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Permit allocation rules and investment incentives in emissions trading systems

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Permit allocation rules and investment incentives in emissions trading systems

Abstract

This paper argues that, in situations where choices are made between mutually exclusive investment projects and where there are economic rents, free allocation of tradable emission permits in emissions trading systems can weaken incentives for firms to invest in less carbon-intensive technologies compared to the case where permits would be auctioned. The reason is that permit allocation rules affect economic rents differentially when different product benchmarks apply to products that are close substitutes. Examples of permit allocation rules favouring more emission-intensive technologies for outputs that are close substitutes are found in the California Cap and Trade Program and in the European Union Emissions Trading System. This lack of technology-neutrality is exacerbated in the long run as future patterns of substitutability between technologies are uncertain. Free permit allocation can broaden support for carbon pricing, but this paper shows that this carries a cost in terms of environmental effectiveness if it discourages investment in low-carbon assets.

JEL classification: D04, D25, D47, H23, H32, L51, Q48, Q52

Keywords: emissions trading systems, permit allocation, technology neutrality, benchmarks, carbon pricing, average carbon prices, decarbonisation, EU ETS, California Cap and Trade Program

Règles d'allocation des quotas et incitations à l'investissement dans le cadre des systèmes d'échange de quotas d'émission

Résumé

Ce document fait valoir que, dans les situations où il s'agit de choisir entre des projets d'investissement s'excluant mutuellement et où il existe des rentes économiques, l'incitation qu'ont les entreprises à investir dans des technologies moins émettrices de carbone peut être plus faible si les permis d'émission négociables sont attribués gratuitement plutôt que par voie d'enchères. Cela tient au fait que les règles d'allocation des permis affectent de façon différenciée les rentes économiques lorsque des référentiels de produit différents s'appliquent à des produits substituables. On trouve des exemples de règles d'allocation qui favorisent le recours à des technologies plus émettrices de carbone en présence de productions substituables dans les systèmes d'échange de quotas d'émission de la Californie et de l'Union européenne. Ce déficit de neutralité technologique est aggravé à long terme dans la mesure où les substituabilités futures entre technologies sont incertaines. L'allocation de permis à titre gratuit peut favoriser une plus large adhésion à la tarification du carbone, mais ce document montre qu'elle a un coût sur le plan de l'efficacité environnementale si elle décourage l'investissement dans des actifs bas carbone.

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Executive Summary

Motivation and Scope

Free allocation of emission permits can help gain support from industry for carbon pricing - a core policy for reducing emissions. Policy makers often envisage moving from free allocation to auctioning of permits over time. Gradually phasing out free allocation and increasing the share of auctioned permits allows raising valuable public revenue at relatively low social costs. However, evidence from the EU Emissions Trading System (ETS) and the California Cap and Trade (CTP) program shows that it remains challenging to increase the share of auctioned permits. A significant share of emitters participating in emissions trading will continue to receive free permits in the foreseeable future.

The paper offers a fresh perspective on the effects of permit allocation rules on low-carbon investment and the long-term impacts of permit allocation rules. The analysis adopts the point of view of an investor that chooses between a low-carbon (clean) and a high-carbon (dirty) technology to produce economically similar outputs, based on total profits. Emissions from production are subject to an emissions trading system. The investor chooses the most profitable technology in an imperfectly competitive market, so there are economic rents.

The main result is that free allocation of tradable emission permits under current allocation rules has the potential to weaken incentives for firms to choose low-carbon technologies, compared to the situation where permits would be auctioned or a uniform tax were levied. The reason is, in general, that the permit allocation rules affect economic rents and, in practice, that existing rules do so in a way that tends to favour more carbon-intensive technologies. Investors value carbon-intensive technologies higher than in the absence of free allocation, as free allocation increases profits, and this risks changing the ranking of technologies in terms of profitablity. In other words, current allocation rules are often an impediment to decarbonisation.

Free allocation can affect technology choice

Recent empirical evidence for the EU ETS shows a negative correlation between free allocation and emission abatement. While the negative correlation could result from emitters with high abatement costs receiving more free allowances, interviews with managers from industrial emitters instead reveal lower perceived incentives for abatement and less low-carbon innovation for firms with more free allocation. The paper provides a plausible economic rationale for this behaviour.

Section 2 of the paper conceptually analyses the impact of allocations on emissions. It considers a stylised example in which an investor can choose between a clean and a dirty technology to meet a given demand (e.g. wind or fossil fuels to generate a given supply of electricity). Investors choose between projects on the basis of total expected profits. Free allocation of permits affects expected profits in ways that potentially differ between technologies.

The average permit price captures the effect of free allocation on total expected profits. If average carbon prices equalled marginal carbon prices, then permit allocation would not affect project rankings, so would be technology-neutral. The same could hold if average carbon prices were equal across technologies and if also carbon-free technologies received permits for free.

Current allocation rules lead to weak incentives for low-carbon investment

Section 3 of the paper looks at permit allocation rules in two of the world's most prominent greenhouse gas emissions trading systems, namely the EU ETS and the California CTP. It identifies three ways in which allocation rules can affect technology choices, other than through the price signal at the margin: first, the benchmarks by which allocations are decided are not always technology-neutral; second, sticking to older and more carbon-intensive technologies can be of strategic interest; third, producing more with older and more carbon-intensive technologies can be of strategic interest.

Benchmarks turn out to be a key factor that, through their effect on expected profits, can alter project rankings. They generally favour carbon-intensive technologies if they are not technology-neutral. Benchmarks are defined for categories of products, implying that product varieties within each category are considered as interchangeable – perfect substitutes. Substitute products can differ in technological properties as long as they satisfy a similar economic need. For substitute products within a benchmark category the allocation is the same, and this guarantees technology-neutrality in the sense that permit allocations do not affect technology choices. However, when products under different benchmarks are in fact substitutes satisfying similar needs, there is an incentive to opt for high-carbon technologies as these generally come with more permits.

A comprehensive analysis of the impacts of non-neutral benchmarks considers both short- and long-run impacts. In the short-run it is costly, yet possible, to become informed on which products are close substitutes. While benchmarks might thus be able to approximate technology-neutrality in the short-run, our analysis suggests that there is ample room for improvement. In the long-run one cannot know about the substitutability of goods, implying that benchmarks cannot be technology-neutral over longer time horizons. Technology-neutrality of a carbon pricing mechanism requires that the treatment of a technology under that mechanism only depends on the carbon emissions generated, and nothing else.

Different benchmarks for close substitutes and low ex-post average carbon rates in the EU ETS and the California CTP imply weak signals for favouring low-carbon investment projects over high-carbon projects. This results in more carbon-intensive investment compared to the case where all permits would be auctioned or a linear carbon tax would be set.

Résumé

Raison d'être et portée

L'allocation des quotas d'émission à titre gratuit peut favoriser l'adhésion des industriels à la tarification du carbone, qui est une mesure fondamentale pour réduire les émissions. Souvent, les décideurs envisagent d'abandonner au fil du temps cette allocation gratuite au profit de l'attribution des quotas par voie d'enchères. Une telle transition procure de précieuses recettes publiques pour un coût social relativement faible. Cependant, les exemples du système d'échange de quotas d'émission (SEQE) de l'UE et du programme de plafonnement et d'échange de la Californie (California Cap and Trade Program, CTP) montrent qu'il demeure délicat d'accroître la proportion des quotas attribués par voie d'enchères. Dans un avenir prévisible, une part significative des émetteurs intégrés aux systèmes d'échange continueront d'obtenir leurs quotas gratuitement.

Ce document jette un regard neuf sur les effets des règles d'allocation des quotas sur l'investissement bas carbone et sur les répercussions à long terme de ces règles. L'analyse se place du point de vue d'un investisseur qui choisit entre une technologie bas carbone (propre) et une technologie fortement émettrice de carbone (sale) pour assurer des productions économiquement équivalentes, en se basant sur les bénéfices totaux. En l'occurrence, les émissions engendrées par la production sont soumises à un système d'échange de quotas d'émission. L'investisseur choisit la technologie la plus rentable sur un marché de concurrence imparfaite, de sorte qu'il existe des rentes économiques.

Le principal résultat de l'analyse est que l'allocation gratuite des quotas selon les règles actuelles est susceptible d'affaiblir l'incitation qu'ont les entreprises à privilégier des technologies bas carbone par rapport à une situation d'attribution des quotas par voie d'enchères ou de perception d'une taxe uniforme. Cela tient en général au fait que les règles d'allocation des quotas se répercutent sur les rentes économiques et que, dans la pratique, les règles existantes ont tendance à favoriser ce faisant des technologies plus émettrices de carbone. Les technologies à fortes émissions de carbone ont plus de valeur aux yeux des investisseurs en présence d'une allocation gratuite, car celle-ci augmente les bénéfices, et cela risque de modifier le classement des technologies en fonction de leur rentabilité. En d'autres termes, les règles d'allocation actuelles font souvent obstacle à la décarbonation.

L'allocation gratuite peut se répercuter sur les choix technologiques

Des données empiriques récentes concernant le SEQE de l'UE montrent qu'il existe une corrélation négative entre allocation gratuite et réduction des émissions. Alors que cette corrélation négative pourrait s'expliquer par l'attribution de quotas gratuits plus nombreux aux émetteurs confrontés à des coûts de réduction élevés, il ressort au contraire d'entretiens avec des responsables d'entreprises industrielles émettrices de carbone que les incitations perçues à réduire les émissions et l'innovation bas carbone sont plus faibles dans les entreprises qui bénéficient d'une allocation gratuite. Ce document présente une explication économique plausible à ce comportement.

La deuxième section du document propose une analyse théorique de l'impact de l'allocation sur les émissions. Elle s'appuie sur un exemple simplifié d'un investisseur qui a le choix entre une technologie propre et une technologie sale pour répondre à une demande donnée (par exemple, entre des éoliennes et des combustibles fossiles pour produire une certaine quantité d'électricité). Les investisseurs font leur

choix entre différents projets en fonction des bénéfices totaux attendus. L'allocation gratuite des quotas a des répercussions sur les bénéfices attendus qui peuvent varier selon les technologies.

Le prix moyen des quotas tient compte de l'effet de l'allocation gratuite sur les bénéfices totaux attendus. Si les prix moyens du carbone étaient égaux aux prix marginaux du carbone, l'allocation des quotas ne modifierait pas le classement des projets et serait donc neutre sur le plan technologique. Le cas échéant, il en irait de même si les prix moyens des quotas étaient identiques pour l'ensemble des technologies et si les quotas gratuits bénéficiaient aussi aux technologies décarbonées.

Avec les règles d'allocation actuelles, l'incitation à investir dans la sobriété carbone est faible

La troisième section du document se penche sur les règles d'allocation des quotas dans deux des systèmes d'échange de quotas d'émission de gaz à effet de serre les plus en vue, à savoir le SEQE de l'UE et le CTP californien. Elle met en lumière trois aspects des règles d'allocation, en plus du signal prix marginal, qui peuvent influer sur les choix technologiques : premièrement, les référentiels servant à déterminer les allocations ne sont pas toujours neutres sur le plan technologique ; deuxièmement, il peut y avoir un intérêt stratégique à maintenir des technologies plus anciennes fortement émettrices de carbone ; et troisièmement, il peut y avoir un intérêt stratégique à produire davantage avec de telles technologies.

Les référentiels s'avèrent être un facteur clé qui peut modifier le classement des projets en raison de son effet sur les bénéfices attendus. Ils favorisent généralement les technologies fortement émettrices de carbone lorsqu'ils ne sont pas neutres sur le plan technologique. Les référentiels sont définis par catégorie de produits, de sorte que les divers produits relevant d'une même catégorie sont considérées comme interchangeables et parfaitement substituables. Peu importe que les produits substituables aient des caractéristiques technologiques différentes, pourvu qu'ils satisfassent un besoin économique similaire. Les produits substituables à l'intérieur d'une même catégorie donnent lieu à une allocation identique, ce qui est un gage de neutralité technologique en ce sens que les allocations de quotas n'influencent pas les choix technologiques. En revanche, lorsque des produits faisant l'objet de référentiels différents sont en fait des substituts qui satisfont des besoins similaires, il y a une incitation à opter pour les technologies grosses émettrices de carbone dans la mesure où elles donnent lieu à l'attribution d'une plus grande quantité de quotas.

Une analyse approfondie est consacrée aux impacts à court et long termes de référentiels non neutres sur le plan technologique. À court terme, il est coûteux – mais possible – d'obtenir des informations pour déterminer quels produits sont étroitement substituables. Les référentiels peuvent donc être en mesure de créer une situation de neutralité technologique approximative à court terme, mais il ressort de notre analyse que la marge d'amélioration est considérable. À plus long terme, la substituabilité des biens est impossible à connaître, et les référentiels ne peuvent donc pas assurer la neutralité technologique sur la durée. Pour être neutre sur le plan technologique, un mécanisme de tarification du carbone doit traiter les différentes technologies uniquement à l'aune des émissions de carbone qu'elles produisent, à l'exclusion de tout autre critère.

Comme des produits étroitement substituables font l'objet de référentiels différents et que les taux moyens ex post sur le carbone sont bas dans le SEQE-UE et le CTP californien, l'incitation à investir

dans des projets sobres en carbone plutôt que dans des projets à fortes émissions de carbone est faible. Par conséquent, les investissements se caractérisent par une intensité d'émission de carbone plus forte que si tous les quotas étaient attribués par voie d'enchères ou que si une taxe carbone linéaire était appliquée.

Permit allocation rules and investment incentives in emissions trading systems

1. Introduction

This paper asks whether free allocation of tradable emission permits in emissions trading systems can weaken emission abatement incentives for firms. The analysis adopts the point of view of an investor that chooses between a more and a less carbon-intensive technology to produce similar outputs, where similarity does not refer to technological properties, but satisfying a similar need (economic substitutes). This choice is made in an imperfectly competitive market, so there are economic rents, and the emissions from production are subject to an emissions trading system. The investor does not care about the cap itself but takes the price of permits into account when choosing a technology. Consistent with a decarbonisation perspective, the analysis focuses on the investment and long-term impacts of permit allocation rules.

The main result is that free allocation of tradable emission permits has the potential to weaken incentives for firms to choose low carbon technologies, compared to the situation where permits would be auctioned or a uniform tax were levied. The reason is, in general, that the permit allocation rules affect economic rents and, in practice, that existing rules appear to do so in a way that tends to favour more carbon-intensive technologies. This differential incentive has the potential to affect investment project rankings in the sense that more emission-intensive technologies become more appealing than less emission-intensive technologies, whereas the reverse would hold if all permits were auctioned or a tax equal to the auctioning price applied.

The examination of the incentives to invest in low-carbon (clean) or carbon-intensive (dirty) technologies adopts the viewpoint of an investor choosing a technology in an industry where emissions are subject to a cap. From a macroscopic perspective, allocation rules do not affect total emissions under a binding cap in the short-term, because additional emission cuts by one emitter allow other emitters to emit more. However, the present analysis shows that free allocation of permits can lead to heterogeneous carbon prices across production technologies and products, which implies that abatement is no longer cost-effective. In other words, free allocation increases overall abatement cost in the short-term. In the long-term, free allocation can also reduce overall abatement, through its potential effect on the setting of caps. Caps are generally specified only for times frames significantly shorter than the investment cycles of currently carbon intensive products such as steel, cement, chemical and mineral products. If free allocation locks in dirty investment today, it may be harder to set more stringent caps in the future.

The analysis contributes to the literature on the choice of policy instrument to reduce emissions of pollutants or greenhouse gases. There is wide consensus among economists that market-based instruments are more likely to deliver abatement at the lowest possible cost than standards and

technology mandates, essentially because they decentralise the abatement decisions to those best placed to make them and because they provide an enduring abatement incentive (static and dynamic efficiency). Views on the relative merits of taxes and emissions trading systems diverge more strongly. Goulder and Schein (2013) collect and evaluate the main arguments, focussing on climate change policy, and conclude that market-based instruments that set prices exogenously (taxes and trading systems with price constraints) display a number of appealing features compared to endogenous price mechanisms (trading systems with no price constraints).

Goulder and Schein (2013) argue that free allocation of permits does not weaken abatement incentives compared to taxation or full auctioning of permits because each additional unit of emissions carries an opportunity cost (namely, the value of the permit required for it). This summarises what can be called "the standard view", which focusses on opportunity costs related to marginal emission reductions (see e.g. Smith, 2008, or Phaneuf and Requate, 2017, for alternative presentations of the standard view).

Here, it is argued that the standard view does not necessarily apply if infra-marginal decisions are considered. This is because free allocation affects economic rents in ways that can change the ranking of investment projects. The argument is different from arguments relating to incentives for firms to emit more now with the hope of receiving more permits in the future (see Phaneuf and Requate, 2017, Chapter 8.5, for a review).[1] The present paper points out that investors take permit allocations into account when choosing a technology. They may also try to influence future allocations through their present emissions, but that is a separate issue.

Recent empirical findings for the European Union (EU) Emissions Trading System (ETS) show a negative correlation between free allocation and emission abatement. In an analysis covering nearly all industrial installations within the EU ETS, Brouwer et al. (2016) find that installations with allocations above historical emissions increase their emissions, while installations with allocations below historical emissions decrease their emissions in subsequent years. Interviewing managers of Belgian ceramic plants, Venmans (2016) reports lower perceived abatement investment incentives for firms with allocations above actual emissions compared to firms with allocations below actual emissions.

Looking at low-carbon innovation, a topic closely related to low-carbon investment, Martin et al. (2012) report lower innovation efforts in firms with a higher share of free allocation, based on interviews with managers in 770 manufacturing firms in the EU. Innovation efforts drop significantly above the thresholds that grant additional free permits to firms in both trade and carbon intensive industries. The authors argue that these findings question the "standard view".[2] The argument put forward in this paper is not the only possible explanation for the empirical findings, but it is one argument worth considering that has – to our knowledge – been overlooked up to now.

[1] Our argument also differs from the insight that imperfect competition in the permit trading market implies that cost-effective abatement is no longer obtained unless the initial permit allocation equals the efficient one.

[2] Fowlie and Perloff (2013) report that the timing of allowance allocation did not affect short-run abatement of NOx emissions in California's Regional Clean Air Incentives Market (RECLAIM) emissions trading program. While this finding is consistent with the standard view the authors also note that their study does not allow any conclusions about the effects of allocation on abatement decisions in the long-run.

Section 2 of the paper conceptually analyses the impact of allocations on emissions. It considers a stylised example in which an investor can choose between a clean and a dirty technology to meet a given demand (e.g. wind or fossil fuels to generate a given supply of electricity). It adapts the framework of Devereux and Griffith (1998a) to the case of tradable permits. Investors choose between projects on the basis of total expected profits. Free allocation of permits affects profits in ways that potentially differ between technologies, if there are economic rents in the market. Otherwise said, free permit allocation has an effect on average carbon prices, and average carbon prices affect profits and can alter project rankings. If average carbon prices equalled marginal carbon prices permit allocation would not affect project rankings, so would be technology-neutral. The same could hold if average carbon prices were equal across technologies and if also carbon-free technologies received permits for free.

Ensuring that investments in long-lived assets are low carbon is critical to full decarbonisation of the economy. Keeping global temperature increases well below 2°C as called for in the Paris Agreement implies carbon neutrality in the second half of this century, requiring near full decarbonisation in many sectors (Evans, 2014; Rogelj, 2015). The emphasis on full decarbonisation leads us to focus on investment in long-lived assets. This differs from the focus on abatement at the margin implicit in the standard analysis, and this ultimately drives the differing insight.

The long-term view that follows from a focus on full decarbonisation also implies that the caps of emissions trading systems can be considered as endogenous. In the short-term, with a fixed cap, free allocation will not affect overall abatement within an emissions trading system as long as the cap is binding. Yet, even in the short-term free allocation can affect abatement incentives for individual firms, compromising the economic efficiency of emissions trading. If not technology-neutral, firms receiving allowances for free may choose against low-cost clean investment opportunities that they would have undertaken in the absence of free allocation.

A second implication of the long-term view is that a broad rather than a narrow view of substitutability of goods is taken. The broad view entails that all outputs that serve a specific demand are considered to be, or can become, substitutes during the transition to a low-carbon economy. This means, for example, that bricks, steel, cement and wood are all seen as potential substitutes to satisfy the specific demand for living space. In other words, substitutability is considered in the broad economic sense and relates to demand, not to narrow product characteristics such as the share of recycled steel. Future demand patterns are unknown, implying also uncertainty about substitution patterns.

Section 3 of the paper looks at permit allocation rules in two of the world's most prominent greenhouse gas emissions trading systems, namely the European Union Emissions Trading System (EU ETS) and the California Cap-and-Trade Program (CTP). It identifies three ways in which allocation rules can affect technology choices, other than through the price signal at the margin: first, the benchmarks by which allocations are decided are not always technology-neutral; second, sticking to older and more carbon-intensive technologies can be of strategic interest; third, producing more with older and more carbon-intensive technologies can be of strategic interest.

Benchmarks turn out to be a key factor that, through their effect on expected profits, can alter project rankings. They generally favour carbon-intensive technologies if they are not technology-neutral. Benchmarks are defined for categories of products, implying that product varieties within each category are considered as interchangeable – perfect substitutes. For substitute technologies within a benchmark

category the allocation is the same, and this guarantees technology-neutrality in the sense that permit allocations do not affect technology choices. However, when products under different benchmarks are in fact substitutes, there is an incentive to opt for high-emission technologies as these generally come with more permits.

A comprehensive analysis of the impacts of non-neutral benchmarks considers both short- and long-run impacts. In the short-run it is costly, yet possible, to become informed on which products are close substitutes. While benchmarks might thus be able to approximate technology-neutrality in the short-run, our analysis suggests that there is ample room for improvement. In the long-run one cannot know about the substitutability of goods, implying that benchmarks cannot be technology-neutral over longer time horizons. Technology-neutrality of a carbon pricing mechanism requires that the treatment of a technology under that mechanism depends on the carbon emissions generated, and nothing else.

Different benchmarks for close substitutes and low ex-post average carbon rates in the EU ETS and the California CTP implies weak signals for favouring low-carbon investment projects over emission-intensive projects. This results in more carbon-intensive production compared to the case where all permits would be auctioned or a linear carbon tax would be set.

Section 4 discusses the scope, relevance and limitations of the analysis, sums up and concludes.

2. Taxes, emissions trading and the choice to invest in clean or dirty technologies

This section develops a simple framework to show how permit allocation rules have the potential to affect the ranking of mutually exclusive investment projects in terms of their total economic profits. In order to do so, it considers a firm choosing to invest in either a clean or a dirty production technology while taking demand for the final product as given. To fix ideas, one can think of a steel producer investing in a new production site who decides on using either the electric-arc furnace (EAF) or the blast-furnace (BF) route. EAF steel is significantly less carbon-intensive than BF steel, and both options are highly capital-intensive. The choice will largely determine the emissions that will result per unit of steel produced steel at the new site. Similar choices arise in other industries and in the energy sector. For example, an electricity producer can produce electricity either with a clean asset like solar power, or a dirty asset, such as a lignite plant. Solar and lignite plants are long-lived assets with lifetimes ranging from 20 to 60 years. A profit-maximising electricity producer will decide for the option with the highest expected profits.

A key assumption in the subsequent analysis is that investors and firms operate in imperfectly competitive markets and that there are rents. Evidence suggests that mark-ups are ubiquitous. For example, Christopolou and Vermeulen (2012) find that average mark-ups for industries range between 13% and 28% across eight European countries and the United States. Comparing five different studies

for the United Kingdom, the Department of Transport (2005) reports a best estimate of industry mark-ups in the UK of 20%. Mark-ups are found to differ between industries, but there is little evidence for a change in mark-ups over time (Christopolou and Vermeulen, 2012).

Consistently positive mark-ups across industries and countries point towards imperfect competition being a reasonable assumption.[3] The importance of this assumption for the subsequent analysis is that it is the presence of economic rents that explains the potential relevance of the average carbon rates to investment decisions. As will become clear, if the market structure would drive all rents to zero, then only the marginal carbon rate would affect investors' choices, and the standard view would apply. Here, it is assumed that the market structure is such that the economic rent from free permit allocation is not reduced to zero.

The question is whether there are any differences in the discrete choice between a clean and a dirty investment under a tax or an emissions trading system in which all permits are auctioned and an emissions trading system in which there is some free allocation. For the tax or for full auctioning – the two have identical economic properties in this simple model – it is assumed that the marginal rate is paid for the entire base, as is commonly the case.[4] In emissions trading systems, governments commonly allocate some permits to emitters for free.

Free allocation of permits creates rents, possibly altering the ranking of projects under emissions trading compared to taxes. Studying lump-sum allocation only, Requate (2005) does not find any differences between taxes and emissions trading regarding technology choice, a result confirmed in the present analysis. However, when considering allocation rules as commonly observed in emission trading systems, technology-neutrality disappears. Technology-biased allocation, for example through benchmarks, diminishes the incentives to invest in clean technologies under emissions trading. This is shown by modifying the framework developed by Devereux and Griffith (1998a, 1998b), adapting it for the analysis of emissions trading instead of only taxation. The same results would hold in a generalised version of the Requate (2005) model.

2.1. A simple framework for analysing rents from permit allocation and technology choice

Consider the revenues from an investment in clean (subscript c) or dirty (subscript d) technologies, under a tax (superscript T) and a trading system (superscript E), where P is the output price, Q_i is output, c_i is the constant unit cost, t is the emission tax rate, α and β are the emission intensities of output (with $\alpha<\beta$

[3] The reported mark-ups are either measured above average costs or above marginal costs, but including opportunity costs of capital. If mark-ups were simply measured above marginal costs, not considering the opportunity cost of capital, they could reflect the need to recover fixed costs, and would not necessarily indicate imperfect competition.

[4] The currently proposed carbon tax in South Africa is an exception to this rule in that it provides emitters with emissions permits for which no carbon tax has to be paid, i.e. the carbon tax does not apply to the entire emissions base.

by assumption), F_i are fixed costs, p is the market clearing price for permits[5], and A_i is the permit allowance, for $i = c, d$. Revenues (R) – rents – are taken to be positive. Square brackets indicate functional dependence, round brackets indicate multiplication.

$$R_c^T = PQ_c - c_cQ_c - t\alpha Q_c - F_c > 0 \quad (1a)$$

$$R_d^T = PQ_d - c_dQ_d - t\beta Q_d - F_d > 0 \quad (1b)$$

$$R_c^E = PQ_c - c_cQ_c - p\alpha Q_c + pA_c[.] - F_c > 0 \quad (2a)$$

$$R_d^E = PQ_d - c_dQ_d - p\beta Q_d + pA_d[.] - F_d > 0 \quad (2b)$$

A profit-maximising investor will select the project with the highest rent, both under a tax and an emissions trading system. To see how project rankings under both policies may differ, consider first any possible differences in rents between clean and dirty projects for each policy, assuming Q_c=Q_d=Q:

$$\Delta R^T = R_c^T - R_d^T = -(c_c - c_d)Q - t(\alpha - \beta)Q - (F_c - F_d) \quad (3)$$

$$\Delta R^E = R_c^E - R_d^E = -(c_c - c_d)Q - p(\alpha - \beta)Q + p(A_c[.] - A_d[.]) - (F_c - F_d) \quad (4)$$

Taxes and emissions trading send the same investment incentives if the differences in rents between the clean and the dirty technology are the same ($\Delta R^T = \Delta R^E$). To allow comparison, consider the case where taxes and trading systems send the same signal at the margin, i.e. $t = p$. For rents to be equal under both policies, permit allocations should not differ between the clean and the dirty technology:

$$\Delta R^T = \Delta R^E \quad iff \quad p(A_c[.] - A_d[.]) = 0 \quad (5)$$

Expression 5 says that, unless permit allocations are entirely technology-neutral (in which case the bracketed expression equals zero), project ranking under taxes and trading systems can differ because permit allocations affect rents under emissions trading (Equation 4). If the investor was indifferent under taxes, then she cannot be indifferent under emissions trading, so the ranking changes. The ranking, however, does not necessarily change in the general case where the investor is not indifferent between technologies under taxes, because the difference caused by the value of permit allocations will still alter rents, but not necessarily by enough to alter project rankings.

Making statements about the direction in which allocations could bias project choice requires knowledge of the permit allocation rule. If allocations depend positively on own emissions, as is generally the case with benchmarks and with grandfathering per tonne of output[6], then $\alpha<\beta$ implies that $A_c<A_d$, from which

[5] A positive p implies that investors experience a scarcity of permits or expect future scarcity of permits as a result of the overall emission cap. As p expresses the shadow price of the emission constraint from the cap there is no need to explicitly model the cap when considering the investment decision of an individual investor (cf. Phaneuf and Requate, 2017). It is assumed that investors take p as given. In other words, decisions of an individual investor are considered not to affect permit prices within the overall emissions trading system, in which the emissions of an individual emitter are typically small compared to the overall emissions under the cap.

[6] The definition of grandfathering varies in the literature on emissions trading. Some refer to grandfathering as allocation based purely on historical emissions, independent of production volumes. Others refer to allocation on historical emissions per tonne of output produced. This paper adheres to the second definition.

follows $R_d^E > R_c^E$, assuming that the investor was indifferent between the two projects under the tax ($R_c^T = R_d^T$) and the tax rate equalled the permit price. This means that allocation based on own emissions favours dirty technologies over clean technologies compared to a tax set at the same rate as the permit price. If, however, the allocation is purely lump-sum and both the clean and the dirty technology would receive the same amount of permits (A_c=A_d), then the allocation would be fully technology-neutral even if it still generates rents (but without effect on the efficiency-properties of emissions trading).

2.2. Average and marginal effective permit prices

The previous section has shown how permit allocation can change investment project rankings through its effect on economic rents, compared to the ranking obtained under linear taxation or full auctioning. Both linear taxation and full auctioning are technology-neutral, because they apply evenly to the entire emission base. A remaining question is how to compare the strengths of the incentives to prefer clean over dirty investments between taxes and emissions trading with free allocation. As mentioned in the previous section, investment signals are equal if differences in rents between the clean and the dirty technology are equal ($\Delta R^T = \Delta R^E$). Setting equations 3 and 4 equal and solving for *t* gives

$$t = p(1 - \tfrac{A_c - A_d}{(\alpha-\beta)Q}). \qquad (6)$$

The correspondence between tax rates and permit prices depends on the allocation rule. Consider first a lump-sum allocation, meaning that all investors receive the same amount of permits, independent of the technology. Clean and dirty investment projects thus receive the same amount of permits. Plugging A_c=A_d into equation 6 implies that *t* has to equal *p*. In other words, under lump-sum allocation, or any other technology-neutral allocation rule, taxes and emissions trading provide the same incentives to investors for choosing between clean and dirty projects if the marginal tax rate equals the permit price.

Grandfathering and partial grandfathering per tonne of output imply that allocations depend on (historical) emissions of firms and thus depend on technologies, which can be expressed as $A_i = \gamma E_i$. E_i are the emissions that result from producing output with technology *i*, and γ is a factor between 0 and 1: $\gamma=1$ implies full grandfathering, $0< \gamma<1$ implies partial grandfathering, and $\gamma=0$ implies zero free allocation or full auctioning. $A_i = \gamma E_i$ also summarises benchmarking when benchmarks depend on technologies. Plugging $A_i = \gamma E_i$ into equation 6 gives $t = p\,(1-\gamma)$. Note that $A_i = \gamma E_i$ implies$\gamma = A_i/E_i$, which means that γ is the share of free allocation in a firm's overall emissions. This leads to

$$t = p\,(1 - \tfrac{A_i}{E_i}), \qquad (7)$$

whereby the expression on the right hand side is the firm's average cash cost for permits that need to be purchased so that all emissions, E_i are covered by a permit (either a freely allocated or a purchased permit). This expression is also referred to as the average permit price.

Under partial grandfathering per tonne of output and technology-dependent benchmarking, the average permit price provides the same incentives to invest in clean technologies as the marginal tax rate, as shown by equation 7. The higher the share of free allocation in overall emissions the lower become the incentives to invest in clean technologies as expressed by the marginal tax rate. Under full grandfathering

per tonne of output, A_i equals E_i and there is no incentive to invest in clean technologies as also shown by an equivalent marginal tax rate of zero.[7]

3. Permit allocation rules in the California CTP and the EU ETS

Section 2 argued that the way tradable permits are allocated can affect the decision to invest in clean or dirty technologies and thus long-term carbon emission reductions. In order to obtain insights into how relevant these theoretical findings might be for currently existing emissions trading systems, this section studies the permit allocation rules of the California Cap and Trade Program (CTP) and the EU Emissions Trading System (ETS). In both systems, permit allocation rules differ significantly across sectors (see Table 1). Subsection 3.1 discusses the industry sector and subsection 3.2 the electricity sector. Subsections 3.3 and 3.4 briefly sketch the treatment of natural gas and the transport sector in the California CTP, respectively. Subsection 3.5 presents estimates of ex-post marginal and average effective permit prices and finds average values well below marginal ones in most cases, suggesting that the potential for free allocation to affect investment choices is real.

[7] Emissions trading can also be implemented by defining emission standards for products and allowing emitters with fewer emissions than the standard to trade their abatement surplus with emitters surpassing the standard. Such a system does not have an explicit cap, but instead the cap is implicitly defined through emission standards and production volumes. In terms of incentives, this is equivalent to 100% free allocation according to benchmarks.

Table 1. Allocation rules in the California Cap and Trade Program and the EU ETS

	California Cap and Trade Program	EU Emissions Trading System
	Industry	
Benchmark	74 benchmarks Products usually narrowly defined Different benchmarks for close substitutes, e.g. baked and fried potato chips Benchmarks generally specified as 90% of average carbon intensity for a product	More than 50 benchmarks Products frequently narrowly defined Different benchmarks for close substitutes, e.g. electric arc and blast furnace steel Benchmarks generally defined as average carbon intensity of 10% best performing installations for a product
Supposed leakage risk	3 categories of leakage risk by narrowly defined sectors As of 2018, High risk: 100% free allocation through 2020 Medium risk: 75% free allocation through 2020 Low risk: 50% free allocation through 2020 Risk assessment on basis of emissions per unit of value added	2 categories of leakage risk (yes or no) If yes, 100% of benchmark freely allocated If no, 80% freely allocated in 2013 declining to 30% in 2020 97% of installations supposed to face leakage risk Risk assessment on basis of trade intensity or the ratio of change in production costs due to carbon pricing and value added or a combination of the two measures
	Electricity	
	Requirement for suppliers to sell permits, received for free from state government, at public auctions and use revenues to the benefit of the customers	Full auctioning
	Natural gas outside industry	
	Requirement for suppliers to sell permits, received for free from state government, at public auctions and use revenues to the benefit of the customers	Not covered
	Transport and other fuel outside industry	
	Full auctioning	Not covered.

3.1. Industry

Both the California CTP and the EU ETS allocate permits to industry according to specific formulas (see Annex A for detail) as specified in the regulations governing the emissions trading systems (European Commission, 2011; California Office of Administrative Law, 2015, Article 95870). The formulas consist of several elements, namely *benchmarks* for products, allocation factors that depend on *supposed leakage risk* by product, *time-dependent factors* that account for the decline in caps over time, and installation-specific *historical output*. The following paragraphs discuss how these elements affect incentives for investing in low-carbon and carbon-neutral technologies.

3.1.1. Benchmarks

Benchmarks are the main ingredient of the allocation formula. They specify the amount of permits that a producer of a certain product, e.g. cement, receives for producing one metric tonne of that product, subject to adjustments by the other ingredients of the allocation formula. The EU ETS has 52 product benchmarks, plus an additional heat and an additional fuel benchmark for cases where no product benchmark applies. Several sub-benchmarks exist for refineries, for the different fuels produced. The California CTP has 72 product benchmarks.

The benchmark values in both the EU ETS and the California CTP rely on historical emissions for producing the respective product. In the EU ETS, the product benchmark is the average carbon intensity,

i.e. the average CO_2 emissions per metric tonne of the product produced, of the 10% best performing installations for that product (European Commission, 2011). In the California CTP, the product benchmark equals 90% of the average carbon intensity of all installations producing that product (California Office of Administrative Law, 2015, Article 95870). For example, the benchmark for cement in California is 90% of the average carbon intensity of all cement producers in California.

Benchmarks matter for the decision to invest in clean and dirty production technology if they are not fully technology-neutral. This was shown in the previous section for the case where both technologies produce identical outputs, and by analogy holds where the outputs are close substitutes. For example, if benchmarks provide more permits for dirty technologies (A_D) than for clean technologies (A_c), they can place dirty technologies ahead of clean ones, even if technology-neutral benchmarks or taxes would do the opposite.

Are benchmarks technology-neutral?

Technology-neutrality of a carbon pricing mechanism requires that the treatment of a technology under that mechanism depends on the carbon emissions generated, and nothing else. Benchmarks can be defined for processes or for products. In the first case, if the same product produced using a dirty production process receives more permits for free than when produced using a clean production process, the benchmark incentivises dirty technology. If the benchmark hands out more permits for clean production, it incentivises clean technology. Neither case is technology neutral.

The second approach, defining benchmarks for products, helps to overcome the problem which process benchmarks suffer. Permit allocation is the same with product benchmarks, no matter how the product is produced and this is technology-neutral in the sense that technology choices do not affect permit allocations. However, technology-neutrality only applies to substitute technologies within a product benchmark.

Substitutability across product benchmark categories is generally not specified. When products under different benchmarks are in fact substitutes, there is an incentive to opt for high-emission technologies to the extent that these come with more permits, by the argument of the previous section. In other words, full technology-neutrality across benchmarks would be obtained if the same benchmark applied to all products that are substitutes or could become substitutes during the transition to a net-zero carbon economy. With fully technology-neutral benchmarks there would be no difference in allocations for the clean and the dirty production technology (A_C=A_D) and the marginal permit price would determine the incentives to invest in clean or dirty production technology, all else equal, just like a carbon tax would.

The question whether benchmarks are technology-neutral is ultimately a question about whether products are substitutes or not. Economic definitions of substitutes are based on the markets in which products compete and market definition is a complex issue (OECD, 2012). In the present context, it is safe to say that fully technology-neutral benchmarks are elusive for emissions trading systems, and that full neutrality is possible only under full auctioning or a carbon tax. But how close could one get to technology-neutrality in a practical sense?

Transitioning to a carbon-neutral economic growth path requires a broad definition of markets. An overly narrow definition would ignore possibilities for substitution to cleaner production methods. Consider steel and wood as an example. Taking a narrow market definition, steel and wood may be considered to

be different products.[8] Taking a broader view and looking at what is built with steel and wood, e.g. living or office space as the product to be compared, wood and steel are substitutes. From an economic viewpoint, it is the broad market definition that matters.

The markets in which different products compete will likely change over time and so will the products that are considered to be substitutes. Living space is not the only market for which steel and wood are used, and one may argue that in other markets, wood is no substitute for steel. However, over time, if carbon prices were to make steel more expensive and wood, a carbon sink, cheaper, wood may replace steel in other markets. The use of wooden fundaments for wind power plants is already being explored (Timber Tower, 2016). Other, completely new or rediscovered, building materials may emerge as substitutes over time (cf. EMPA, 2017).

Consider another building material, cement. Conventional cement is carbon-intensive and accounts for 7% of total emissions regulated by the EU ETS (Branger and Sato, 2017). The carbon intensity of cement largely depends on how much and what kind of clinker is used in the overall cement mix. To reduce emissions, producers can either reduce the share of clinker or replace clinker with a substitute (fly-ash, steel-slag, puzzolan, etc.) that produces fewer or no emissions. The EU ETS, however, has defined two different benchmarks for cement production, depending on the kind of clinker used (see Table 2). Benchmarks for cement in the EU ETS grant more free permits to the more emission-intensive clinker and may hence be considered technology biased. This discourages European cement producers from cutting emissions by either using less clinker or a substitute, even in the short run. In comparison, the California CTP has only one overall benchmark for cement production, which encourages Californian cement producers to reduce emissions by using less clinker and more substitutes.[9]

[8] With a very narrow market definition, it could be argued that different steel grades would not be substitutes as they have different physical properties. However, economic substitution is not about physical equivalence of products, but about observed patterns of preferring one good to another when prices or incomes change. Hence market demand, not physical properties, matter for evaluating substitutability.

[9] It is sometimes argued that one overall benchmark for cement would discourage standalone clinker production as only final cement producers would receive permits for free. While such discouragement may happen, decarbonisation goes along with reduced production of emission intensive materials such as clinker.

Table 2. Benchmarks differ significantly for close substitutes

ETS	Product	Permits per metric tonne	Δ free allocation of permits
California CTP	fried potato chips	0.919	~ 60% higher
California CTP	baked potato chips	0.570	
California CTP	corn chips	0.639	~ 30% higher
California CTP	corn curls	0.492	
California CTP	facial tissue	1.455	~ 15% higher
California CTP	paper towel	1.700	
EU ETS	blast furnace steel	1.328*	~ 360% higher
EU ETS	electric arc steel	0.283	
EU ETS	white clinker (for cement production)	0.987	∞ - higher
EU ETS	grey clinker (for cement production)	0.766	∞ - higher
EU ETS	clinker substitutes (for cement production)	0	

Notes: *Additional allowances are granted for the production of coking coal and steel pellets, which are inputs for blast furnace steel. See Section 4 for a short description of the blast furnace steel production route. Sources: California Office of Administrative Law (2015) and European Commission (2011).

This discussion illustrates two main challenges for encouraging clean investment while handing out permits for free. First, technology-neutral benchmarks are hard to define. While one benchmark for one product category encourages emission reductions more strongly than multiple ones, fully technology-neutral permit allocation requires one benchmark for all products that are, or may become, substitutes. Continuing with the above example, cement competes with wood, steel and other building materials. A technology-neutral benchmark would need to define the relevant market, e.g. building materials. Establishing, however, which products do or do not belong to the building materials market would be a tremendously complex task economically and a very cumbersome task administratively.

Second, permit allocations will weaken the incentive of the emissions trading system for green investments if clean alternatives do not receive any allocation of permits – given they do not produce any emissions and hence no benchmark is defined – but the dirty alternatives do receive permits for free. For example, firms that produce clean cement using carbon-neutral clinker substitutes only do not receive any permits for free, neither in the EU ETS nor in the California CTP, as their emissions are below the thresholds for inclusion in emissions trading systems. Firms producing dirty cement benefit, however, from free permits. Free allocation thus diminishes the incentives from carbon pricing to switch to cleaner production.

Table 2 provides further examples of benchmarks that discriminate allocations based on production technology, even when markets are narrowly defined. For instance, steel production using a blast furnace (dirty technology) emits about 360% more emissions than the same amount of steel when produced using an electric-arc furnace (clean technology). At the same time, the dirty technology receives 360% more permits for one tonne of steel produced in the EU ETS, reducing the incentives to invest in the clean production technology. In total, steel production accounts for 7% of EU ETS emissions (Branger and Sato, 2017). Another example is the production of potato chips in California. Fried chips emit 60% more emissions on average per tonne than baked chips, but also receive 60% more permits. This counteracts

encouragements to invest in the cleaner baked potato chip production resulting from the marginal price of emissions.

Benchmarks differ across trading systems

Related to the question of technology-neutrality of benchmarks is the question of how benchmarks compare across different emission trading systems. A rent-seeking firm may claim to already have the most efficient production technologies in place and that further reducing emissions would require new technologies. A comparison of benchmarks for the same products in the EU ETS and the California CTP reveals that benchmarks widely differ across the Atlantic (Table 3).

Benchmarks are calculated based on the emissions of the most carbon-efficient firms, as explained at the beginning of this section. The comparisons illustrate that even with the technologies available today significant emission reductions are possible, even for narrowly defined products. While costs and market structure today may differ across the Atlantic, technology frontiers for low-carbon production can be expected to be global in the long-run. Currently, European electric arc steel producers receive about 50% more permits for free than Californian electric arc steel producers,[10] while Californian dolime[11] producers receive about 50% more permits than European ones. The latter case implies that European dolime producers are significantly more carbon-efficient than Californian producers with the technologies available today.

Table 3. Benchmarks differ significantly across the Atlantic

Product	Permits per metric tonne
Californian electric arc steel	0.199
European electric arc steel	0.283
Californian dolime	1.540
European dolime	1.072
Californian recycled boxboard	0.550
European recycled boxboard	0.273

Sources: California Air Resources Board (2011).

3.1.2. Supposed leakage risk

Supposed leakage risk factors are the second ingredient of allocation rules. If firms in countries with a high carbon price would shift their production to countries with a lower carbon price, the associated shift in emissions would be called *carbon leakage*. Papers reviewing the (quasi-experimental) empirical evidence find that carbon prices reduce emissions, but hardly affect variables related to competitiveness

[10] The EU ETS Benchmark contains an adjustment for indirect emissions from electricity use.

[11] Dolime is a mineral used, for example, as fertiliser and within several industrial processes.

such as turnover, exports, value added, investment and employment (Martin et al., 2016; Arlinghaus, 2015; Partnership for Market Readiness, 2015). While the empirical evidence for any carbon leakage is weak to non-existent, rent-seeking firms face strong incentives to argue that they face leakage risk because they can convert free permits to cash.

To implement supposed leakage risk factors, each economic subsector (generally defined at four digit or even narrower industrial classification levels) is assessed as to whether it is supposedly subject to leakage risk or not. Firms in the EU ETS in subsectors which are supposed to be under leakage risk will receive 100% of benchmarked permits for free, while firms in subsectors not considered to be under leakage risk received 80% of permits for free in 2013 and this share is declining to 30% in 2020. In the California CTP, each subsector is assessed as to whether it supposedly faces high, medium or low leakage risk. Firms in subsectors with supposed high leakage risk receive 100% of benchmarked allocations until 2020, while firms in subsectors with supposedly medium or low leakage risk receive 75% or 50% of benchmarked emissions from 2018 onwards. Rules beyond 2020 are still under discussion in both emissions trading systems.

To the extent that different supposed leakage risks apply to products that can be substitutes, the leakage risk factor may amplify the effects of benchmarks that discriminate based on technology. In practise this concern may, however, be limited as 95% of industry emissions in the EU ETS are supposedly under leakage risk (de Bruyn et al., 2013).

Supposed leakage risk in the California CTP depends on whether the ratio of emissions and value added by subsector exceeds certain thresholds. In the EU ETS, supposed leakage risk is assessed according to multiple criteria. A subsector is supposed to be under leakage risk either if its trade intensity, i.e. net exports over total EU market size, exceeds 30%, or if its carbon intensity, i.e., total carbon costs at an assumed permit price of EUR 30 per tonne CO_2 divided by value added, would exceed 30%. In addition, if trade intensity exceeds 10% and carbon intensity 5%, a subsector is also considered to be under leakage risk.

The current rules for assessing whether firms in the EU ETS are under supposed leakage risk are not well aligned with the factors that managers of manufacturing firms state would matter for their decisions to relocate plants or not (Martin et al., 2014). Especially trade-intensity on its own is hardly related to leakage risk, even though it defines leakage risk status for 75% of the subsectors on the supposed leakage list (Marcantonini et al., 2016). Carbon intensity is more stronglycorrelated with stated risk to relocate than trade intensity. Martin et al. conclude that better targeting can substantially reduce free allocation while holding stated relocation risk constant.

While carbon intensity better reflects relocation risk than trade intensity, prudent regulators may want to bear in mind that it is based on value added. Value added is hard to measure by subsector. For example, firms that produce multiple products have some leeway in how to report value added. Firms may thus try to gain more permits for free by reporting high carbon intensity. They could do so by shifting reported value added from activities that are regulated by an emissions trading system to nonregulated activities.

3.1.3. Time-dependent factors

Time-dependent factors in the allocation formula ensure that the amount of freely allocated permits declines as the overall caps of emissions trading systems decline. If permits were only allocated

according to benchmarks and supposed leakage risk, the amount of freely allocated permits would remain stable over time, except for installations with no or low supposed leakage risk.

In the EU ETS, the so called Cross-Sectional-Correction (CSC) factor sets the number of allocations allocated for free to industry to decline as the overall cap of the emissions trading systems declines by 1.74% a year from 2013 to 2020 (European Commission, 2009). This implies that in the year 2020 installations will receive about 82% of the permits that they receive for free according to their benchmarks and supposed leakage risk factor. In the California CTP, the time-dependent correction factor ensures that the amount of freely allocated permits declines at about 3% a year in proportion to the cap. This ensures that the share of freely allocated permits within the overall cap does not increase over time.

The time-dependent factors restrict the amount of free allocation and thus limit the impact that technology-biased benchmarks have on the decision to invest in green or dirty technologies. Yet, this effect is small given that caps, on which the correction factors depend, decline only marginally over time. Comparing the California CTP with the EU ETS, the cap declines substantially faster in the California CTP. Installations in the California CTP may thus expect fewer free permits over time compared to installations in the EU ETS. As a result, Californian polluters may also perceive a stronger encouragement to invest in clean technologies.

3.1.4. Historical output

The final component of the allocation formulas, *historical output*, can also impact decisions of firms to produce output using clean or dirty technologies. Moreover, specific rules on how historical output is updated, if output changes significantly, may encourage firms to produce more output than demanded by the market and do so in a more emission-intensive manner.

In the California CTP, historical output is last year's output. This might increase the incentives to produce more at the margin as any additional production also increases the number of permits obtained for free in the following year. In the EU ETS, historical output is the maximum of median output either between 2006-2008 or 2009-2010. If installations substantially increase or decrease output, the historical output values are updated at certain activity thresholds. This generally encourages installations to produce more than they would in absence of these rules.

The updating of historical output levels in the EU ETS, which co-determine the allocation of free permits, at certain activity thresholds can lead firms to try to increase future free allocations. The activity-level thresholds specify that free allocations are reduced by 50%, 75% or 100% if annual production falls below 50%, 25% or 10% of historical output (European Commission, 2011). Branger et al. (2015) show that installations in the cement sector increase clinker production in order to exceed the activity level thresholds and obtain more free allocation. There are three ways in which installations increase production to obtain more free permits. First, firms with multiple production sites increase production in installations which are less utilised, and decrease it in those that are highly utilised. While this likely increases production costs, it does not affect overall output. Second, firms export more to foreign markets. Third, firms increase the share of (emission-intensive) clinker in overall cement production while reducing the share of (emission-extensive) fly-ashes or slag, which are substitutes for clinker. The last mechanism implies that the current rules to update historical output in the EU ETS are

technology-biased against clean production, at least in the case of cement. EU legislation for updating historical output levels in the ETS is currently revised.

3.2. Electricity

In the electricity sector, full auctioning of permits is common. With the temporary exemption of some central European states, electricity generators in the EU ETS that sell electricity to end-use customers do not receive any permits for free and have to buy permits at auctions or the spot market. As a result, there is no difference for electricity generators between the marginal permit price they pay for generating one unit of electricity with a given technology and the average permit price they pay over the lifetime of the investment.

California allocates permits to electricity distribution utilities and requires investor-owned utilities to sell these permits at public auctions. The revenues received from the auctions have to be used to the benefit of electricity customers. This policy seeks to safeguard electricity customers against paying the compliance costs of the cap and trade programme.

The Californian Air Resources Board (CARB) encourages utilities to pass through the costs of the permit to customers in electricity rates, i.e., what customers pay per kWh, and return the proceeds from auctions non-volumetrically, i.e., by providing a lump-sum payment to each electricity customer. This approach effectively increases the marginal price that electricity users pay for electricity while it changes the average price for electricity users only slightly. Given that the lump-sum payment is the same for all users in a given class of electricity consumers, average electricity prices will slightly increase for customers who use a lot of electricity, while those with little use will see their average electricity price fall.

There is a discussion in the empirical literature whether households' energy demand responds to marginal or average energy prices (Alberini et al., 2011). Ito (2014) exploits nonlinear price variation in electricity prices resulting from spatial discontinuities in electricity service areas in Orange County, California to show that households respond to average electricity prices rather than to marginal electricity prices. This finding suggests that Californian households will likely stick with their current electricity use patterns as average electricity prices remain largely stable and thus fail to reduce electricity demand in response to the cap and trade programme.

The California CTP will likely impact electricity generators' dispatch decisions, for example, whether to run a dirty coal power plant or a less emission-intensive natural gas power plant, but it remains an open question to what extent it also encourages investment in cleaner generation facilities, like renewables. Electricity distribution utilities receive freely allocated permits based on their electricity supply and demand forecasts for each trading period. Within a trading period this incentivises electricity distribution utilities to invest in cleaner generation, as lower emissions implies that fewer permits need to be purchased. However, across trading periods, incentives to invest in clean generation can be weak, as investment in cleaner generation today can imply receiving fewer permits for free in the future.

3.3. Natural gas outside industry

Distributors of natural gas in California also receive free permits, which they have to auction to the benefit of their customers.[12] As with electricity, the permit price is required to be passed through to customers in form of higher rates per kWh of natural gas consumed and any return from the sale of permits that is redistributed to households lump-sum. This means that marginal prices for natural gas increase while average prices are hardly affected. As discussed above, recent empirical literature suggests that households respond rather to average than to marginal energy prices (cf. Ito, 2014), which would mean that the California CTP would have hardly any impact on reducing natural gas use and the emissions associated with that use.

3.4. Transport and other fuel outside industry

The California CTP requires suppliers of gasoline and diesel to acquire permits to cover the emissions that result from the combustion of these transport fuels. The EU ETS currently does not cover transport fuels. Given that suppliers of transport fuels in California have to acquire all permits at auction or in the secondary market, there is no difference between marginal and average permit prices. In the absence of significant market power, suppliers of fuels can be expected to fully pass through the permit prices into higher fuel prices for end-users. The higher fuel prices encourage end-users in turn to both reduce emissions today, e.g. by driving less (by avoiding low-value trips or using public transport) or more fuel-efficiently, as well as over time, e.g., by investing into more fuel-efficient or alternative fuel vehicles or changing location. Fully auctioning all permits for transport and other fuels outside industry ensures that the emissions trading encourages both emission reductions from running operations more efficiently as well as investing in clean assets.

3.5. Marginal and average effective permit prices

The permit allocation rules of an ETS can influence the incentives it provides for investing in clean technologies. Benchmarks can discriminate between technologies. In addition, supposed leakage risk factors and procedures for updating historical production level may lead firms to try to increase future free allocations possibly amplifying the technology bias.

If permit allocations are not fully technology-neutral, the average permit price rather than the marginal permit price best reflects the incentive from carbon pricing to prefer clean over dirty investments. For grandfathering per tonne of output and technology-dependent benchmarking, Section 2.2 has shown that the average permit price provides the same incentives to invest in clean technologies as the marginal permit price under full auctioning or an equivalent marginal tax rate. Note that the marginal permit price still matters even when allocations are not technology-neutral. First, a higher marginal permit price translates into a higher average permit price for a given share of free allocation. Second, the marginal permit price matters on its own for marginal production decisions once a firm has decided to invest in a (clean or dirty) technology. Taken together, average permit prices may be seen as the lower bound of the

[12] Natural gas is not covered by the EU ETS except for the generation of electricity or use by large industrial installations.

carbon price that signals to firms whether to reduce emissions or not (impacting mainly discrete investment decisions) while the marginal effective carbon rates are the upper bound (mainly affecting marginal production decisions).

Table 4 compares marginal and average effective permit prices for two economic sectors, electricity generation and industry, in the EU ETS and the California CTP in 2013. In the electricity sector full auctioning of permits is the rule rather than the exception, so that only a small difference between marginal and average permit prices is observed for the EU ETS, a difference which results from temporary free allocation for power plants in some central European countries. This means that in the electricity sector, incentives from permit prices to invest in clean electricity generation are fairly close to the incentives of utilising cleaner plants in daily production decisions. Nevertheless, prices are currently likely too low to either strongly affect investment or production decisions. In the industry sector, average permit prices are low and significantly below permit prices as a result of allocation rules. This implies that carbon pricing today barely incentivises the industrial sector to invest in clean production technologies. Also marginal prices are fairly low, so that the industrial sector also faces few incentives to cut emissions in day-to-day operations.

Table 4. Estimated marginal and average permit prices in California and the EU in 2013

ETS	Sector	Emissions	Freely allocated permits	Share of freely allocated permits	Marginal permit price	Average permit price
California Cap & Trade	Electricity	80'946'223	*	*	$12.83	$12.83*
	Industry	56'042'078	53'894'995	0.96	$12.83	$0.49
EU ETS	Electricity	746'767'565	197'450'780	0.26	€4.38	€3.22
	Industry	792'553'182	803'672'140	1.01	€4.38	-€0.06

Notes: * Electricity providers in California receive permits free of charge that they have to auction. The proceeds of the auctions have to be used to the benefit of their customers, e.g., by lowering electricity tariffs. For the estimation of the average permit price in the Californian electricity sector, in this table it is assumed that electricity providers fully consider the opportunity costs of permits for daily dispatch decisions and thus for investment decisions.

4. An illustration of how benchmarks and free allocation (dis)incentivise clean investment

This section elaborates the example of steel production to clarify how free permit allocation and benchmarking results in weak incentives for low carbon investment. To focus on the impacts of permit allocation it deliberately abstracts from any other policy variables that may influence steel production choices.

There are two main production options for steel, namely the blast furnace (BF) and the electric arc furnace (EAF). In the EU, 39.4% of steel was produced using the EAF in 2015, and 60.6% was produced

using the BF. In the United States, EAF steel (62.7%) dominates BF steel (37.3%; World Steel, 2016). California produces exclusively EAF steel (American Iron and Steel Institute, 2017). The example will focus on the EU ETS, where both production routes are prominent.

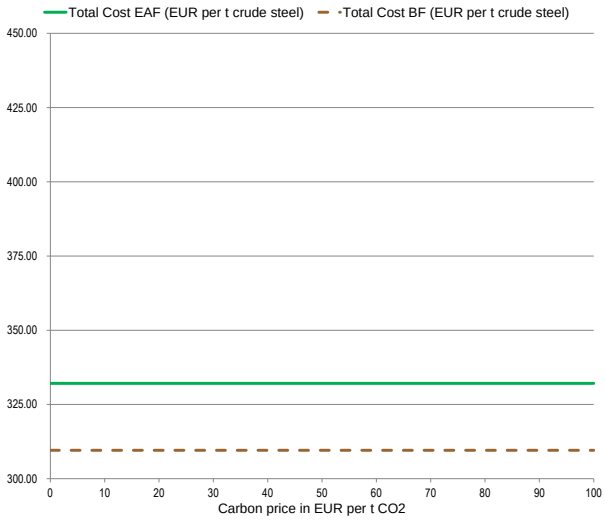
The BF technology consists of several processes that fall into three steps: raw material preparation, iron making, and steel making. In the first step, coal is transformed to coke and the iron ore is sintered and pelletised. The second step uses coke and the previously processed iron ore to produce hot metal, which still contains unwanted impurities. In the final step, a basic oxygen furnace removes these impurities. In the EU ETS, raw steel production using the BF involves three benchmarks for free allocation in the EU ETS: one for producing coke, a second for sintering iron ore, and a third for the emissions that relate to the blast furnace and basic oxygen furnace steps. Together, 100% free allocation according to benchmarks leads to 1.65 allowances per tonne of raw steel for a typical plant (own calculation based on European Commission, 2012 and Remus et al., 2013).

The EAF route uses steel scrap to produce raw steel using electricity as an energy source. The benchmark for EAF steel is 0.283 allowances per tonne of raw steel. There are no free permits for the electricity used. In overall, EAF steel is significantly cleaner than BF steel in terms of carbon emissions.

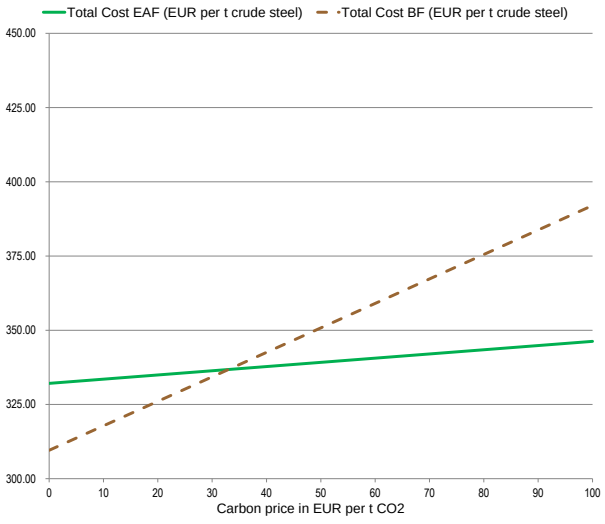
While BF steel is significantly more carbon intensive than EAF steel, BF steel can be cheaper to produce at low carbon prices. Considering production costs for typical plants, and excluding any carbon prices, the cost of producing one tonne of BF steel is found to be EUR 310 (Steelonthenet, 2017a), while one tonne of EAF steel costs EUR 332 to produce (Steelonthenet, 2017b).[13] Assuming that the revenues from BF and EAF steel are the same, an investor will prefer investment in a BF steel plant to an EAF plant given higher expected revenues if she expects that cost structures remain stable.

Figure 1. Total costs of steel production

a) 100% free allocation according to benchmarks



b) 50% free allocation according to benchmarks



[13] USD - EUR parity is assumed for simplicity.

How will carbon prices affect the choice between an EAF and a BF plant under otherwise similar circumstances? Figure 1 compares total production costs for typical BF and EAF plants for various carbon prices, where for simplicity it is assumed that the plants emit exactly the amount of carbon emissions specified by the benchmarks. In the example it is also assumed that EAF and BF steel are fully substitutable.[14]

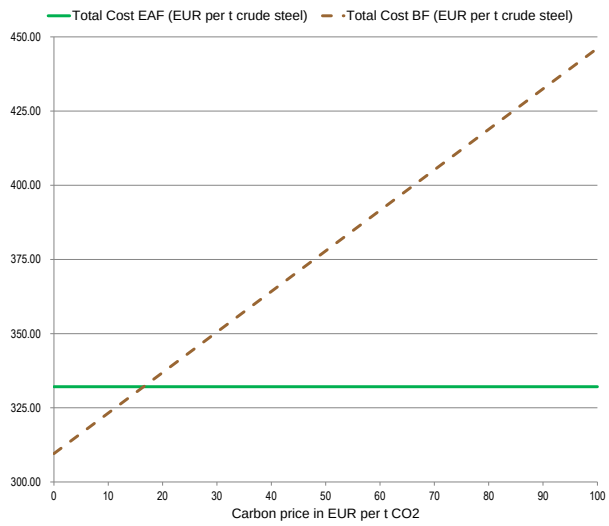
Panel a) shows the situation where emitters receive 100% of benchmark allowances for free. This means emitters only have to pay for permits if they emit more than the benchmark. In this case marginal permit prices have no effect on the investment decision. While BF steel is significantly more carbon intensive than EAF steel and thus requires more permits, the separate benchmarks for both production processes result in significantly more free permits for BF steel. If both plants emit exactly according to benchmarks and allocation rules stipulate 100% free allocation, carbon prices will not affect production costs. The investor will choose the same technology as in the situation without a carbon price.

Panel b) compares total production costs when emitters receive only 50% of benchmark allowances for free. In this case it is cheaper to produce BF steel up to a marginal permit price of EUR 33 per tonne of CO_2. With higher permit prices, EAF steel is now cheaper than BF steel. This shows that, if not all permits are distributed for free, carbon pricing can affect the technology choice. Note that the *average* permit price from which it becomes cheaper to produce EAF instead of BF steel is EUR 16.5 per tonne of CO_2. The average permit price is simply the cash cost for one tonne of carbon emissions, i.e. 0.5 (as 50% of allowances are distributed for free) times the marginal permit price.

[14] While the vast majority (up to 90% and over) of steel product grades can be produced by either the BF or EAF route (Genet, 2012), some grades may require a specific production method with existing production technology. If some steel grades (currently produced only with the BF route) become more expensive than others (produced with both routes), demand for the less expensive steel grades can be expected to increase and decrease for the more expensive ones. In the short-term there can also be an increased risk of production-shifts to abroad for the steel grades currently produced only with the BF route. This is because the carbon costs cannot be readily mitigated by shifting to the cleaner EAF route. Over time, new technology may allow to produce all grades using both routes. In addition, as discussed in the earlier subsection on technology-neutrality of benchmarks, steel can be replaced by other more carbon-efficient building materials. Martin et al. (2016) and Arlinghaus (2015) review the empirical evidence on competitiveness effects of carbon pricing more broadly. The discussion and conclusion briefly touches on policy implications.

Figure 2. Total costs of steel production cont.

a) One product benchmark independent of process



b) Full auctioning

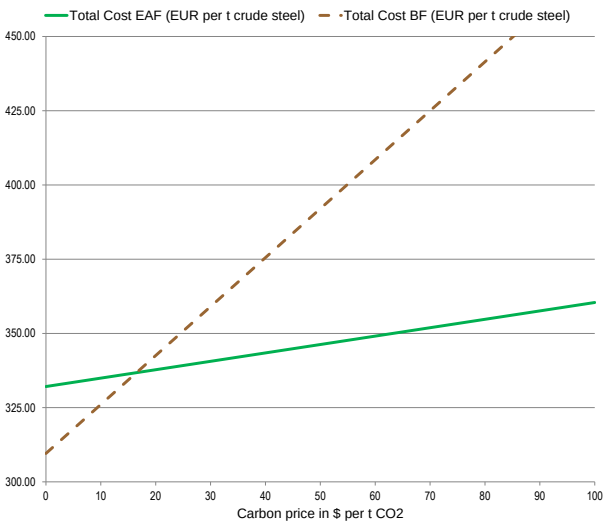


Figure 1 considered the (existing) case of technology-specific benchmarks. Figure 2, panel a) considers the hypothetical situation where there is a single benchmark for steel, independent of the production process. Concretely, it is assumed that each tonne receives 0.283 allowances for free, equalling the amount of the EAF benchmark considered before. Production costs are now lower for EAF steel for a marginal permit price of EUR 16.5 or more. Using one product benchmark, independent of the production technology, results in stronger incentives to invest in clean technologies than two production technology dependent benchmarks.

While defining benchmark for products instead of production technologies helps to incentivise investments in clean technologies, it does not provide any incentives for substitution to cleaner products. A carbon price that only depends on emissions would provide additional incentives to substitute steel with wood or other low-carbon materials, where possible.

Panel b) of Figure 2 shows the situation when all permits are fully auctioned. With permit prices of EUR 16.5 or more, EAF steel is cheaper to produce than BF steel. Full auctioning guarantees full technology neutrality as all emissions have to pay the full carbon price. This means that low-carbon substitutes for steel also become more attractive to investors as they become relatively cheaper with higher carbon prices.

The examples above rely on highly stylised cost structures. Input prices for steel production generally vary over time and can also vary across countries. Hence, sometimes EAF steel can be cheaper to produce than EAF steel independent of carbon prices. Investors will form expectations about input prices when deciding to invest in which kind of plants and choose for the option that they expect to be most profitable over the lifetime of the investment.

In order to assess the importance of carbon prices in such a decision under uncertainty, it is helpful to look at carbon costs as a share of total production costs. With a low share of carbon costs in total costs one can expect that other cost factors dominate investments decisions, while a high share of carbon costs

likely has a stronger impact on investment decisions. Based on the above examples and assuming full auctioning, the carbon costs of BF steel are 3% of total costs with a carbon permit price of EUR 5, 14% at EUR 30 and 24% at EUR 60. For EAF steel, the corresponding costs shares are close to 0% at EUR 5, 2% at EUR 30 and 5% at EUR 60. This shows that, while EAF steel production costs turn out to be fairly unresponsive to higher carbon prices, production costs of BF steel respond strongly. Investors expecting higher carbon prices are therefore more likely to prefer EAF over BF steel production. However, with free allocation cost shares will be substantially lower compared to the example of full auctioning and so will be the incentives to invest in the cleaner EAF steel.

5. Discussion and conclusion

Using a simple analytical model to make the conceptual argument, and considering existing permit allocation rules of the EU ETS and the California CTP, the analysis has shown that permit allocation rules today can discourage investment in clean technologies through their effect on ranking of investment projects. The reason is that the product benchmarks are not fully technology-neutral but instead often favour dirty technologies. The technology bias from benchmarks can be amplified by supposed leakage risk factors, and in the EU ETS also by the rules for updating historical production levels.

It has been argued that, since full technology-neutrality is impossible under rules-based free allocation and since approximations to it become more difficult if a long term view is taken (as is required if the objective is to decarbonise the economy), the auctioning of permits is the preferred solution for an emissions trading systems. Alternatively, carbon taxes could be used. For countries that do not have an emissions trading system, implementing a tax that consistently taxes the carbon content of fuels may well be the simpler and administratively more efficient way to reduce emissions, e.g. when the tax can be grafted onto existing excise tax systems. Excise taxes are also generally seen as fairly simple to collect. Emissions trading systems, in contrast, generally require a whole new set of institutions.

Allocation rules are at least partly the result of efforts to gain support for carbon pricing. Policy makers might fear reductions in the competitiveness of industrial firms and also might be concerned about the equity impacts of carbon pricing. While addressing these concerns can be a prerequisite for implementation, a welfare-maximising perspective suggests addressing these concerns in ways that do not compromise environmental effectiveness or economic efficiency.[15,16]

[15] In addition, compensation for competitiveness may be counterproductive in the long run. Albrizio et al. (2014a) observe that while the most productive firms tend to benefit from carbon pricing, less productive firms do not. Compensation through free allocation then becomes a trade-off between helping the least productive firms, which likely struggle for reasons other than carbon pricing, or raising revenue from carbon pricing for other, potentially more productive and inclusive goals. Moreover, carbon prices are the most likely to increase the level of productivity in a country among the various policies to reduce CO2 emissions (Albrizio et al. (2014b). Johnstone et

The widespread use of rules-based free allocation renders the implementation and operation of emissions trading systems complex and costly. Allocation rules contain benchmarks, leakage risk factors, rules for updating production levels, etc., all of which need to be developed and specified. These direct costs of complexity weaken a key advantage of price-based abatement policy, which is that it is in principle less information-intensive for the regulator than command-and-control approaches. If the price-based policy becomes highly information-intensive, it may be worth asking if command-and-control might not be the more direct way to go. In addition to the direct costs from complexity, it also risks creating information asymmetries. Firms face strong incentives to overstate supposed leakage risks as this will likely make governments provide them with more free permits, and they potentially can do so as they are better informed about technologies and market conditions than the government.

A quickly declining cap is sometimes seen as a fix for not fully auctioning all permits, but it can also be argued that a declining cap and full auctioning are strategic complements rather than substitutes. They are substitutes in the sense that both raise average permit prices and thereby incentives for clean investment. A lower cap increases marginal permit prices, meaning that average permit prices increase for a given share of free allocation. More auctioning leaves marginal permit prices unaffected (abstracting from any general equilibrium effects), but raises average permit prices as the share of free allocation declines. However, both a slowly declining cap decline and free allocation are ways to build support for carbon pricing. In the long run, more auctioning will incentivise more clean investment, which in turn will increase support for a faster declining cap.

Full auctioning of emission permits, carbon taxes and other energy taxes require political support for implementation to be feasible. Several strategies exist to build increasing support over time and strengthen carbon pricing over time. First, gradual implementation of full auctioning and gradual carbon price increases give households and firms time to adjust. This can help building support for higher carbon prices and sets clear expectations on the rates that emitters will have to pay in the future. Second, as long as some permits are still allocated for free, governments can publish the resulting loss in revenues together with other reports on tax expenditures and subsidies. This will make the costs of free allocation transparent and allows building further support among firms and households for a phase-out. Countries may also consider publishing their carbon pricing gap (OECD, 2016), i.e., the extent to which emissions

al. (2010) find stronger stimulation of technological progress for more stringent, more predictable and more flexible environmental policies. Cohen and Tubb (2015) survey evidence confirming that flexible environmental policies (e.g. carbon pricing) are more likely to have a positive significant impact on productivity growth than less flexible ones.

[16] Governments that seek to ensure that energy users do not bear the full compliance costs of emissions trading or aim to protect vulnerable households from higher energy cost can at the same time aim to keep the incentives to reduce energy demand and emissions intact. Switzerland, for example, returns the majority of revenues from its carbon tax lump-sum to each resident via reduced payments for health insurance. Relatedly, if governments seek to ensure that vulnerable households are protected from the effects of higher energy prices, targeted transfers via the social benefit system are more effective than reduced marginal or average energy prices. Flues and Van Dender (2017) show for a sample of 20 OECD countries that higher carbon prices can reduce energy affordability risks if a third of the additional revenues is redistributed back to households with an income-tested transfer.

are priced less than the damage they cause to society, which will help building up momentum for higher carbon prices. Third, revenues from carbon pricing can provide transitional support and accommodate equity considerations in ways that are aligned with incentivising abatement and clean production. For example, by using carbon pricing revenues to reduce other business tax contributions governments can ensure that overall tax contributions of the business sector do not increase. These strategies appear superior to free allocation of tradable permits, particularly if one focusses on the incentives to invest in the long-lived low-carbon assets that are essential to the low-carbon transition.

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Annex A

Details on permit allocation rules in the California CTP and EU ETS

Permit allocation in the EU ETS (European Commission, 2011) and the California CTP (California Office of Administrative Law, 2015, Article 95870) depend on Benchmarks, a supposed leakage risk assistance factor, a time-dependent factor to account for the annual decline in the cap and historical output. While there are some differences between the two system and some special rules may apply in specific circumstances the general allocation rules can be summarised in a formula for each system.

Equation 1 summarises the allocation rules for the EU ETS:

$$A = Alloc_{i,s,t} = BM_{s,2008} * AF_{s,t} * CSC_t * Prodlevel_{\max[median_i(2006-2008, median_i(2009-2010)]} \quad (1),$$

whereby

$Alloc_{i,s,t}$: free allocation to firm *i* in Sector *s* in year *t*

$BM_{s,2008}$: Benchmark for Sector S determined as 10% most efficient firms based on data from 2007-2008

$$AF_{s,t} = \begin{cases} 100\% \; if \; on \; leakage \; list \\ 80\% \; in \; 2013 \; declining \; to \; 30\% \; in \; 2020 \; otherwise \end{cases}$$

CSC_t: cross-sectional correction factor for each year

$Prodlevel_{\max[median_i(2006-2008), median_i(2009-2010)]}$: Maximum of median output of firm *i* in either 2006 to 2008 or 2009 to 2010

Equation 2 shows how permits are allocated for free in the California CTP:

$$A = Alloc_{i,s,t} = BM_{s,2008} * AF_{s,t} * C_t * Output_{i,t-2} \quad (2),$$

whereby

$Alloc_{i,s,t}$: free allocation to firm *i* in Sector *s* in year *t*

$BM_{s,?}$: Benchmark for Sector S determined as 90% of average emissions in year ?

$$AF_{s,t} = \begin{cases} 100\% \; if \; high \; leakage \; risk \\ 100\% \; declining \; to \; 75\% \; in \; 2018 \; if \; medium \; leakage \; risk \\ 100\% \; declining \; to \; 50\% \; in \; 2018 \; if \; low \; leakage \; risk \end{cases}$$

C_t: Correction for declining cap (about 3% each year)

$Output_{i,t-2}$: Lagged output of firm *i*