 1997). Roemer further proves that a Pareto-efficient equilibrium in tragedy of the commons situations can be reached without introducing assumptions about moral preferences, altruism, or other prosocial preferences.[1] The seminal work by Kant that underlies Roemer (2015) is considered one of the most significant texts in the history of ethics. As a deontological theory, Kantian ethics focus on the morality of actions rather than consequences as suggested by utilitarianism. Actions can be morally required, forbidden, or permitted regardless of the consequences. Belonging to the category of deontological theories in which one has a moral obligation to abide by a set of defined principles, the Kantian theory differs from utilitarian theories in several ways. Moral

[1] A special case of the categorical imperative, as featured by the model in Roemer (2015), was actually applied already by Brekke et al. (2003).

worth comes only when the agent chooses to do something because it is a duty and the agent would choose to do so even if he or she does not like the consequences. An act may be morally wrong even if it leads to the greatest happiness or the best outcome. The rightness or wrongness of a choice or following a rule is a matter of the preference of that choice or rule, not of its consequences. A pure utilitarian approach, on the other hand, holds that the morality of a choice is solely a matter of the overall good (e.g., pleasure, happiness, or fulfilling preferences) produced by the consequences of a choice or following a moral rule. This distinction is also reminiscent of the distinctions between *moral preferences* and *moral rules* in Rabin (1995) and between *preferences over outcomes* and *preferences over actions* in Vanberg (2008).

In recent decades, the Kantian approach has had a substantial impact on a wide range of theory and scholarship in academic, as well as practical, literature on business ethics and managerial decision-making (for an overview, see, e.g. Stroud, 2002, Bowie 1999, L'Etang 1992). However, to the best of our knowledge, there is so far no literature on what the Kantian approach would imply for business ethics and agents' decision-making in carbon trade markets.

In this paper, we analyze the outcomes when a Kantian approach informs individual and managerial decision-making in one region of the emissions trading scheme preferring a more stringent cap compared to other regions. The paper is organized as follows. Section 2 presents the analysis and the development of our results. Specifically, in section 2.1 we describe Kant's categorical imperative. Section 2.2 derives the moral constraints for consumers with Kantian preferences when making consumption decisions which generate greenhouse gas emissions levels. In section 2.3, the moral constraints are derived for Kantian agents engaging in carbon trade markets. In section 2.4, we model a market equilibrium and analyze welfare and distributional effects in a carbon market with and without labelled allowances. Finally, the paper ends with Results and Discussion in section 3.

2. Kantian Ethics and Climate Change

To derive the principles of the self-imposed moral constraints from the categorical imperative for Kantian agents in our model of a compliance carbon market, we first explore the Kantian categorical imperative on a voluntary carbon market. Consider the following simple illustration of trade in a voluntary carbon market: Suppose that the sustainable level of emissions to avoid climate destabilization is 3 tons of carbon per capita. Agent A emits 4 tons and intends to buy carbon allowances compensating for the 1 ton exceeding the sustainable level. Agent B offers a 1 ton allowance by reducing his emissions from 5 to 4 tons. Agent C offers to sell a 1 ton allowance by reducing his emissions from 3 to 2 tons. The two trade alternatives for Agent A are illustrated in table 1.

Table 1. Emissions allocations with different trade alternatives

Trade alternative	Agent A emissions after trade	Agent B emissions after trade	Agent C emissions after trade	Traders total emissions after trade	Total emissions after trade
Agent A–Agent B trade	4	4	3	8	11
Agent A–Agent C trade	4	5	2	6	11

Does it matter whether Agent A buys the allowances from Agent B or Agent C? When it comes to preferences over outcomes in terms of climate impacts (or anyone's preferences about these outcomes), there is no difference between trade with Agent B and trade with Agent C as both trade alternatives result in a total of 11 tons . However, from a Kantian approach, we claim that there may be a substantial difference between the two trades. If Agent A buys the allowance from Agent C, the sum of their emissions per capita is 4 + 2 = 6 tons, which is within the sustainable level of 6 tons in total for the two agents engaging in trade. If Agent A instead buys from Agent B, the sum of their emissions levels would be 4 + 4 = 8 tons, which exceeds the sustainable level of 6 tons for the two agents. This exchange consists of trade between two agents who are *both* exceeding the sustainable level. If all trade were like theirs, the exchanged allowances would be contradictory to the intention to counteract climate change. Specifically, we will claim that a Kantian agent will be willing to engage in A–C trade but not A–B trade. Existing carbon trade markets then impose transaction costs on Kantian agents, as they need to separate the total market supply of allowances into sustainable and unsustainable allowances. Under what circumstances can a socially efficient outcome from carbon trade markets be achieved under Kantian preferences?

Kant’s ethics theory proposes a nonconsequential moral theory based on the duty to do the right things. To determine whether an action is right, Kant developed the categorical imperative, which states, “So act that the maxim of your action could become a universal law” (Sullivan, 1989, 346). Hence, before an agent makes a decision to act, he or she should ask himself or herself whether that action could be raised to universal law as a command for all other rational beings to follow. If it can be implemented in this way, it is morally right; if not, it is morally wrong.

Consider one of Kant’s own illustrations of whether making a promise that you do not intend to keep is morally right or wrong. You ask a friend to lend you money, knowing that you will not be able to pay it back. Would such an action be morally right? According to utilitarianism, the answer could ultimately depend on whether the utility that you would have from the money is greater or lower than the loss in utility your friend would face. A Kantian test would instead use logics and intuitively go as follows: First, describe the act as a maxim, M : “I will borrow money without the intention of paying it back in order to get myself out of a bind." Then follows Kant's categorical imperative (CI), turning M into a universal law, M^U: "Everyone must borrow money without intending to pay it back in order to get himself out of a bind." In this example, it leads to what in Kantian terms is called a "contradiction in conception." A system where everyone could promise whatever occurred to him or her with the intention of not keeping the promise would make the very concept of a promise cease to have credibility. The maxim "borrow money without intending to pay it back" cannot be universalized without contradiction and fails the test, and consequently, M describes a morally impermissible act. The test can be performed with other examples, such as stealing money. In a system where everyone is to steal, the *concept* of property rights does not exist, and the intention and *concept* of stealing become impossible, since stealing presumes the existence of property rights. Hence, such a maxim about stealing money would lead to a contradiction in conception and consequently be a morally impermissible act.[2]

Kantian tests further identify some permissible acts as *duties* (obligatory acts) that one is morally required to do in certain circumstances. Saving a drowning child, keeping promises, and paying back loans are examples that are identified as duties in the test. Technically, a duty is identified as the negation of a maxim that fails the Kantian test. "I shall steal money from others" fails the test, and therefore the negation of the maxim ($\neg M$), "I shall *not* steal money from others," is a duty.

To identify whether an act A is a duty therefore requires two tests. The outcomes from Kantian tests are summarized in table 2. If a maxim of A passes test I, then test II is implemented on the maxim where the *omission* of the act ($\neg A$) is tested. If the maxim of A passes the test and the

[2] It should be noted that in Kant's description of contradiction in conception, it is not the consequences (in our example, the undermining of human relationships, and anarchy from everyone stealing, and so on) that cause a maxim to fail the test, but the logical contradiction in universalizing the intention behind the act. In other words, the Kantian test counts intentions behind the acts, while utilitarianism counts consequences of the acts.

maxim of $\neg A$ fails the test, then A is identified as a duty, an obligatory act. For example, the act of "making a promise with the intention to break it" is morally impermissible. If everyone always broke his or her promises, the intention of making and then breaking one's promise becomes impossible, since the concept of a promise does not exist. The intention would self-defect. On the contrary, if both maxims of A and $\neg A$ pass the test, A is a permissible act, as is $\neg A$. Consequently, a duty must always be a permissible act. If A fails the test, A is impermissible. If both A and $\neg A$ fail, the Kantian test is indefinite. An example of the latter could be if a person is facing two drowning children and can save only one of them. A maxim that one should save child 1 but not child 2 fails, but so does its negation, that one should save child 2 but not child 1, and the test is indefinite.[3]

Table 2. Kantian Test Outcomes

Test I	Test II	Result
A pass	$\neg A$ fail	A is a duty
A pass	$\neg A$ pass	A is morally permissible
A fail	$\neg A$ pass	A is morally impermissible
A fail	$\neg A$ fail	Test is indefinite

There is a close logical relationship between Kant's idea of maxims that can be universalized and sustainable actions. According to Kant ([1785] 1997), acts that fail the test are usually also discovered as morally impermissible in successful cultures (those that thrive and survive). The rational demand for universality implies, according to Kant ([1785] 1997), that we can rationally formulate universal categorical imperatives that are derived from our rational nature and apply equally to all. Morality is held to apply to all rational agents by virtue of their rationality. In the

[3] It should be noted that there are other examples when Kantian tests become indefinite and result in other problems with definiteness. This has been extensively analyzed in literature but is beyond the scope of this paper (see e.g. Rentmeester, C. 2010, Kant, I. [1785] 1997 and Sullivan 1989).

context of climate change, Schönfeld (2007), argue that Kant's Categorical Imperative characterizes the potential of a rule to evolve into a general and naturally self-sustaining schema of action, which is also what makes the action right. In other words, sustainable actions are morally right simply *because* they can be universalized, and hence, develop as common norms in the society. Unsustainable actions are morally wrong simply *because they cannot* be universalized, and hence, cannot develop as common norms.

2.1 Applying Kantian Ethics to Climate Change

In this section, we use a Kantian approach to derive the principles of the first moral constraint for agents (individuals, organizations, or governments)—namely, how much CO_2 to emit (hereafter referred to as the agent's emissions level). We model Kantian agents similarly to the way moral rules are modelled in Rabin (1995). In the following sections, we denote such agents as K-rational to distinguish them from rational agents in standard rational choice theory. K-rational means that the agent acts in accordance with Kant's categorical imperative. However, when the categorical imperative does not bind them to follow the Kantian moral law, these agents act according to instrumental rationality, which applies to rational choice theory.[4]

We assume that the atmosphere, as a sink for CO_2 emissions, is a scarce resource and global common good. Overusing it will result in detrimental climate change impacts. Furthermore, we assume the agent's emissions level is determined by the consumption level of a composite good.[5] Using Kantian terminology, the morally permissible emissions level is a level that can be generalized as a maxim. The Kantian test determines the maximum morally permissible

[4] For non-moral issues, Kant denotes hypothetical imperatives (if you want consequences *y*, do *x*), which are consistent with instrumental rationality.

[5] We will consistently speak of consumption, but the reasoning is transferable to carbon use in production.

emissions level of a K-rational agent as the highest emissions level that does not result in any contradiction. We postulate the following maxim, M_1:

M_1: "As a K-rational agent, I shall consume at level c_i, generating emissions flow $e_i(c_i)$ to the atmosphere."

Then follows the categorical imperative turning this maxim into its universal law, M_1^U:

M_1^U: "Every agent shall consume at level c_i, generating emissions flow $e_i(c_i)$ to the atmosphere."

It is evident that there would be an emissions limit value (ELV) level $\hat{e}_i(\hat{c}_i)$ corresponding to a consumption level $\hat{c}_i$, which leads to a contradiction in conception, and the Kantian test fails. This arises when the aggregate emissions level reaches the Kantian emissions limit value $\hat{E}_c$,

$$\hat{E}_c \equiv \sum_{i=1}^{n} \hat{e}_i(\hat{c}_i) \qquad (1)$$

where the assimilate capacity of the atmosphere, as a sink for emissions, is exceeded. A system where everyone exceeds $\hat{e}_i(\hat{c}_i)$ would, in Kantian terms, make the very concept of using the atmosphere as a sink for one's emissions logically impossible, and consequently, describes a morally impermissible act. Again it would not be the irreversible damages or the loss of utility from climate destabilization *per se* that causes the test to fail, according to Kant, but the contradiction in conceptions.[6]

[6] According to Kant ([1785] 1997), universalizing a maxim leads to its being valid to one of two contradictions: a *contradiction in conception* (where the maxim, when universalized, is no longer a viable means to the end) or a *contradiction in will* (where the will of a person contradicts what the universalization of the maxim implies). Our example above exemplifies the contradiction in conception. An example of *contradiction in will* would be when everyone consumes and emits the same emissions levels $e_i(c_i)$ large enough such that the aggregated emissions level E_w prevents at least one other individual from consuming that same level of consumption c_i. This would not be a logical contradiction in concept since one person not being able to consume my level due to climate destabilization does not make my concept of consuming and emitting logically impossible. However, according to Kant it would be a contradiction in will to want to consume the level c_i in a universalized maxim implying that another individual will

If $e_i(c_i) \geq \hat{e}_i(\hat{c}_i)$, maxim M_1 prescribes an intention to choose a consumption level, and generate emissions, leading to a contradiction in concept such that maxim M_1 cannot be universalized in M_1^U. Hence, a chosen consumption level can be universalized only if $e_i(c_i) < \hat{e}_i(\hat{c}_i)$. Since M_1 self-defects and cannot be universalized without contradiction when $e_i(c_i) \geq \hat{e}_i(\hat{c}_i)$, the negation $(\neg M_1)$ is a duty to act on. In other words, maintaining $e_i(c_i) < \hat{e}_i(\hat{c}_i)$ is a duty for the agent making it immoral for a K-rational agent choosing a consumption level corresponding to an emissions level $e_i(c_i) \geq \hat{e}_i(\hat{c}_i)$.[7] The self-defection of M_1 then concludes with this proposition:

Proposition 1: *It is a duty for a K-rational agent to not exceed the Kantian ELV per capita, hence* $e_i(c_i) < \hat{e}_i(\hat{c}_i)$.

The duty implies that the Kantian ELV emissions per capita are equal for agents but would not imply that consumption levels are so.

The Kantian test provides a fundamental ethical principle for how to set the endogenous Kantian ELV that is independent of the agent's personal preferences or norms. With the same scope, the answer will be the same regardless of who performs the test. Although, science per se cannot produce such a normative principle, it can be used to empirically quantify $\hat{E}_c$ given this principle. A scientific estimation of $\hat{E}_c$ may correspond to larger emissions levels than zero, and levels that

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not be able to consume the same level because of climate destabilization. According to Kant, maxims that violate contradictions in conception are morally impermissible and lead to a "perfect duty" to not do, while maxims violating contradictions in will, lead to an "imperfect duty" to not do. The former dominates the latter. Contradictions in conception and contradictions in will, would not necessarily lead to duties on the same emissions levels. In the context of climate change we would not necessary expect that E_w and E_c would be equal. In our analysis we choose to use an example containing a contradiction in conception.

[7] Another example where this contradiction is easily seen is overfishing. A test of overfishing fails since the concept of overfishing, when universalized, contradicts the concept of fishing. Again, it is not the bad consequences of an extinct fish stock, but the contradiction in conceptions, that causes the test to fail.

could have some impact on the climate only as long as it is within the assimilative capacity of the atmosphere.

2.2 Applying Kantian Ethics to CO_2 Emissions Trading

We now turn to deriving the moral constraints for Kantian agents in carbon markets where carbon allowances are traded.[8] Critics have claimed that buying carbon allowances is immoral because it allows one to pay others to deal with the problem rather than change one's own behavior (for overviews, see, e.g., Aldred 2012; Caney and Hepburn 2011). However, we find that Kantian agents should engage in emissions trading, since it is a duty to do so whenever their emissions exceed the Kantian ELV.

In this section we choose to analyze a voluntary carbon market as the lack of a mandatory cap simplifies the analysis. However, the results in this section also convey to a compliance market as we will see in section 2.3. We use the same framework as in section 2.1 and ask whether it would be morally impermissible for Kantian agents to exceed the Kantian ELV such that $e_i(c_i) \geq \hat{e}_i(\hat{c}_i)$, provided that the agent engages in emissions trading that compensates the excess $e_i(c_i) - \hat{e}_i(\hat{c}_i) \geq 0$.

Proposition 2: *It is a permissible act and a duty for a K-rational agent to engage in emissions trading to compensate any emissions* $z_i \equiv e_i(c_i) - \hat{e}_i(\hat{c}_i) > 0$ *that exceed the Kantian ELV* $\hat{e}_i(\hat{c}_i)$.

Proof: We first define allowances that are traded by a Kantian agent as Kantian allowances.

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[8] The term *allowances* hereafter refers to credits and permits bought and sold on both compliance and voluntary markets.

Define first the maxim M_2: "I shall exceed the Kantian emissions limit, $\hat{e}_i(\hat{c}_i)$, by any amount z_i > 0." Secondly, define the maxim *C*: "I shall buy z_i > 0 units of Kantian allowances," and consider for the first test the maxim M_3, which omits buying, as follows:

$$M_3 \leftrightarrow \neg C \wedge M_2 \qquad (2)$$

That is, M_3 says, "I shall *not* buy z_i > 0 units of Kantian allowances *and* exceed the Kantian emissions limit, $\hat{e}_i(\hat{c}_i)$, by any amount z_i > 0." Acting on M_2 and not *C* is identical to acting on M_2, whatever the act is in the omitted maxim *C*. Hence M_3 is identical to M_2 and must share the same contradiction as M_2 and is impermissible according to proposition 1 in a test I. Since M_3 fails the test I for the same reason as M_2, then $\neg M_3$ must be a duty that must pass a test II. First we derive the maxim $\neg M_3$ to identify what are the properties of the duty, and then we perform test II on it. The duty is the negation of expression (2):

$$\neg M_3 \leftrightarrow \neg(\neg C \wedge M_2) \qquad (3)$$

Using De Morgan's Law yields

$$\neg M_3 \leftrightarrow \neg(\neg C \wedge M_2) \Leftrightarrow \neg\neg(\neg\neg C \vee \neg M_2) \qquad (4)$$

Applying the rule of double negation on the right-hand side identifies the duty:

$$\neg M_3 \leftrightarrow C \vee \neg M_2 \qquad (5)$$

Translating the conditionals in (5) into words gives the duty $\neg M_3$: "I shall buy z_i > 0 units of Kantian allowances *or* shall *not* exceed the Kantian emissions limit, $\hat{e}_i(\hat{c}_i)$, by any amount z_i > 0." Finally, perform test II. Universalizing $\neg M_3$ gives $\neg M_3^U$: "Everyone shall either buy z_i > 0 units of Kantian allowances *or* shall not exceed the Kantian limit, $\hat{e}_i(\hat{c}_i)$, by any amount z_i > 0."

The disjunction on the right-hand side in (5) is an inclusive disjunction that allows one or the other or both to be valid, which gives three possibilities: (i) Maxim $\neg M_2$ is invalid and C is valid. Emissions exceed $\hat{e}_i(\hat{c}_i)$ by the amount z_i, and there is purchase of z_i units of Kantian allowances. (ii) Maxim $\neg M_2$ is valid and C is invalid. Emissions do not exceed $\hat{e}_i(\hat{c}_i)$, and there is no purchase of Kantian allowances. (iii) Maxim $\neg M_2$ is valid and C is valid. Emissions do not exceed $\hat{e}_i(\hat{c}_i)$, and there is purchase of z_i units of Kantian allowances.

There is no contradiction in that everyone "either buys z_i units of Kantian allowances or does not exceed $\hat{e}_i(\hat{c}_i)$," as the disjunction (5) allows for any of the three cases (i)–(iii). Thus no contradiction would result as if only (i) had been the derived duty. Consequently, $\neg M_3$ does not fail and is a duty to act on. **Q.E.D.**

Thus in a system where *every* agent buys carbon allowances to compensate for his or her emissions above the Kantian ELV, the intention of compensating their own emissions by buying carbon allowances becomes impossible in Kantian terms, since the concept of allowances is no longer a viable means to the ends. Merely buying carbon allowances is not sufficient for making one´s emissions *above* the Kantian ELV morally permissible.

Proposition 3: *If no Kantian allowances, z_i, are available on the market, the duty to engage in emissions trading to compensate any emissions, $z_i \equiv e_i(c_i) - \hat{e}_i(\hat{c}_i) > 0$, in proposition 2 is not satisfied, and there is instead a duty for a K-rational agent to not exceed the Kantian ELV per capita $\hat{e}_i(\hat{c}_i)$ following proposition 1.*

Proof: Follows directly from (5); that is, $(C \vee \neg M_3), \neg C \Rightarrow \neg M_3$. **Q.E.D.**

Universalizing the duty $\neg M_3$ implies that everybody must either buy z_i > 0 allowances or not exceed the emissions limit $\hat{e}_i(\hat{c}_i)$ by any amount z_i > 0. This can be universalized only if any allowances bought are traded for emissions not yet emitted below the emissions limit, $\hat{e}_i(\hat{c}_i)$. In other words, the duties in proposition 2 mimic trade on a hypothetical compliance market with the cap $\hat{E}$ and the initial allocations $\hat{e}_i(\hat{c}_i)$ for all agents $i = 1,2,3,\ldots, n$.

Proposition 4: *K-rational agents mimic transactions on a cap-and-trade market with a cap equal to* $\hat{E}$ *and initial allocations* $\hat{e}_i(\hat{c}_i)$.

Another way to express the result is to say that the allowances of an agent whose emissions exceed the Kantian ELV have been depleted, since the allowances originate from a reduction counted from the agent's emissions level that is already in excess of the Kantian ELV both before and after the trade took place. By demanding such allowances as compensation for excess emissions, a buyer violates his duty in proposition 3.

2.3 Emissions Trade Subject to Kantian Preferences

In this section, we analyze a carbon market equilibrium when two types of traders, Kantian firms and regular firms, simultaneously engage in trade in a compliance market with a mandatory cap, Q_P. Both types of firms maximize profit by producing and selling final goods. While regular consumers of final goods, q_R, optimize in accordance with standard economic theory and without any constraints, Kantian consumers optimize given that the Kantian categorical imperative is fulfilled with the duties in propositions 1–4. Kantian consumers will buy goods, q_K, only from firms that verify that they engage in Kantian trade on the carbon market. We call such firms Kantian firms to distinguish them from regular firms. We assume that the representative regular firm maximizes the profit function

$$\pi_R = aq_R - k\frac{q_R^2}{2} + P(e_0 - e_R) \qquad (6)$$

where $q_R \geq 0$ is a final good and $a > 0$ is the price on the final goods market and $k > 0$ is a production cost parameter. Production generates emissions and the firm participates in a cap-and-trade market with allowance price, $P > 0$, choosing its output, q_R, while taking its initial emissions, $e_0 > 0$, as given. To simplify, we assume a one-to-one relationship between output and emissions, $e_R = q_R$, and maximize the profit function (6) with respect to e_R. The first order condition is then

$$\frac{\partial \pi_R}{\partial e_R} = a - ke_R - P = 0 \qquad (7)$$

Rewriting the first order condition (7) yields

$$P = a - ke_R \qquad (8)$$

as the representative regular firm's inverse `demand for emissions´ derived from the marginal revenue, a, that it receives from selling the final goods minus the marginal cost of production.

We assume that a segment of consumers on a final goods market exhibit Kantian preferences such that they are willing to pay, $a_k = \gamma a$, for final goods, q_K, where $\gamma \geq 1$ and $q_K > 0$, produced by Kantian firms that verify that they follow Kantian trade according to proposition 1 to 3 on the cap-and-trade market with the cap Q_P. We further assume that only a subset, $Q_K < Q_P$, of this amount of allowances fulfills Kantian moral constraints in propositions 1 to 3. In other words, these allowances are supplied by sellers that can verify their emissions reductions below a level that is consistent with Kantian trade according to proposition 1 to 4 for the region. We denote such allowances, K-allowances. Searching, identifying and verifying that an allowance belongs to the set of K-allowances, Q_K, impose a transaction cost per allowance. To simplify, we express this transaction cost as a share of the final goods price, θa_k, where $0 \le \theta \le 1$. Again, using a one-to-one relationship, $e_K = q_K$, between emissions and output we can now write the profit function of Kantian firms as:[9]

$$\pi_K = a_K e_K - k\frac{e_K^2}{2} - \theta a_K e_K + P(e_0 - e_K) \qquad (9)$$

Kantian firms, maximizing profit, seek to verify that their emissions from production fulfills the Kantian trade principles on the carbon market against the voluntary cap, Q_K, which is more stringent than the mandatory cap Q_P. The first order condition of (9) with respect to e_K is then

$$\frac{\partial \pi_K}{\partial e_K} = a_K(1-\theta) - ke_K - P = 0 \qquad (10)$$

Finally, using that $a_K = \gamma a$ we can write the inverse demand function of the representative Kantian firm as follows

$$P = a\gamma(1-\theta) - ke_K \qquad \gamma(1-\theta) \ge 0 \qquad (11)$$

For simplicity, we assume that no technology shifts alter technologies behind the demand conditions and that there is perfect competition on all markets.

Equations (8) and (11) represent the aggregate inverse demand functions of regular and Kantian firms, respectively, on the carbon market. Kantian firms, satisfying Kantian consumers' preferences, by proposition 2 and 3, only demand K-allowances, e_K, from the subset, $Q_K < Q_P$, while regular firms are indifferent, and arbitrage, between any type of allowances, e_R and e_K,

[9] To simplify, we do not explicitly assume the existence of abatement technology that decouples output and emissions. Optimal adjustment in emissions and net revenues only occurs via adjustments in output.

while selling final goods to regular consumers. The demand functions in equations (8) and (11) after arbitrage, ΔR, then become

$$e_R(P_R) = \frac{a - P_R}{k} - \Delta R \tag{12}$$

$$e_K(P_K) = \frac{a\gamma(1-\theta) - P_K}{k} + \Delta R \tag{13}$$

$$0 \leq \Delta R \leq Q_K \tag{14}$$

where $\Delta R \geq 0$ is the arbitrage demand quantity by regular firms as they switch from demanding regular allowances to K-allowances whenever these are lower priced. That the quantity ΔR can take only nonnegative values in equation (14) is explained by the fact that Kantian firms do not demand regular allowances. Finally, ΔR is bound by the total number of K-allowances, Q_K, in (14). Equilibrium on the market for regular allowances implies

$$\frac{a - P_R}{k} - \Delta R = Q_p - Q_K \tag{15}$$

Equilibrium on the market for K-allowances implies

$$\frac{a\gamma(1-\theta) - P_K}{k} + \Delta R = Q_K \tag{16}$$

In summary, both regular and Kantian firms produce physically identical final goods, q_R and q_K, use identical technology and face identical costs of production.[10] They trade allowances on the same cap-and-trade market. The difference is that Kantian firms profit from Kantian consumer's willingness to pay extra for a more stringent carbon trade during production than what the mandatory cap offers or what can be verified at voluntary markets without a cap.

[10] Without loss of generalization we here assume that firms have the same costs of production. The transaction costs needed to satisfy Kantian consumers will therefore be the only source of heterogeneity in costs.

Solving for equilibrium with arbitrage, using (14)–(16), results in five different sets of equilibria (see Appendix for proofs of results), denoted I–V in Table 3, depending on the Kantian demand parameter, γ, and transaction costs parameter, θ, which in turn determine how the aggregate demand by Kantian firms varies with respect to the aggregate demand of regular firms.

Proposition 5: *Under demand conditions in case I, aggregate demand of regular firms is sufficiently large with respect to aggregate demand of Kantian firms for emissions trade to result in the equilibrium price* P_0^* *on a single market with only regular firms engaging in regular trade. Being perfect substitutes K-allowances and regular allowances become a homogenous good against the mandatory cap* Q_P.

Proof: Appendix A1.

This case identifies the set of equilibria in which the Kantian demand parameter, γ, takes a low value and/or the transaction cost parameter, θ, takes a high value. The aggregate demand of regular firms is sufficiently strong for them to buy all K-allowances and regular allowances. The optimal response by Kantian firms is to quit Kantian trade on the carbon market and become regular firms selling final goods to regular consumers. Hence, case I represents the regular cap-and-trade market with all allowances as a homogeneous good.

Table 3. Carbon market conditions with various demand conditions and policy stringency

Case	Carbon market conditions	Prices	Quantities	Arbitrage Quantity	Welfare effects from labelling allowances	Demand conditions
I	Single carbon market with only regular trade	P_0^*	$e_K^* = 0$ $e_R^* = Q_P$	$\Delta R = Q_K$	$\Delta W > 0$ $\Delta CS_T > 0$, $\Delta PS_T > 0$ $\Delta CS_K > 0$, ΔPS_K [1] ΔCS_R [1], ΔPS_R [1]	$a\gamma(1-\theta) = a - kQ_P$ $a\gamma(1-\theta) - kQ_K < a - k(Q_P - Q_K)$
II	Dual carbon market with arbitrage	$P_K^* = P_R^* \geq P_0^*$	$e_K^* - \Delta R < Q_K$ $e_R^* + \Delta R > Q_P - Q_K$	$\Delta R = \dfrac{a - a\gamma(1-\theta) - kQ_P}{2k} + Q_G$		$a\gamma(1-\theta) > a - kQ_P$ $a\gamma(1-\theta) - kQ_K < a - k(Q_P - Q_K)$
III	Dual carbon market with no arbitrage	$P_K^* = P_R^* > P_0^*$	$e_K^* = Q_K$ $e_R^* = Q_P - Q_K$	$\Delta R = 0$	$\Delta W > 0$ $\Delta CS_T = 0$, $\Delta PS_T > 0$ $\Delta CS_K = 0$, $\Delta PS_K > 0$ $\Delta CS_R = 0$, $\Delta PS_R = 0$	$a\gamma(1-\theta) > a - kQ_P$ $a\gamma(1-\theta) - kQ_K = a - k(Q_P - Q_K)$
IV	Dual carbon market with no arbitrage	$P_K^* > P_R^* > P_0^*$	$e_K^* = Q_K$ $e_R^* = Q_P - Q_K$	$\Delta R = 0$		$a\gamma(1-\theta) > a - kQ_P$ $a\gamma(1-\theta) - kQ_K > a - k(Q_P - Q_K)$
V	Single market with only Kantian trade	$P_K^* > P_R^* > P_0^*$	$e_K^* = Q_K$ $e_R^* = 0$	$\Delta R = 0$		$a\gamma(1-\theta) - kQ_K > a$

Note: The cases I–V derive from a comparative static analysis, differentiating the carbon market equilibrium solution with respect to transaction costs θ and policy stringency Q_p in the last column, resulting in that the aggregate demand of regular firms being relatively large in cases I and II and the aggregate demand of Kantian firms being relatively large in cases IV and V.

[1] Ambiguous sign with the elasticity of demand on the carbon market as the conclusive determinant.

Proposition 6: *Under demand conditions in case II, the aggregate demand of regular firms is sufficiently large with respect to aggregate demand of Kantian firms for emissions trade to result in equal equilibrium prices,* $P_K^* = P_R^* > P_0^*$*, for K-allowances and regular allowances, respectively, due to arbitrage,* ΔR*, by regular firms. Both Kantian and regular firms buy K-allowances.*

Proof: Appendix A2.

In this case the aggregate demand by Kantian consumers is sufficiently large, and/or the transactions costs for verifying Kantian trade are sufficiently low, for Kantian firms to begin buying K-allowances. Regular firms still arbitrage buying both K-allowances and regular allowances. K-allowances are initially priced lower than regular allowances, however, arbitrage by regular firms leads to equal prices of K-allowances and regular allowances which are larger than the single price, P_0^*, in case I due to the larger demand for K-allowances.

Proposition 7: *Under demand conditions in case III, equilibrium prices,* P_K^* *and* P_R^**, of K-allowances and regular allowances, respectively, are equal from the beginning on a dual market with no arbitrage by regular firms. Both prices are larger than the single price,* P_0^**, in case I when only regular firms engage in trade. Hence prices are ordered as* $P_K^* = P_R^* > P_0^*$*.*

Proof: Appendix A3.

This case identifies the special case when equilibrium prices are equal from the beginning on a dual market before any arbitrage take place by regular firms. Both prices, P_K^* and P_R^*, are larger than the single market price, P_0^* in case I as the demand of Kantian firms also drives up the price of regular allowances, P_R^*, to be higher than the single price P_0^* in case I where all firms on the carbon market are regular firms.

Proposition 8: *Under demand conditions in case IV, the aggregate demand of Kantian firms is sufficiently large, in comparison with the aggregate demand of regular firms, to thwart any arbitrage by regular firms. The cap-and-trade market splits with dual equilibrium prices at different level,* $P_K^* > P_R^* > P_0^*$.

Proof: Appendix A4.

As the demand parameter, γ , takes an ever higher value and/or the transaction cost parameter, θ , takes an even lower value, Kantian firms begin to signal their ambition to final consumers by engaging in Kantian trade at a higher price, P_K^*. Regular firms still trade under a lower carbon price against the less stringent mandatory policy cap Q_P .

Proposition 9: *Under demand conditions in case V, the aggregate demand of Kantian firms is sufficiently large to prevent any arbitrage by regular firms while the policy stringency has reached the same level as the number of K-allowances such that* $Q_P - Q_K = 0$. *Only Kantian firms remains on a single carbon market with a single price* $P_K^* > P_R^* > P_0^*$

Proof: Appendix A5.

Toward the end of all trading periods, when $Q_K = Q_P$, trade only in K-allowances remains. The regular allowances have vanished, and the market has become a single market with a single price, this time satisfying Kantian trade.

The five cases I-V presents a continuum spanning five sets of market equilibria, each with distinct properties, depending on the Kantian demand parameter, γ , and the transaction costs parameter, θ . The equilibria of cap-and-trade markets seen in climate policy today correspond to case I where allowances are a homogeneous good traded at a single price. The cases II-IV are dual markets where private incentives have found a way to differentiate trade among firms with different ambition level, and so capitalize a larger willingness to pay for this higher ambition.

2.3.1 Welfare and distributional effects of introducing labelled allowances

Both the demand parameter, γ, and the transaction cost parameter, θ, are conclusive for which set of equilibria that will prevail on the carbon market. A high value on γ, representing a larger demand of consumers with Kantian preferences, tends to push the equilibrium away from the cases I and II towards a dual market and dual prices. A high value on θ tends to push the equilibrium away from case III and IV towards a less efficient dual carbon market with arbitrage or a single market where the carbon market only consists of regular firms.

We now assume that the operating authority of the trading scheme creates a registry that labels the subset, Q_K, of the total number of allowances with a "K", so they fulfill the principles of "Kantian trade" in propositions 1 to 4. The substance behind this labelling is that the total number of allowances labelled "K" satisfies the Kantian Q_K as a voluntary cap below the mandatory cap Q_P of the compliance scheme. The administrative measures taken by the trading authority merely involve introducing the labelling of "K" for the subset, Q_K, of allowances and keep track of these allowances in the registry and the transaction log of the trading scheme.[11]

Once allowances are labelled and its number consistent with the Kantian Q_K limit of the region, proposition 4 applies, implying that Kantian agents, do not any longer need to bother about how the K-labelled allowances are allocated or who owns them. From a Kantian perspective, sellers and buyers of K-allowances can then be any firm. Hence, disclosing the K-allowances by

[11] The analogy with third-degree price discrimination, where a seller exploits differences in elasticities among groups by setting different prices for identical goods across buyer groups, may seem evident, but the analogy is in fact not complete. The introduction of K-labelled allowances is an information disclosure, as K-labelled allowances have substantially different attributes to Kantian agents when it comes to trade procedures.

labelling them, eliminates the transaction cost, θ, of searching, identifying and verifying K-allowances.

Proposition 10: *Under all demand conditions defined in cases I–V, the total welfare W always increases from introducing K-labelled allowances that decreases* θ*. In the cases I and II the total welfare increase is due to that both the total consumer surplus and the total producer surplus increases on the carbon market. The consumer surplus of Kantian firms always increases while the effects on the consumer surplus of regular firms and the producer surplus of sellers of allowances are ambiguous with the relative elasticities of demand on the carbon market as the conclusive determinants. In the cases III-V the increase in total welfare is due to the increase in producer surplus of sellers of K-labelled increases while there is no effect on the producer surplus of regular allowances and the consumer surplus of any firms.*

Proof: Appendix A6.

2.3.2 Effects of the cap on the prices of allowances

The successive reductions in each trading period of the mandatory cap, Q_P, will affect the relationship between Q_P and the constant cap, Q_K. In early trading periods one can expect, Q_P, to be significantly larger than Q_K, the latter in principle serving as a future prediction for Q_P. The relative change in scarcity between K-labelled and regular allowances taking place during several trading periods may move the market equilibrium across the sets of equilibria with different properties in cases I-V. In principle, two alternative scenarios may occur depending on the relative demand conditions. In both cases trade will only occur with labelled allowances since all regular allowances have vanished when, $Q_K = Q_P$. In the first scenario, regular firms have relatively large demand for allowances. As the policy cap is becoming more stringent, the relative price of regular allowances increases, which increases arbitrage, and $Q_K = Q_P$ establishes in case I or II, with arbitrage and trade by only regular firms or by both types of firms. In the alternative scenario, Kantian firms have a relatively large demand. The price of regular allowances never catches up with the price of labelled allowances preventing arbitrage. Finally $Q_K = Q_P$ establishes with equilibrium in case V and trade only with labelled allowances by Kantian firms.

While the price of regular allowances tends to increase as a result of increased scarcity when the policy cap is becoming more stringent, the price of labelled allowances will not always do so. Under demand conditions in cases III–V, the price, P_K^*, of labelled allowances is not influenced by changes in the policy cap, Q_P. This is evident from equation (A.17) in appendix A4 showing that $P_K^* = a\gamma(1-\theta) - kQ_K$ is independent of Q_P. That labelled allowances are subject to lower political risk than unlabelled allowances in dual markets without arbitrage may result in relatively lower price volatility and that the price of labelled allowances will contain an insurance premium that the price of unlabelled allowances will not contain in these equilibria.

3. Results and Discussion

The policy literature and the increasing use of carbon emissions trading schemes in climate policy suggest that carbon markets are one of the most important mechanisms in climate policy. Until today, the economic literature has assumed that regions within an emissions trading scheme agree on the most essential aspect which is the cap. However, in reality we see that regions in for instance EU ETS have different opinions on the stringency of the cap. This has generated a discussion to what extent countries or regions that want to take leadership within in a trading regime should implement additional national policy instruments that may counteract the efficiency of the emissions trading scheme. In this paper we studied a carbon market where two segments of consumers, or regions, belonging to an emissions trading regime, have different ambitions about the stringency of the cap. We introduced a segment of final consumers with Kantian preferences implying that they prefer a more stringent cap consistent with emissions levels that will not lead to climate stabilization. In cap-and-trade markets with a cap not consistent with such emission levels, Kantian firms should instead search for allowances from sellers whose emissions reductions can be verified as being below such emissions levels, In existing carbon markets this would impose transaction costs. We then analyzed the disclosing of the K-allowances by labelling a subset of allowances matching the Kantian emissions limit of the regions that belong to the trading scheme. The number of labelled allowances then serve as a voluntary cap capturing the higher willingness to pay, and trade against a more stringent cap, by certain agents. We showed that arbitrage always prevents labelled allowances from being priced lower than regular allowances. Labelling could be introduced by trading schemes based on the emissions per capita from the regions of the trading scheme using the Kantian approach as guidance. Since labelling involves simply maintaining the label on a subset of allowances in the electronic registry, the additional administrative costs of labelling allowances should be low.

We find that the total welfare always increases by introducing labelled allowances as long as a segment of final consumers that have Kantian preferences exist. In a single market equilibrium with only regular firms, and a dual market equilibrium where regular firms arbitrage between labelled and unlabelled allowances, both the total consumer surplus and the total producer surplus increases from labelling. Specifically, the consumer surplus of Kantian firms increases while the effects on the consumer surplus of regular firms and the producer surplus of sellers of labelled and regular allowances are ambiguous depending on the relative elasticities of demand.

In the cases with dual carbon markets without arbitrage, the increase in total welfare remains but now due to an increase in the producer surplus of sellers of labelled allowances..

The allocation of labelled allowances can also be used for achieving distributional objectives. When labelled allowances, consistently capping the Kantian limit of a region are introduced, proposition 4 applies, implying that the allocation of labelled allowances no longer matters for Kantian agents as it does on markets without labelling. Labelled allowances can therefore be either auctioned or freely allocated according to an allocation rule that is free of choice by policymakers without violating the “Kantian trade” principles in propositions 1-3. One possible allocation rule, for instance, would be that policymakers adopt a Kantian approach for the allocation in an international cap-and-trade scheme where labelled allowances are allocated to regions or countries having emissions per capita below the Kantian limit. This would usually be developing countries which then would receive the producer surplus of labelled allowances.

After all, labelled allowances would likely be most efficient in large international trading schemes with a large amount of actors leaving a large amount of actors also for each market in dual equilibrium. Labelled allowances could be auctioned, where arbitrage always prevents that they would be lower priced than regular allowances, or freely allocated. Allocation rules could then take into account different income levels, emissions per capita as well as needs or other fairness and equity principles. More importantly, since trade in labelled allowances is voluntary, against a voluntary cap and a mandatory cap, the system is consistent with a bottom up approach where the efforts are built up gradually driven by actors and regions that wants to take leadership.

Our analysis used a simple analytically tractable model exploring the comparative statics of the sets of equilibria of markets with labelled and unlabelled allowances. Still, we leave several aspects for future research. Heterogeneous production and abatement costs would allow for deeper studies of the distributional effects among agents with different ambition levels in trading schemes. Study of imperfect markets would explore the strategic incentives. Dynamic analysis would be able to trace movements of equilibria for labelled and unlabelled allowances due to for instance technology adoption, increased scarcity from a tightening cap as well as the effects of political risk and differences in insurance premiums contained in dual pricing of labelled and unlabelled allowances.

Appendix A1

Proof of proposition 5.

Case I

In this case $P_K^* < P_R^*$ holds, which is the demand condition in case I in table 3

$$a\gamma(1-\theta) - kQ_K < a - k(Q_P - Q_K), \qquad \text{(A.1)}$$

together with the second demand condition in case I in table 3

$$a\gamma(1-\theta) = a - kQ_P \qquad \text{(A.2)}$$

Using equilibrium conditions in (15) and (16) together with (A.1) yields that arbitrage, ΔR, by regular firms will continue with until equilibrium is reached when $P_R^* = P_K^*$. At most this can go on until $\Delta R = Q_K$ implying that regular firms buy all K-allowances. Using this in analogy with equations (A.6) – (A.8) we obtain the arbitrage quantity

$$\Delta R = Q_K + \frac{a - a\gamma(1-\theta) - kQ_P}{2k} = Q_K \qquad \text{(A.3)}$$

Rearranging yields

$$a\gamma(1-\theta) = a - kQ_P \qquad \text{(A.4)}$$

which is the demand condition defining case I in table 3. Using the demand function (8) of regular firms and the equilibrium condition, $e_R = Q_P$, yield the single equilibrium price in case I

$$P_0^* = a - kQ_P \qquad \text{(A.5)}$$

with arbitrage until the equilibrium price $P_0^* = a - kQ_P$ is established. It is easily seen that whenever (A.2) holds, (A.1) also holds. **Q.E.D**

Appendix A2

Proof of proposition 6.

Case II

In this case $P_K^* < P_R^*$ holds initially, which yields the demand condition in table 3

$$a\gamma(1-\theta) - kQ_K < a - k(Q_P - Q_K) \qquad \text{(A.6)}$$

and arbitrage, $\Delta R > 0$, by regular firms. Using equilibrium conditions in (15) and (16), arbitrage will continue with until equilibrium is reached at $P_R^* = P_K^*$. Using this and rearranging the equilibrium conditions in (15) and (16) yield

$$a\gamma(1-\theta) - k(Q_K - \Delta R) = a - k(Q_P - Q_K + \Delta R) \qquad \text{(A.7)}$$

Solving for ΔR gives the arbitrage quantity by regular firms

$$\Delta R = Q_K + \frac{a - a\gamma(1-\theta) - kQ_P}{2k} > 0 \qquad \text{(A.8)}$$

Substituting (A.8) into the equilibrium conditions (15) and (16)

$$P_K^* = a\gamma(1-\theta) - k(Q_K - \Delta R)$$

$$P_R^* = a - k(Q_P - Q_K + \Delta R)$$

and rearranging yields the equilibrium prices P_R^* and P_K^* respectively:

$$P_K^* = \frac{a + a\gamma(1-\theta) - kQ_P}{2} \qquad \text{(A.9)}$$

$$P_R^* = \frac{a + a\gamma(1-\theta) - kQ_P}{2} \qquad \text{(A.10)}$$

From (A.9) and (A.10) follows that $P_K^* = P_R^*$.

We now prove that $P_K^* = P_R^* > P_0^*$. Using (A.10) and (A.5) we get that

$$\frac{a + a\gamma(1-\theta) - kQ_P}{2} > a - kQ_P. \tag{A.11}$$

which establishes $P_R^* > P_0^*$. **Q.E.D.**

Rearranging (A.11) also yields the first demand condition defining case II in table 3

$$a\gamma(1-\theta) > a - kQ_P \tag{A.12}$$

Appendix A3

Proof of proposition 7.

Case III

In this case $P_K^* = P_R^*$ holds from the beginning due to demand conditions in table 3

$$a\gamma(1-\theta) - kQ_K = a - k(Q_P - Q_K) \tag{A.13}$$

and thus there is no arbitrage $\Delta R = 0$. Too verify this, rearrange (A.13) which yields

$$Q_K + \frac{a - \alpha p(1-c) - kQ_P}{2k} = 0 \tag{A.14}$$

Prove that $P_R^* > P_0^*$. Using (A.13) and (A.5) we should prove that

$$a - k(Q_P - Q_K) > a - kQ_P. \tag{A.15}$$

which is true since $Q_K > 0$.

Note that in case II, $P_K^* < P_G^*$ initially holds until arbitrage, $\Delta R > 0$, results in $P_K^* = P_R^*$ while in the case III, $P_K^* = P_R^*$, immediately occurred in the equilibrium. **Q.E.D.**

Appendix A4

Proof of proposition 8.

Case IV

In this case $P_K^* > P_R^*$ holds, which is the demand condition in case IV in table 3

$$a\gamma(1-\theta) - kQ_K > a - k(Q_P - Q_K) \quad \text{(A.16)}$$

for which there is no arbitrage by Kantian firms following proposition 3. A dual carbon market then emerges with dual equilibrium prices

$$P_K^* = a\gamma(1-\theta) - kQ_K \quad \text{(A.17)}$$

$$P_R^* = a - k(Q_P - Q_K) \quad \text{(A.18)}$$

We then prove that the inequality $P_K^* > P_R^* > P_0^*$ holds under these circumstances. The inequality $P_K^* > P_R^*$ is established directly by the demand condition (A.16). From (A.5) follows that $P_0^* = a - kQ_P$ and from (A.18) that $P_R^* = a - k(Q_P - Q_K)$. Hence we should prove that $a - k(Q_P - Q_K) > a - kQ_P$, which is true since, $Q_K > 0$. **Q.E.D.**

Appendix A5

Proof of proposition 9.

Case V

In this case $P_K^* > P_R^*$, which establishes the demand condition in table 3 for case V

$$a\gamma(1-\theta) - kQ_K > a - k(Q_P - Q_K) \quad \text{(A.19)}$$

when

$$Q_P - Q_K = 0 \quad \text{(A.20)}$$

Substituting (A.20) in (A.19) yields

$$P_K^* = a\gamma(1-\theta) - kQ_K > a \qquad \text{(A.21)}$$

which implies that there are only Kantian firms engaged in trade on the market when $Q_P - Q_K = 0$ in case V. The prices are established at different price levels $P_K^* > P_R^* > P_0^*$. First, $P_K^* > P_R^*$ is established directly by the demand condition (A.21). Second, $P_R^* > P_0^*$ is shown by using $P_R^* = a - k(Q_P - Q_K)$ in (A.18) together with (A.5) and (A.20) to prove that $a - k(Q_P - Q_K) > a - kQ_P$, which is true since $Q_P > 0$. **Q.E.D.**

Appendix A6

Proof of proposition 10.

Derivation of welfare levels.

Case I

Only regular firms demand allowances under demand condition $a\gamma(1-c) < a - kQ_P$ in table 3

Consumer surplus of regular firms is derived by using equation (A.5) and equilibrium condition $e_R = Q_P$.

$$CS_R = \frac{\left(a - P_0^*\right)}{2} e_R\left(P_0^*\right) = \frac{kQ_P^2}{2} \geq 0 \qquad \text{(A.22)}$$

Producer surplus of sellers of regular allowances is derived by using (A.5) and equilibrium condition $e_R = Q_P$.

$$PS_R = P_0^* e_R\left(P_0^*\right) = \left(a - kQ_P\right)Q_P = aQ_P - kQ_P^2 \geq 0 \qquad \text{(A.23)}$$

Consumer surplus of Kantian firms is derived by using equations (11) and (A.5) together with equilibrium condition $e_K = 0$.

$$CS_K = \frac{\left(a\gamma(1-\theta) - P_0^*\right)}{2} e_K\left(P_0^*\right) = 0 \qquad \text{(A.24)}$$

since $e_K\left(P_0^*\right) = 0$ when $a\gamma(1-\theta) = a - kQ_P$ from equation (A.4)

Producer surplus of sellers of Kantian allowances is derived by using (A.5) and equilibrium condition $e_K = 0$.

$$PS_K = P_K^* e_K\left(P_0^*\right) = 0 \qquad \text{(A.25)}$$

since $e_K\left(P_0^*\right) = 0$ when demand condition $a\gamma(1-\theta) = a - kQ_P$ holds in case I. **Q.E.D.**

Case II

Consumer surplus of regular firms is found by substituting (A.10) in the expression for consumer surplus and using the quantity $e_R + \Delta R$:

$$CS_R = \frac{\left(a - P_R^*\right)}{2}\left(e_R + \Delta R\right) \geq 0$$

Rearranging yields

$$CS_R = \frac{1}{4k}\left(a\gamma(1-\theta) - a - kQ_P\right)\left(a\gamma(1-\theta) - a - kQ_K\right) \geq 0 \qquad \text{(A.26)}$$

Producer surplus of sellers of regular allowances is found by substituting (A.10) in the expression for producer surplus and using the equilibrium quantity $e_R + \Delta R$:

$$PS_R = P_R^* e_R\left(P_R^*\right) = P_R^*\left(e_R + \Delta R\right) \geq 0$$

$$PS_R = -\frac{1}{2k}\left(a + a\gamma(1-\theta) - kQ_P\right)\left(a\gamma(1-\theta) - a - kQ_K\right) \geq 0 \qquad \text{(A.27)}$$

Consumer surplus of Kantian firms is found by substituting (A.9) in the expression for consumer surplus and using the quantity $e_K - \Delta R$:

$$CS_K = \frac{\left(a\gamma(1-\theta) - P_K^*\right)}{2}\left(e_K - \Delta R\right) \geq 0$$

Rearranging yields

$$CS_K = \frac{1}{4k}\left(a\gamma(1-\theta) - a + kQ_P\right)\left(a\gamma(1-\theta) - a + kQ_P - kQ_K\right) \quad \text{(A.28)}$$

Producer surplus of Kantian firms is found by substituting (A.9) in the expression for producer surplus and using the equilibrium quantity $e_K - \Delta R$:

$$PS_K = P_K^* e_K\left(P_K^*\right) = P_K^*\left(e_K - \Delta R\right) \geq 0$$

$$PS_K = \frac{1}{2k}\left(a + a\gamma(1-\theta) - kQ_P\right)\left(a\gamma(1-\theta) - a + kQ_P - kQ_K\right) \geq 0 \qquad \text{(A.29)}$$

Total welfare

Total consumer surplus in cases I-II is defined as

$$CS_{I-II} = CS_K + CS_R \geq 0$$

Substituting (A.26) and (A.28) yields

$$CS_{I-II} = \frac{1}{4k}\left(a\gamma(1-\theta) - a + kQ_P\right)\left(2a\gamma(1-\theta) - a + kQ_P - 2kQ_K\right) \geq 0 \quad \text{(A.30)}$$

Total producer surplus in case II is defined as

$$PS_{I-II} = PS_K + PS_R \geq 0$$

Substituting (A.27) and (A.29) yields

$$PS_{I-II} = \frac{1}{2}\left(a + a\gamma(1-\theta) - kQ_P\right)Q_P \geq 0 \qquad \text{(A.31)}$$

Total welfare in case II

$W_{I-II} = CS_{II} + PS_{II} \geq 0$

Substituting (A.30) and (A.31) yields

$$W_{I-II} = \frac{1}{4k}\left(a\gamma(1-c) - a + kQ_P\right)\left(2a\gamma(1-\theta) - a + kQ_P - 2kQ_K\right) + \frac{1}{2}\left(a + a\gamma(1-\theta) - kQ_P\right)Q_P \geq 0$$

(A.32)

<u>Case III-V</u>

Consumer surplus of regular firms is found by substituting (A.18) in the expression for consumer surplus and using the quantity $Q_P - Q_K$:

$$CS_R = \frac{\left(a - P_R^*\right)}{2} e_R\left(P_R^*\right) = \frac{\left(a - P_R^*\right)}{2}\left(Q_P - Q_K\right) \geq 0$$

which yields

$$CS_R = \frac{k\left(Q_P - Q_K\right)^2}{2} \geq 0 \qquad \text{(A.33)}$$

Producer surplus of sellers of regular allowances is found by substituting (A.18) in the expression for producer surplus and using the equilibrium quantity:

$$PS_R = P_R^* e_R\left(P_R^*\right) = P_R^*\left(Q_P - Q_K\right) \geq 0$$

which yields

$$PS_R = a\left(Q_P - Q_K\right) - k\left(Q_P - Q_K\right)^2 \geq 0 \qquad \text{(A.34)}$$

Consumer surplus of Kantian firms is found by substituting (A.17) in the expression for consumer surplus and using the equilibrium quantity Q_K:

$$CS_K = \frac{\left(a\gamma(1-\theta) - P_K^*\right)}{2} e_K\left(P_K^*\right) = \frac{\left(a\gamma(1-\theta) - P_K^*\right)}{2} Q_K \geq 0$$

which yields

$$CS_K = \frac{kQ_K^2}{2} \geq 0 \tag{A.35}$$

Producer surplus of Kantian firms is found by substituting (A.17) in the expression for producer surplus and using the equilibrium quantity Q_K:

$$PS_K = P_K^* e_K\left(P_K^*\right) = P_K^* Q_K \geq 0$$

which yields

$$PS_K = a\gamma(1-\theta)Q_K - kQ_K^2 \geq 0 \tag{A.36}$$

Total welfare

Total consumer surplus in the cases III-V is defined as

$$CS_{III-V} = CS_K + CS_R \geq 0$$

Substituting (A.33) and (A.35) yields

$$CS_{III-V} = \frac{kQ_K^2}{2} + \frac{k\left(Q_P - Q_K\right)^2}{2} \geq 0 \tag{A.37}$$

Total producer surplus in case II is defined as

$$PS_{III-V} = PS_K + PS_R \geq 0$$

Substituting (A.34) and (A.36) yields

$$PS_{III-V} = a\left(Q_P - Q_K\right) - k\left(Q_P - Q_K\right)^2 + a\gamma(1-\theta)Q_K - kQ_K^2 \geq 0 \tag{A.38}$$

Total welfare in case II is defined as

$$W_{III-V} = CS_{III-V} + PS_{III-V} \geq 0$$

Substituting (A.37) and (A.38) yields

$$W_{III-V} = \frac{kQ_K^2}{2} + \frac{k(Q_P - Q_K)^2}{2} + a(Q_P - Q_K) - k(Q_P - Q_K)^2 + a\gamma(1-\theta)Q_K - kQ_K^2 \geq 0$$

(A.39)

Welfare effects

The welfare effects of reducing the transaction cost, θ, is analyzed the comparative statics of the market equilibrium.

Cases I-II

We start with the analysis of dual market in case II and then continue with case I. The change in consumer surplus of regular firms is derived by differentiating (A.26) with respect to θ.

$$\frac{\partial CS_R}{\partial \theta} = -\frac{a\gamma}{4k}\left(2a\gamma(1-\theta) - 2a - k(Q_P + Q_K)\right)$$

and rearranging

$$\frac{\partial CS_R}{\partial \theta} = -\frac{a\gamma}{4k}\left(a\gamma(1-\theta) - \frac{k(Q_P + Q_K)}{2a} - 1\right) \qquad \text{(A.40)}$$

where the sign is ambiguous and depends on the ratio between a and k, the elasticity of demand on the carbon market.

Change in producer surplus of sellers of regular allowances is derived by differentiating (A.27) with respect to θ.

$$\frac{\partial PS_R}{\partial \theta} = \frac{a\gamma}{2k}\left(2a\gamma(1-\theta) - k(Q_P + Q_K)\right) \qquad \text{(A.41)}$$

where the sign is ambiguous and depends on the ratio between a and k, the elasticity of demand on the carbon market.

Change in consumer surplus of Kantian firms is derived by differentiating (A.28) with respect to θ.

$$\frac{\partial CS_K}{\partial \theta} = -\frac{a\gamma}{4k}\left(2a\gamma(1-\theta) - 2a + 2kQ_P - kQ_K\right)$$

and rearranging

$$\frac{\partial CS_K}{\partial \theta} = -\frac{a\gamma}{4k}\left(a\gamma(1-\theta) + \frac{k(Q_P - Q_K/2)}{a} - 1\right) \leq 0 \qquad \text{(A.42)}$$

since $a\gamma(1-\theta) \geq 1$.

Change in producer surplus of sellers of Kantian allowances is derived by differentiating (A.29) with respect to θ.

$$\frac{\partial PS_K}{\partial \theta} = -\frac{a\gamma}{2k}\left(2a\gamma(1-\theta) - kQ_K\right) \qquad \text{(A.43)}$$

where the sign is ambiguous and depends on the ratio between a and k, the elasticity of demand on the carbon market.

The change in total consumer surplus is obtained by using (A.40) and (A.42) which gives

$$\frac{\partial CS_{I-II}}{\partial \theta} = -\frac{a\gamma}{4k}\left(4a\gamma(1-\theta) - 4a + 3kQ_P - 2kQ_K\right) \leq 0 \qquad \text{(A.44)}$$

since $a\gamma(1-\theta) \geq 1$.

Change in total producer surplus is obtained by using (A.40) and (A.43) which gives

$$\frac{\partial PS_{I-II}}{\partial \theta} = -\frac{2a\gamma}{4} Q_P \leq 0 \qquad \text{(A.45)}$$

Change in total welfare $W = CS_{I-II} + PS_{I-II}$ is defined as

$$\frac{\partial W_{I-II}}{\partial \theta} = \frac{\partial CS_{I-II}}{\partial \theta} + \frac{\partial PS_{I-II}}{\partial \theta} \qquad \text{(A.46)}$$

Using (A.44) and (A.45) gives

$$\frac{\partial W_{I-II}}{\partial \theta} = -\frac{a\gamma}{4k}\left(4a\gamma(1-\theta) - 4a + 3kQ_P - 2kQ_K\right) - \frac{2a\gamma}{4k} kQ_P \leq 0 \qquad \text{(A.47)}$$

since $a\gamma(1-\theta) \geq 1$.

The demand conditions in case I is the equation $a\gamma(1-\theta) = a - kQ_P$ in equation (A.2). Given this, any reduction in the transactions cost parameter, θ, will produce the inequality $a\gamma(1-\theta) > a - kQ_P$ in (A.2), which is the demand condition of the dual market in case II. Hence, the results on welfare effects in case II also hold in case I.

Case III-V

Change in consumer surplus of regular firms is derived by differentiating (A.33) with respect to θ.

$$\frac{\partial CS_R}{\partial \theta} = 0 \tag{A.48}$$

Change in producer surplus of sellers of regular allowances is derived by differentiating (A.34) with respect to θ.

$$\frac{\partial PS_R}{\partial \theta} = 0 \tag{A.49}$$

Change in consumer surplus of Kantian firms is derived by differentiating (A.35) with respect to θ.

$$\frac{\partial CS_K}{\partial \theta} = 0 \tag{A.50}$$

Change in producer surplus of sellers of Kantian allowances firms is derived by differentiating (A.36) with respect to θ.

$$\frac{\partial PS_K}{\partial \theta} = -a\gamma Q_K < 0 \tag{A.51}$$

The change in total consumer surplus is obtained by using (A.48) and (A50) gives

$$\frac{\partial CS_{III-V}}{\partial \theta} = 0 \tag{A.52}$$

The change in total producer surplus is obtained by using (A.49) and (A51) gives

$$\frac{\partial PS_{III-V}}{\partial \theta} = -a\gamma Q_K < 0 \tag{A.53}$$

The change in total welfare $W = CS_{III-V} + PS_{III-V}$ is defined as

$$\frac{\partial W_{III-V}}{\partial \theta} = \frac{\partial CS_{III-V}}{\partial \theta} + \frac{\partial PS_{III-V}}{\partial \theta} \tag{A.54}$$

Using (A.52) and (A.53) in (A.54) yields

yields

$$\frac{\partial W}{\partial \theta} = -a\gamma Q_K < 0 \tag{A.55}$$

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